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Quantitative Models of Sovereign Risk and State-Contingent Debt

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Abstract

This thesis examines sovereign risk and sovereign debt via a financial markets perspective, attributing a special role to uncertainty. An extensive literature review of sovereign debt crisis models and of the empirical literature on the determinants of sovereign spreads is provided, with an emphasis on debt sustainability, on multiple equilibria, on self-fulfilling debt crises and on the distinction between fundamentals against market sentiment.

A novel application of an old niche model of self-fulfilling currency crises is offered for sovereign debt. The model explains how the presence of uncertainty is bound to lead to the unique self-fulfilling crisis outcome. Uncertainty emerges in three forms: as informational uncertainty, as strategic uncertainty or as sunspots. The game theory device of 'higher order beliefs' is applied to financial markets.

In the empirical estimation chapter, a novel measure of uncertainty related to Greek sovereign risk is developed via a Threshold-GARCH model. Principal Component Analysis is performed to derive a measure of the relative risk of the Eurozone periphery. Subsequently, a threshold regression model is estimated for the Greek sovereign spread for the period between January 1999 and December 2020. In this model, a fundamentals-based regime is distinguished from a market-sentiment-driven regime for Greek sovereign spreads according to a critical threshold of uncertainty. The regime-dependent behavior of the Greek sovereign spread is subsequently mapped onto the Greek debt crisis narrative timeline. Periods of crisis relate to high-uncertainty regimes. A Component GARCH-M model of the Greek sovereign spread is estimated. A short-term component of Greek debt sustainability uncertainty is distinguished from a long-term component. Periods of crisis are shown to coincide with periods of high short-term liquidity-driven market sentiment. An event study of the impact of key dates on Greek sovereign risk complements the analysis.

The final quantitative chapter evaluates how the Greek public debt-to-GDP ratio would have evolved had the public debt been partially or fully indexed to GDP growth at the outbreak of the Greek debt crisis as a historical counterfactual. By applying Monte Carlo simulations of the possible paths of the debt-to-GDP ratio, fan charts point to the conclusion that Greece may not have been a good candidate for the introduction of GDP-linked bonds, *ceteris paribus*.

Περίληψη

Η διατριβή εξετάζει την απόκλιση των αποδόσεων των κρατικών ομολόγων (sovereign spreads) και το δημόσιο χρέος από τη σκοπιά των κεφαλαιαγορών, αποδίδοντας ιδιαίτερο ρόλο στην αβεβαιότητα. Παρέχεται εκτενής βιβλιογραφική επισκόπηση των μοντέλων κρίσεων δημοσίου χρέους και της εμπειρικής βιβλιογραφίας, σχετικά με τους παράγοντες που καθορίζουν την απόκλιση των αποδόσεων των κρατικών ομολόγων (sovereign spreads) με έμφαση στη βιωσιμότητα του χρέους, στις πολλαπλές ισορροπίες, στις αυτοεκπληρούμενες κρίσεις χρέους και στο διαχωρισμό μεταξύ θεμελιωδών μεγεθών έναντι του «συναισθήματος της αγοράς» (market sentiment).

Παρέχεται μία νέα εφαρμογή στο δημόσιο χρέος ενός παλαιού θεωρητικού υποδείγματος αυτοεκπληρούμενων νομισματικών κρίσεων. Η νέα εφαρμογή εξηγεί πώς η παρουσία της αβεβαιότητας οδηγεί νομοτελειακά στο μοναδικό αποτέλεσμα, δηλαδή σε κρίση. Η αβεβαιότητα εμφανίζεται με τρεις μορφές: ως προς την πληροφόρηση, ως προς τη στρατηγική και ως ηλιακές κηλίδες ("sunspots"). Το εργαλείο των "higher order beliefs" της θεωρίας παιγνίων εφαρμόζεται εν προκειμένω στις κεφαλαιαγορές.

Στο κεφάλαιο της εμπειρικής εκτίμησης, προκύπτει μία νέα μέτρηση της αβεβαιότητας σχετικά με την απόκλιση της απόδοσης του ελληνικού δεκαετούς ομολόγου από το αντίστοιχο γερμανικό (sovereign spread) μέσω του υποδείγματος Threshold GARCH. Η μέθοδος Principal Component Analysis εφαρμόζεται στη μέτρηση του σχετικού ρίσκου της περιφέρειας της Ευρωζώνης. Στη συνέχεια, προσαρμόζεται ένα υπόδειγμα threshold regression στην απόκλιση της απόδοσης του ελληνικού δεκαετούς ομολόγου από το γερμανικό (sovereign spread) για την περίοδο μεταξύ Ιανουαρίου 1999 και Δεκεμβρίου 2020. Στο υπόδειγμα αυτό, ένα καθεστώς (regime) που καθορίζεται από τα θεμελιώδη μεγέθη διαχωρίζεται από ένα καθεστώς «συναισθήματος της αγοράς» με βάση ένα οριακό επίπεδο αβεβαιότητας. Στη συνέχεια, η ανωτέρω οριζόμενη συμπεριφορά της απόκλισης της απόδοσης του ελληνικού δεκαετούς ομολόγου από το αντίστοιχο γερμανικό (sovereign spread) τοποθετείται πάνω στο χρονοδιάγραμμα του αφηγήματος της ελληνικής κρίσης χρέους. Περίοδοι κρίσης χαρακτηρίζονται από υψηλή αβεβαιότητα. Ακολούθως, εφαρμόζεται ένα Component GARCH-M υπόδειγμα της απόκλισης της απόδοσης του ελληνικού δεκαετούς ομολόγου από το αντίστοιχο γερμανικό (sovereign spread). Ένας βραχυπρόθεσμος συντελεστής της αβεβαιότητας ως προς τη βιωσιμότητα του ελληνικού δημόσιου χρέους διαχωρίζεται από έναν μακροπρόθεσμο συντελεστή. Περίοδοι κρίσεως συμπίπτουν με τις περιόδους υψηλού επιπέδου βραχυπρόθεσμου «συναισθήματος της αγοράς» (market sentiment), το οποίο καθορίζεται από τη ρευστότητα (liquidity-driven). Συμπληρωματικά στην ανάλυση, η μέθοδος event study επιβεβαιώνει την επίδραση ημερομηνιών-κλειδιά στην απόκλιση της απόδοσης του ελληνικού ομολόγου από το αντίστοιχο γερμανικό (sovereign spreads).

Ένα τελικό υπολογιστικό κεφάλαιο αξιολογεί πώς θα εξελισσόταν το ελληνικό δημόσιο χρέος προς ΑΕΠ στο ξέσπασμα της ελληνικής κρίσης χρέους (historical counterfactual), εάν όλο ή μέρος του χρέους συνδεόταν με το ΑΕΠ (GDP-indexation). Εφαρμόζοντας προσομοιώσεις (Monte Carlo) των πιθανών εξελίξεων στο χρόνο του λόγου χρέους προς ΑΕΠ, διαγράμματα-χωνιά (fan charts) οδηγούν προς το συμπέρασμα πως η Ελλάδα δεν θα ήταν καλή περίπτωση για την εισαγωγή ομολόγων με ρήτρα ΑΕΠ (GDP-linked bonds), με αμετάβλητα τα λοιπά δεδομένα (ceteris paribus).

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> "How did you go bankrupt?"
> "Two ways. Gradually, then suddenly."
> – **Ernest Hemingway, The Sun Also Rises**

Chapter 1: Introduction

This thesis has been inspired by the Greek government debt 'Odyssey' which began in October 2009, upon the revelation of the Greek government deficit, and ended with Greece's official 'graduation' from the Third Programme of Economic Adjustment in August 2018. The government debt and deficits that led to the eruption of the Greek debt crisis were built prior to the onset of the crisis, as despite the Maastricht Treaty Criteria imposed on Greece upon accession to the Economic and Monetary Union (EMU), the Greek economy suffered from long-standing imbalances, the result of which was reflected as a fiscal divergence from EMU requirements. Political and electoral concerns exacerbated the imbalances, adding to an uncertain environment about Greece's potential for convergence.

The loss of market access and inability of the government to roll over its debt led to the request of Official loans from the International Monetary Fund (IMF) but also from Greece's peers within the Eurozone—first, on a bilateral basis, and subsequently on an institutional basis following the establishment of European institutions, such as the European Stability Mechanism (ESM), in response to the crisis. Three successive official sector loan packages were contracted and were accompanied by conditionality requirements and country surveillance by Official Creditors. In 2012, the largest government bond exchange in history was conducted under the Private Sector Involvement (PSI), which resulted in a reduction of net debt outstanding by more than 30% of GDP. During this period, the profile of the Greek debt changed dramatically, with subsequent restructuring agreements and commitment for longer term measures contingent upon the successful implementation of fiscal consolidation and structural reform progress.

Over the course of Greece's membership in the EMU, Greek sovereign risk has undergone various phases, rising and declining, along with sovereign credit ratings and the debt repayment capacity of the Greek government. Institutional surveillance and local administrative bodies have frequently published reports with macroeconomic forecasts and debt sustainability analyses. In retrospect, however, forecasts have failed to materialize, official institutions have acknowledged mistakes in basic calculations infamously involving the Greek multiplier, while austerity measures proved to be burdened with difficulty in implementation. Political unrest, changes in government, controversial ideas and deliberation delays pushed the end of the crisis way past its original forecast.

This thesis is not an analysis of the factors that led to the build-up of imbalances and the difficulties entailed in resolving the Greek debt crisis. Nor is it an analysis of Greek debt sustainability or a historical narrative. Instead, based on relevant economic theory and models, it adopts a market-based perspective focusing on the very short-run behavior of sovereign risk. The thesis evaluates the literature on sovereign debt and sovereign risk and seeks to complement it with a novel application of an old currency crisis model, adapted to sovereign risk within the Economic and Monetary Union (EMU). The proposed theoretical model and a related empirical application account for the role of uncertainty in the emergence of bad outcomes for sovereign risk and sovereign debt. The regime-dependent behavior of the sovereign spread is modelled, while an investigation into the "fundamentals-versus-market-sentiment" determinants of sovereign risk is pursued. The short-run component of market sentiment is distinguished from long-run market-sentiment via an appropriate econometric technique applied to financial returns models and currency crisis models. The analysis is complemented by a brief event study of the very short-run impact of news announcements or key political events on Greek sovereign spreads over the course of the Greek debt crisis.

This thesis provides a contribution with respect to the distinction between fundamentals and market sentiment and accounts for the role of market-based idiosyncratic uncertainty on market-based refinancing concerns of the government, from a theoretical and an empirical point-of-view. Noting the state-contingency of short-term market-based factors and resulting state-contingent debt repayment capacity of the Greek sovereign, the thesis also examines whether a state-contingent solution in the form of GDP-linked bonds could have proven beneficial as a solution to ward against the crisis upon its eruption. Therefore, in contrast to the majority of analyses of the Greek debt crisis, this thesis adopts a market-based perspective on debt sustainability.

The major contributions of this thesis are the following: In Chapter 3, the brief theoretical model shows how, in the context of sovereign debt under multiple equilibria, the presence of asymmetric information and noise generates strategic uncertainty among market participants, leading to a crisis outcome for debt refinancing conditions in a self-fulfilling manner. The model applies an older currency-crisis explanation for market dynamics to sovereign debt to show how uncertainty interacts with market activity and brings the government into a self-fulfilling debt crisis outcome. Unlike all previous research on self-fulfilling crises which focuses on fiscal dynamics, this thesis elaborates on the mechanism via which uncertainty induces trading activity which in turn results in an excess of the maximum sustainable interest rate in financial markets and a self-fulfilling debt crisis. Therefore, light is shed on the short-run interplay between uncertainty, information about fundamentals, trading activity and expectations and their effect towards a state-contingent debt crisis outcome.

As an empirical application of this market-induced state-contingency of government debt, Chapter 4 develops a regime-switching threshold regression model of Greek sovereign spreads, in which two distinct risk pricing regimes are noted according to a threshold of uncertainty, defined and estimated within the Chapter. The presence of multiple equilibria is noted and complemented by a two-regime model for a bad and a good equilibrium outcome. Two regimes are distinguished: a regime of fundamentals-based risk pricing and a regime in which market-sentiment affects outcomes. Furthermore, light is shed on a short-run component of market-sentiment and uncertainty in the Greek sovereign spread, which is shown to operate through market liquidity. Event studies of the sovereign spread at key dates complement the analysis.

Chapter 5 evaluates a market-based policy solution with respect to the dynamics of the Greek government debt. This chapter is the first study to examine the historical counterfactual effect of

GDP-linked bonds on the evolution of the Greek government debt, *both* from an ex ante *and* from an ex post macroeconomic perspective, as a means to test whether the contractual state-contingent repayment of GDP-linked bonds would have been a solution to ward the Greek debt against uncertain future states as in 2010 (i.e. prior to the contracting of the first bailout package in 2010).

As often witnessed in economics, 'uncertainty' has played a central role in the evolution of the risk of sovereign default during the Greek debt crisis. This thesis takes a multifaceted, though certainly non-exhaustive, approach on uncertainty and its effect on financial market outcomes. A basic distinction is made between risk, a form of uncertainty where outcomes may be described based on some known probability distribution (the 'known unknowns') and Knightian uncertainty (the 'unknown unknowns') (Knight, 1921), where uncertainty is pervasive in the sense that the distribution of possible outcomes, over and above the actual outcome, is unknown. Although Knightian uncertainty implies an inability to predict and portray its outcomes, this thesis has attempted to provide a theoretical and quantitative approach to its impact.

In particular, with respect to uncertainty, Chapter 2 highlights the ambiguities involved in the definition of debt sustainability and the forecast and measurement uncertainty introduced in exercises of debt sustainability analysis or relevant metrics. Chapter 3 models three types of uncertainty: *informational uncertainty*, which relates to market efficiency and transparency and is depicted as noise; *strategic uncertainty*, which describes a coordination failure among financial market participants, induced by an initial doubt on financial market information; and *sunspots*, the occurrence of an exogenous random shock to fundamentals, which enriches the multiplicity of potential outcomes. Chapter 3 provides an explicit description differentiating between multiple equilibria and a bad regime for government debt based solely on uncertainty. Empirically, a distinction of two regimes for sovereign risk is pursued in Chapter 4 in a Threshold regression model. Chapter 4 incorporates uncertainty via estimating a model-based measure for Greek sovereign spreads' idiosyncratic risk, in addition to the inclusion of market-sentiment variables that are relevant to uncertain information about government debt capital markets. In Chapter 5, the fan chart approach taken to depict future potential paths for the government debt ratio underscores measurement and forecast uncertainties alongside the multiplicity of outcomes.

This thesis is structured as follows: Chapter 2 provides an extensive review of related literature, introducing the major topics and research strands relevant for each subsequent chapter; Chapter 3 builds a simple market-based model for self-fulfilling crises in government debt; Chapter 4 displays an empirical uncertainty-based distinction between fundamentals and market-expectations effects on Greek sovereign spreads; Chapter 5 examines a policy solution which limits the incidence of a debt crisis by offering a form of market-based insurance against the uncertainty of economic growth outcomes. Simulations of the Greek government debt ratio with and without the (partial) incorporation of GDP-linked bonds are performed for evaluation purposes. Chapter 6 provides concluding remarks on the findings of the thesis.

Chapter 2 Literature Review

2.0. Introduction

Sovereigns borrow to smooth consumption across bad states of the world (Barro, 1979). Access to capital markets serves as a form of insurance against multiple sources of risk and uncertainty. Unlike corporate debt contracts, in the absence of a sovereign bankruptcy court, sovereign debt contracts lack enforcement power as sovereign lenders cannot take effective legal action in the event of default.

Debt sustainability and associated debt thresholds are central to discussions of *sovereign risk* and government default. The literature on theoretical models of default, solvency and liquidity crises provides a background to the topics examined in subsequent chapters.

Section 2.1 surveys the major topics raised in the long-standing literature on sovereign debt sustainability, as relevant to the chapters and findings in this thesis. *Section 2.1.1.* evaluates the notion of sovereign debt sustainability and summarizes empirical assessments of debt sustainability; *Section 2.1.2.* presents sovereign debt default by defining an appropriate debt threshold; *Section 2.1.3.* evaluates theoretical models on the reasons why governments default and presents the costs of sovereign default; *Section 2.1.4.* summarizes seminal studies on multiple equilibria and self-fulfilling sovereign debt crises. *Section 2.1.5* explains self-fulfilling debt crises models in the context of the EMU. *Section 2.1.6* links the concepts of government debt solvency and liquidity.

Section 2.2 elaborates on the determinants of sovereign spreads, a metric which constitutes market-based assessment of debt sustainability and a proxy of the probability of sovereign default.

Section 2.3 provides an overview of 'market sentiment' and uncertainty in macroeconomics and relates this discussion to the distinction between fundamentals and market sentiment in empirical studies of sovereign spreads.

An evaluation of the literature and links to the following chapters of this thesis is offered at the end of the Chapter (Section 2.4).

2.1. Sovereign Debt Default: Debt Sustainability, Debt Thresholds and Multiple Equilibria

2.1.1. Debt Sustainability Analysis

Debt sustainability is a broad term used to place an "informed judgement" on the sovereign's ability to continue servicing its debt obligations at the present and into the future (Debrun et al.,2019a). Given the vagueness of the definition of sovereign default (which could be based on a loss of market access, a non-repayment of interest or capital obligations, the contracting of a bailout loan, or distinctions based on full versus partial debt repudiation) uncertainty is inherent in the operational definition of debt sustainability (Debrun et al.,2019a). Debt sustainability is *a composite informed judgement on both fiscal solvency and the sovereign's current liquidity position*. As such, additional sources of 'measurement uncertainty' are introduced. Firstly, *fiscal solvency assessments* are based on long-term projections of the government budget constraint and macroeconomic fundamentals, which are riddled with forecast errors in addition to uncertainty shocks (risk-related events or Knightian uncertainty). Secondly, *liquidity assessments* depend on uncertain market expectations, which in turn determine the cost of borrowing. Thirdly, interrelations and the measurement of such *long-run and short-run assessment uncertainties* render the topic of debt sustainability analysis into more "art rather than science". This thesis will attempt to shed some light into the different aspects of sovereign risk with respect to debt sustainability and uncertainty.

Debt sustainability is often erroneously confounded with *public sector solvency*, which is explicitly defined as the non-excess of existing obligations over the present value of all future primary balances (Debrun et al., 2019b). However, public debt sustainability is a broader and more elusive concept based on informed judgement calls on "known unknowns", as occurs in most forecasting exercises (Debrun et al., 2019a). According to its budget constraint, in each period, the government engages in a cost-benefit analysis with respect to the default against debt repayment decision (to be presented in section 2.1.3), which indicates that the ex-ante long-run commitment of sovereign debt repayment may often be questionable on a short-run per-period basis (Debrun et al.,2019b). This introduces a role for market beliefs and liquidity issues, which in turn gives rise to the multiple equilibria and self-fulfilling crises, as in section 2.1.4. Debt sustainability encapsulates the operational tools about long-horizon fiscal policy predictions, the conditions necessary (but not sufficient) to ensure solvency, the concept of a 'debt limit' (maximum sustainable debt) and the reasons why a government may be unwilling or unable to meet repayment obligations in the very short run. Therefore, *a substantial degree of uncertainty is involved both in defining and in detecting debt sustainability (Debrun et al., 2019b).* In turn, sovereign risk and the probability of default hinge on this elusive concept.

Empirical methods of assessing debt sustainability are surveyed to relate to the multifaceted nature of the topic. The following section introduces the intertemporal government budget constraint, which is related to econometric assessments of sovereign debt sustainability.

I. The Intertemporal Government Budget Constraint and the Transversality Condition

Central to the topic of debt sustainability is the government budget constraint. In a one-period setup, the current period debt stock D_t should be sufficient to cover interest expenditures (defined based on the average effective interest rate r_t on previous period debt) plus the primary balance deficit PB_t (defined as total non-interest expenditures minus total non-interest revenues) as follows:

$$D_t = (1 + r_t)D_{t-1} + PB_t \qquad (2.1)$$

As taxable income roughly grows with nominal GDP (Y_t), the above nominal amounts may be scaled using Y_t (Debrun et al., 2019b):

$$\frac{D_t}{Y_t} = (1 + r_t)\frac{D_{t-1}}{Y_{t-1}}\frac{Y_{t-1}}{Y_t} + \frac{PB_t}{Y_t} \qquad (2.2)$$

Assuming the Y_t grows at a rate of γ_t and denoting with lower-scale letters the ratios of the associated stocks with respect to Y_t,

$$d_t = \frac{(1+r_t)}{(1+\gamma_t)}d_{t-1} + pb_t \qquad (2.3)$$

Two primary sources of increases in debt are noted, the size of the primary deficit, which in turn is related to the distribution of shocks to an economy and associated fiscal policy decisions, rules and reactions and the so-called *interest-growth differential*, which is responsible for exploding debt dynamics under the so-called "debt-snowballing". [1]

Using $R_t = \frac{(1+r_t)}{(1+\gamma_t)}$, *equation 2.3* is rewritten as:

$$d_{t+1} = R_{t+1} d_t + pb_{t+1} \tag{2.4}$$

$$d_t = \frac{1}{R_{t+1}} d_{t+1} - \frac{1}{R_{t+1}} pb_{t+1} \tag{2.5}$$

Iterating one period forward:

$$d_{t+1} = \frac{1}{R_{t+2}} d_{t+2} - \frac{1}{R_{t+2}} pb_{t+2} \tag{2.6}$$

Substituting for d_{t+1} to find d_t:

$$d_t = \frac{1}{R_{t+1}} \frac{1}{R_{t+2}} d_{t+2} - \frac{1}{R_{t+1}} pb_{t+1} - \frac{1}{R_{t+1}} \frac{1}{R_{t+2}} pb_{t+2} \tag{2.7}$$

In period T:

$$d_t = \prod_{j=1}^{T} \frac{1}{R_{t+j}} d_{t+T} - \sum_{j=1}^{\infty} \prod_{k=1}^{j} \frac{1}{R_{t+k}} pb_{t+j} \tag{2.8}$$

As T tends to infinity:

$$d_t = \lim_{T \to \infty} \prod_{j=1}^{T} \frac{1}{R_{t+j}} d_{t+T} - \sum_{j=1}^{\infty} \prod_{k=1}^{j} \frac{1}{R_{t+k}} pb_{t+j} \tag{2.9}$$

(Debrun et al., 2019b)

Equation 2.9 states that the current debt ratio should be financed by the net present value of future primary balances, adjusted for some terminal value of debt d_{t+T}.

[1]Debt snowballing refers to the explosive dynamics in sovereign debt when the average effective interest rate on debt exceeds the rate of economic growth, such that increases in the denominator of the public debt ratio do not suffice to cover interest payments on existing debt (Debrun et al., 2019b).

According to the 'transversality condition' (or No-Ponzi Scheme condition/ 'no bubbles' condition) government solvency requires that the following equation is satisfied:

$$\lim_{T\to\infty} \prod_{j=1}^{T} \frac{1}{R_{t+j}} d_{t+T} = 0 \tag{2.10}$$

This transversality condition (*Equation 2.10*) states that Ponzi schemes, in which the government refinances its debt ad infinitum by issuing new debt and never repaying it, are ruled out. Tests of debt sustainability examine whether the transversality condition holds; otherwise, the debt ratio is deemed to be on an explosive path. For solvency, the net present value of future primary surpluses should equal current public debt outstanding, ensuring that primary deficits are at some point offset by primary surpluses:

$$d_t = -\sum_{j=1}^{\infty} \prod_{k=1}^{j} \frac{1}{R_{t+k}} pb_{t+j} \tag{2.11}$$

(Debrun et al., 2019b). Debt sustainability is therefore, an intertemporal judgement. Any assessment of debt sustainability under the above definition, requires some assumption about the future distribution of borrowing costs, nominal GDP growth, and the primary balance. Such assumptions introduce additional sources of uncertainty into debt sustainability.[2] *Credibility* (see section 2.1.4) of future fiscal policy commitments is critical to debt sustainability, adding further uncertainty in intertemporal debt sustainability judgements over and beyond current solvency concerns (Debrun et al, 2019b).

II. Testing for Debt Sustainability and the Debt Limit

The literature on debt sustainability is broadly divided into the following research strands (Debrun et al., 2019b): firstly, econometric tests which link debt sustainability to the temporary effect of shocks in the evolution of the public debt ratio (*unit root tests and cointegration tests)*; secondly, practitioners make debt sustainability judgements based on probabilistic models and fan chart projections using a *Debt Sustainability Analysis (DSA) model*; thirdly, *Sovereign Credit Ratings* and

[2] "The bottom line of this discussion could be that government solvency is a genuine 'known unknown' and that assessing it is 'mission impossible' (Wyplosz, 2011)" (Debrun et al.,2019b).

sovereign spreads are additional arbiters of debt sustainability; fourthly, assessments of debt sustainability also involve judgements as to whether the public debt has reached or surpassed a critical debt threshold (*debt limit*) (Blanchard, 1990; Blanchard et al.,1991; Bartolini and Cottarelli, 1991).

i. Econometric Tests of Debt Sustainability

Econometric tests of debt sustainability examine whether the public debt ratio or the relationship of the public debt ratio with its major long-run determinants is stationary. Stationarity would imply that shocks to the debt ratio bear a temporary effect, thereby ensuring fiscal and debt sustainability over the long run. For this purpose, unit root tests and cointegration tests are applied. In such tests, fiscal solvency (long-run fiscal sustainability) and debt sustainability are often confounded, as *only the intertemporal solvency dimension of debt sustainability is examined.*

In Unit Root tests, the debt-to-GDP ratio, the primary balance, or its components (government revenue and expenditure) are required to be stationary to ensure debt sustainability. Stationarity of the associated series is the required criterion of sustainability, in the sense that any shocks affecting either the government debt or the primary balance (or its components) are required to have a temporary effect, thereby ensuring fiscal solvency over the long run.

Econometric tests of fiscal solvency originated in empirical studies of the US budget deficit and debt. Hamilton and Flavin (1986) define government debt solvency as the absence of a unit root in the primary balance under the assumption of a constant interest rate. The stationarity of the primary balance is examined by testing for the existence of a cointegrating relationship between non-interest government revenues and expenditure. Trehan and Walsh (1991) show that if the primary balance is non-stationary, solvency may be ensured so long as the primary balance and the government debt are integrated of the same order. The existence of a unit root in the relationship between the primary balance ratio and the debt ratio would imply that government debt is not sustainable, as the transversality condition would not hold. Similar methods have been applied to panel studies of EMU member states.

Fiscal sustainability is also tested via *fiscal reaction* tests, following the seminal contributions by Bohn (1998, 2005). According to these tests, fiscal sustainability is defined when the reaction of the primary balance surplus to the previous-period debt ratio is positive. Econometrically, this occurs when the coefficient of the lagged debt ratio in the *fiscal reaction function*[3] is positive. A positive coefficient on the lag of the debt ratio implies that the government systematically responds to increases in the government debt ratio by increasing the primary balance surplus or by reducing the primary budget deficit accordingly to ensure long-run solvency (Checherita-Westphal and Zdarek, 2017). Ghosh et al. (2013) caution that Bohn's (1998) condition constitutes a *'weak' criterion of fiscal sustainability*, as it does not preclude cases where the government debt ratio is permanently increasing (Checherita-Westphal and Zdarek, 2017). Stronger tests of fiscal sustainability examine whether debt ratios start at prohibitively high initial levels; alternatively, they inquire into the existence of upper bounds in the ability of the primary balance to adjust to debt increases (*fiscal fatigue*) (Checherita-Westphal and Zdarek, 2017). This line of research proceeds in estimating a so-called debt limit, beyond which financial markets charge increasingly high-risk premia, such that the reaction of the primary balance may not keep up with refinancing costs and the government debt enters into sovereign default territory.

ii. Practitioners' Assessments of Debt Sustainability

Practitioners at international organizations and financial institutions test for country-specific debt sustainability using Debt Sustainability Analysis (DSA) templates, which are based on medium-term projections and the calculation of per-period gross financing needs, used as an input to the evolution of the debt-to-GDP ratio over the long run. This method strikes a balance between long-run, medium-

[3] The fiscal reaction function is a linear function of the primary balance ratio against the lagged value of the primary balance ratio, the lagged value of the public debt ratio, while also controlling for a number of macroeconomic and institutional factors (Checherita-Westphal and Zdarek, 2017). The fiscal reaction function may also take a non-linear form (cubic or spline) to account for fiscal fatigue, namely, instances beyond which the adjustment of the primary balance to changes in debt has reached its limits. In practice, this may occur due to the effect of austerity measures on tax revenues (Checherita-Westphal and Zdarek, 2017). Ostry et al.(2010) and Ghosh et al. (2013) extend fiscal reaction functions by incorporating fiscal fatigue in the primary balance (using a non-linear/cubic fiscal reaction function) to derive an endogenous debt limit, beyond which public debt is not sustainable. Mendoza and Ostry (2008) find a stronger primary-balance reaction to government debt in emerging market economies than in advanced economies. In the context of the EMU, the vast majority of panel studies find evidence of 'weak sustainability' (Checherita-Westphal and Zdarek, 2017, Debrun et al., 2019b).

run and short-run dynamics. To account for uncertainty, this approach is complemented with per-period stress tests of the main variables in the equation of the evolution of the public debt, as well as an analysis of contingent liabilities and of the financial sector.

iii. *The "Probabilistic Approach" to Debt Sustainability*

To account for uncertainty in the projections of future distributions, "the *probabilistic approach"* (Debrun et al., 2019b; Mendoza and Oviedo, 2008) on debt sustainability makes use of fan charts of projected debt ratios. Fan charts are created using scenarios for the distribution paths for the debt-to-GDP ratio, each of which is based on alternative assumptions about the inputs in the equation for its evolution. This approach enables policy decisions based on an informed estimate of the effect of 'known unknowns', in the Kay and King (2020) parlance.

The "reduced-form approach" to building a probabilistic Debt Sustainability Analysis (DSA) model involves random generation of alternative paths to capture forecasting errors (Debrun et al., 2019a).[4] Recent research follows Berti (2013), in using the historical variance-covariance matrix for the stochastic projection of debt ratios. The stochastic nature of this approach enables the consideration of a wide range of uncertainties, reflecting past volatility and shocks. However, the literature has criticized such non-structural reduced-form tools used in the probabilistic analysis of debt sustainability according to the Lucas critique (Lucas, 1976).[5] However, probabilistic tools drawing on historical evidence may still be valid for ex-post evaluations. Alternatively, Vector Autoregressions (VAR models) are used to depict the inter-relations between variables, while also incorporating a fiscal reaction function (Debrun et al., 2019a).

Barnhill and Kopits (2003) link the Value-at-Risk (VaR) method of empirical finance to the DSA as a means of incorporating macroeconomic uncertainty and of computing the probability of worst-case scenarios. First, they calculate the Net Present Value of the consolidated general government balance

[4] This method is followed in Chapter 5.

[5] According to the Lucas critique (Lucas, 1976), changes in economic policy induce changes in the behavior of agents in the model and their expectations, such that econometric results of a policy change based on historical data is invalid.

sheet and an estimate of the variance-covariance matrix. Subsequently, they apply VaR methods to determine the probability that the government has a negative net worth position (Mendoza and Oviedo, 2008).

A further 'probabilistic measure' of evaluating the sustainability of public debt relates to the calculation of the so-called 'fair spread' (Xu and Ghezzi, 2003), indicative of the appropriate risk premium that is reflective of the default probabilities implied by a model of the dynamics of treasury reserves, exchange rates, interest rates and the primary balance (Mendoza and Oviedo, 2008). Along those lines, Chapter 4 makes use of historical data to distinguish between the effect of fundamentals and uncertainty-induced expectations on Greek sovereign spreads, albeit using a different methodology.[6]

iv. Sovereign Credit Ratings and Sovereign Spreads

Two additional assessments of debt sustainability are offered by sovereign credit ratings, which involve the informed overall judgement on sovereign debt prospects by Ratings Agencies, and by sovereign spreads, which reflect the aggregate financial market judgement on the probability of sovereign default compared to a benchmark country.

Credit rating agencies assess the following five factors prior to providing a forward-looking judgement on debt sustainability: "i. *Institutional/structural factors:* government quality and stability, default history, transparency and accountability of government; ii. *Macroeconomic factors:* level of economic development, growth, volatility; iii. *Fiscal factors:* debt stock, fiscal balance, contingent liabilities; iv. *Monetary factors:* inflation, credibility of monetary policy, impact of monetary policy on the real economy; v. *external factors:* Balance of Payments, Net International Investment Position, external debt stock" (Debrun et al.,2019b).

Empirical evidence about whether sovereign credit ratings provide any information on debt sustainability over and above sovereign spreads is mixed. Reinhart (2002) suggest a lag in sovereign

[6] Xu and Ghezzi (2003) develop a continuous-time stochastic model, resembling first-generation models of balance-of-payments crises (Mendoza and Oviedo, 2008).

ratings compared to financial markets. Ferri et al. (1999) show that ratings may amplify financial market conditions. Cavallo et al. (2008) find evidence that sovereign ratings may predict spreads, after controlling for current sovereign spreads and fundamentals.

Sovereign spreads (of government bond yields or of Credit Default Swaps[7]) constitute proxies of the probability of sovereign default, as risk neutral investors require to be compensated for the additional risk borne when holding these assets due to the implied probability of sovereign default.

The following equilibrium condition must hold for a risk-neutral investor lending to a sovereign with a zero-default probability, assuming a zero-recovery rate upon default:

$$(1-\pi)(1+i^*+s)=(1+i^*), \tag{2.12}$$

where (1-π) is the probability of repayment (hence π is the probability of default), i* is the return on a risk-free bond and s is the country risk-premium or spread. To compensate for the probability of default and associated potential losses, the risk-neutral investor requires the borrower to provide compensation in the form of a risk premium (spread s) over the return on similar risk-free bonds i*(Csonto and Ivaschenko, 2013).

Rearranging the above equation yields the relationship between sovereign spreads and the probability of sovereign default as follows (Csonto and Ivaschenko, 2013).:

$$\text{Spread}=\frac{\pi}{1-\pi}(1+i^*) \tag{2.13}$$

Empirical models further specify a functional form for this implied probability of default. Usually the probability of default, which is the metric of a lack of debt sustainability in this line of research, is modelled via the logistic function as follows:

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[7] The Credit Default Swap (CDS) spread contains information on both the probability of default and the recovery rate as follows:
$\pi=\frac{CDS\ spread}{1-\theta}$, where π is the implied market probability of default and 1-θ corresponds to the haircut fraction and θ to the recovery rate (Do Bernardo, 2016).

$$\pi = \frac{\exp\left(\sum_i \beta_i X_i\right)}{1 + \exp \sum_i (\beta_i X_i)} \qquad (2.14)$$

where X_i is a vector of country-specific determinants of the probability of default and β_i are the associated coefficients (Csonto and Ivaschenko, 2013). Section 2.2 of this literature review provides an extensive overview of the determinants of sovereign spreads (and, thus, of market-based assessments of debt sustainability).

v. The Balance Sheet Approach

Niche assessments and policy proposals regarding the framework of debt sustainability analysis have also considered the adoption of a net assets approach, according to which appropriate public-sector accounting criteria would be used to judge the value of all government-owned assets and to develop a balance-sheet for the government, following corporate accounting methods. The balance-sheet approach on public debt sustainability, thus, recommends the use of a net debt metric (Debrun et al., 2019b).[8] Similarly, present value considerations may be used to capture the distribution of debt repayments in the future. For Greece, Paul Kazarian and Japonica Partners (e-Kathimerini, 30/09/2016),[9] have suggested the adoption of IFRS by the government to show that the Greek government debt is sustainable. Arrow et al. (2004) have recommended using the Intertemporal Non-Decreasing Net Worth (INW) as a criterion for debt sustainability (Debrun et al., 2019b). Accordingly, the European Commission computes the S2 indicator of long-term sustainability, which is based on the "difference between the current gross debt and the present value of all future primary balances" required to fulfil the intertemporal budget constraint (Debrun et al., 2019b).

vi. ***Early Warning Signals***

A large literature, focusing predominantly on low-income or emerging market economies, is devoted to the study of fiscal stress episodes using "early warning" signals. Starting with Manasse, Roubini

[8] However, additional uncertainty in the debt sustainability assessment may arise due to potential discrepancies between valuations of government fixed assets which may differ from relevant market values achieved in the case of fire sales during a liquidity crisis (Debrun et al.,2019b).
[9] https://www.ekathimerini.com/212448/article/ekathimerini/comment/japonica-partners-chief-paul-kazarian-insists-greeces-net-debt-is-only-72-bln-euros

and Schimmelpfenning (2003), logistic regression estimation is applied to detect the determinants of fiscal stress given fundamentals.[10] A similar approach is used in panel data assessments of EMU member states' imbalances over the course of the European Semester.

2.1.2. Natural Debt Limit and the Maximum Sustainable Debt level

A complementary definition of debt sustainability relates to whether the observed public debt ratio approaches or surpasses a *maximum sustainable debt threshold* or *debt limit*. As the level of public debt increases beyond a debt threshold, the primary balance cannot increase sufficiently to offset the effect of *debt snowballing*. *Debt snowballing* occurs when the rate at which the government debt grows (r) exceeds the rate at which economic output grows (g) such that responses in the primary balance do not suffice to offset the 'automatic debt buildup' (Debrun et al., 2019b). In that case, the risk premium charged by financial markets on new issues of government debt becomes prohibitively high, such that the government cannot refinance its existing debt obligations and is forced to default. This endogeneity of the risk premium with respect to some threshold level of the debt-to-GDP is further examined via changes in market beliefs regarding debt sustainability in Chapter 3.

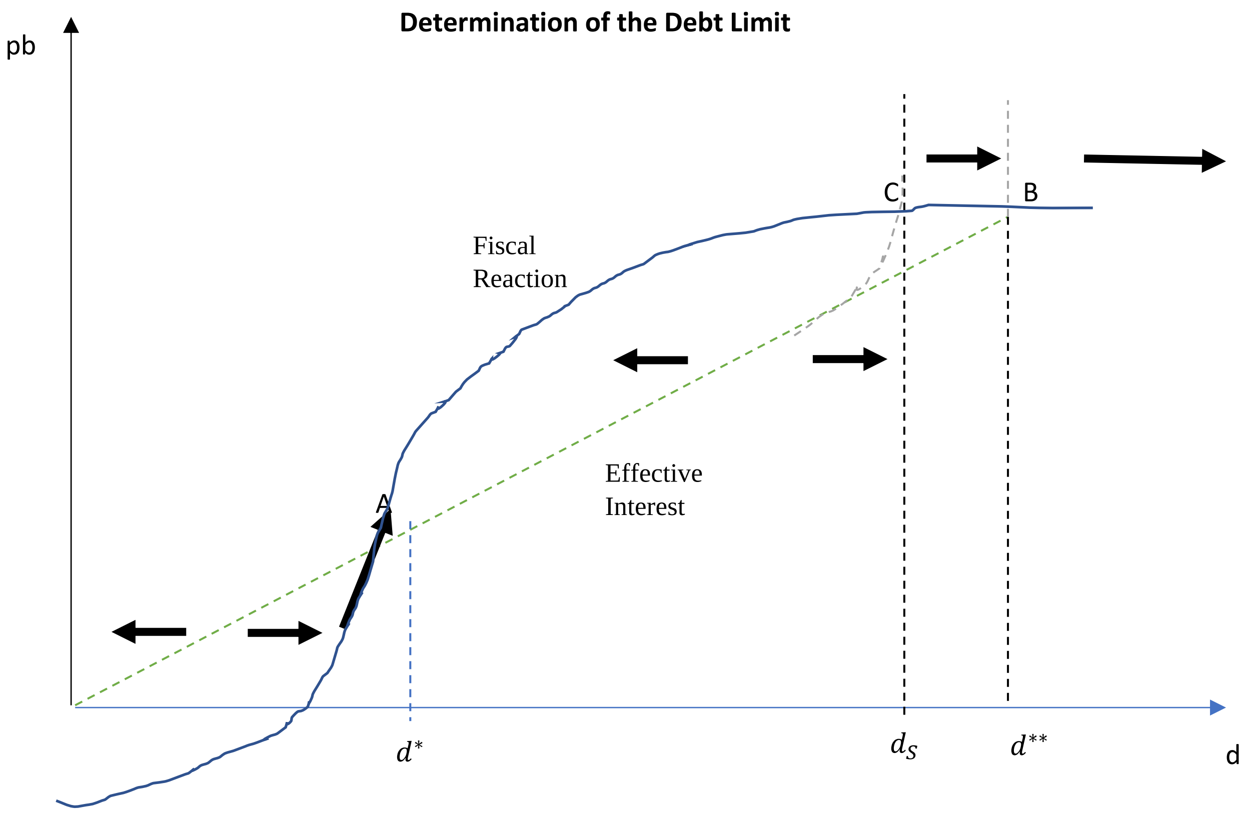
Empirically, debt thresholds are estimated as the turning points in the debt-primary balance relationship in a fiscal reaction function or as the average debt level beyond which distress episodes have been empirically observed (Debrun et al., 2019b). More complex stylized solutions are provided in Dynamic Stochastic General Equilibrium (DSGE) models of sovereign default, which however lie outside the scope of this thesis (e.g. Aguiar and Gopinath, 2006; Mendoza and Yue, 2012 etc.)

Figure 2.1 is a sketch of the standard dynamic representation of the debt limit for a given fiscal reaction function (Ostry et al., 2010) also presented in Debrun et al. (2019b) to illustrate the dynamics with respect to a debt threshold. The vertical axis represents the primary balance (pb) ratio, while the horizontal axis depicts the debt-to-GDP ratio (d).

[10] The IMF applies relevant methods to determine distinct debt thresholds for weak, medium and strong sustainability for low-income countries (Debrun et al.,2019b).

The blue line represents the Fiscal Reaction Function, whose shape is determined by the fiscal adjustment path of the government. The effective interest rate schedule (gray line) represents the real growth-adjusted rate on new debt issuances and rotates upwards due to the default risk premium demanded by investors, approaching a vertical asymptote. Debt limits are defined based on the interaction of the fiscal reaction function and the effective interest rate, which occur at points B and C. The point at which the effective interest rate schedule rotates upwards represents the level of debt at which the primary balance cannot tame the debt-snowballing dynamics, which tend upwards into a vertical asymptote.

Figure 2.1 Determination of the Debt Limit



Source: Debrun et al., 2019

Point B represents the *natural debt limit* d**, beyond which the government defaults with certainty, as the effective interest rate tends to infinity, implying a loss of market access for the government and an inability to rollover its debt. Point C corresponds to the point beyond which the primary balance plateaus due to fiscal fatigue and can no longer adjust to accommodate increases in the effective interest rate. Therefore, Point C is the *maximum sustainable debt limit (ds)*, beyond which the endogenous dynamics of increasing risk premia result in an exploding probability of default.

Immediately prior to points C and B, the effective interest rate rotates upwards due to an increasing risk premium charged by investors on the government debt, and reaches a vertical asymptote once the debt limit is crossed, indicative of the insufficiency of the primary balance reaction to cover debt snowballing dynamics. Judgements on debt sustainability and the probability of default hinge on whether the debt ratio has crossed these endogenously determined thresholds.

As evidenced, negative shocks to the primary balance may affect the perceived probability of default, increase the size of the risk premium and steepen the effective interest rate. In turn, this may send the government debt ratio to the right of the debt limit and into default. The asymptotic nature of the effective interest rate schedule is indicative of the speed in which negative fiscal or macroeconomic shocks could lead to government default following a liquidity crisis.[11]

In the context of the dynamic evolution of public debt, sovereign default arises when the level of the public debt ratio is in excess of its *natural debt limit*. As the public debt ratio increases, so does the probability of default, thereby inducing markets to charge a higher default risk premium, which in turn increases the probability of default, further raising the interest rate, giving rise to the so-called *'fixed point' problem*. The natural debt limit corresponds to the highest ratio of public debt to GDP, for which there exists an interior solution to the 'fixed point' problem at some finite interest rate (Debrun et al., 2019b). To the right of d**, "the fixed-point problem has no interior solutions with a

[11] Chapter 3 provides an explanation for the process via which this may occur.

default probability strictly less than unity," and the government "can no longer borrow at a finite interest rate" (Debrun et al., 2019). Noting this asymptotic behavior, it is recommended that countries' actual sustainable debt ratios lie lower than this debt limit, preferably below the maximum sustainable debt limit *ds* (Debrun et al., 2019b).

The definition of a single debt threshold for debt sustainability involves judgement and measurement uncertainty due to the need to assess future fiscal policy behavior and its limits due to fiscal fatigue, as well as due to potential interest-rate and growth forecast errors. In addition, the computation of a debt threshold is inherently difficult and riddled with uncertainties, as it ultimately depends endogenously on the effect of market expectations.[12]

The ambiguity and uncertainty involved in calculating the above debt ratio thresholds is highlighted by the evolution of the related *theoretical* literature, which evolved from the calculation of a generic long-run steady state of debt **(**Buiter et al., 1985; Blanchard, 1990; Blanchard et al., 1991) into a Natural Debt Limit, which also accounts for fiscal fatigue, or stricter conditions based on the additional constraint that the primary balance is mean-reverting (Bartolini and Cottarelli, 1994).

i. The Steady State of Debt-'Blanchard ratio'

"Steady-state perfect-foresight models" compute the so-called 'sustainable debt-to-output' ratio (see Buiter, 1985; Blanchard, 1990; Blanchard et al., 1991) which is constant over time. This may be defined as the ratio of the primary balance surplus over the differential between the net long-run rate of output growth to the steady state of the real interest rate as follows (Mendoza and Oviedo, 2008):

$$d = \frac{pb}{r-g} \tag{2.15}$$

This long-run debt ratio (d) corresponds to the *target* debt-output ratio achieved by a given projection of the long-run primary balance-to-output ratio (Mendoza and Oviedo, 2008). It may also be viewed

[12] Chapter 3 will elaborate further on this topic and indicate the intricacies between liquidity and debt sustainability, in which small variations in market expectations could lead to spikes in financing costs and a self-fulfilling crisis. Chapter 5 will make use of an associated "overindebtedness threshold" beyond which sovereign spreads have an increasing effect on the evolution of the debt ratio.

as the level of debt consistent with a target primary balance in the long run (the mirror-image of a debt-stabilizing primary balance). Mendoza and Oviedo (2008) caution that this long-run debt ratio is dependent on initial conditions, as also predicted by Barro's tax smoothing model (1979).

ii. *The Natural Debt Limit (NDL)*

The natural debt limit is related to the steady state of debt resulting when the primary balance is assumed to be at its minimum tolerable level, indicative of a 'fiscal crisis' defined as a "sufficiently long sequence of the worst realization of public revenues, and after public outlays have been adjusted to their tolerable minimum" (Mendoza and Oviedo, 2008).

The Natural Debt Limit is the "time-invariant" debt limit imposed by the government for precautionary purposes that offers lenders credible commitment for repayment of debt in all states of nature (Mendoza and Oviedo, 2008). It represents the "growth-adjusted annuity value of government debt when the primary balance is at a state of fiscal crisis" (Mendoza and Oviedo, 1994). Early research on the NDL focused on the real long-term *steady state* of interest. However, Mendoza and Oviedo (2008) incorporate a *time-varying default risk premium over the safe interest rate* and find that resulting NDLs are substantially lower than initial NDLs.

Credible commitment for repayment (repayment with certainty) in all states of nature implies that the NDL should always lie below the *steady state of debt* implied *using minimum primary balance levels*. The NDL corresponds to the long-run debt limit when government revenues are at their minimum and the government has committed to a minimum ratio of government expenditures to GDP:

$$d_{t+1} \leq d^{**} = \frac{\overline{pb}_{min}}{\Gamma_*} \qquad (2.16)$$

The Natural Debt Limit (NDL) (d**) is therefore the "growth-adjusted annuity value" of the maximum primary balance ($\overline{pb}$) in the case of fiscal fatigue (Mendoza and Oviedo, 2008). It corresponds to the debt level beyond which increases in public debt may not be offset by the primary balance and the snowball effect dominates in the long run (Γ*>0) for some growth-adjusted effective interest-rate schedule ($\Gamma * = \mathrm{r} - \mathrm{g}$).

A similar condition for debt sustainability is developed by Bartolini and Cottarelli (1994) who impose a stricter mean-reverting condition for government debt sustainability, requiring that the primary balance more than offsets the debt buildup in response to the debt-snowballing dynamic induced by increasing effective interest rates on new debt and that the debt ratio is mean-reverting (See Appendix A2.1).

The NDL is lower for governments with a higher variability in government revenues (more uncertain tax base), less flexibility to adjust government expenditure (e.g. fiscal targets) and lower growth rates or higher real interest rates (Mendoza and Oviedo, 2008).[13] It corresponds to the maximum level of debt at which the government can guarantee credible commitment to repay, such that stochastic shocks do not induce default. However, a debt ratio consistent with the NDL does not preclude sovereign default. The occurrence of large and unexpected shocks could still induce default triggered by "inability to repay" reasons (Mendoza and Oviedo, 2008). Therefore, default may not be ruled out with certainty for levels below this debt limit, as "radical uncertainty" (Kay and King, 2020) could still tilt the dynamics into default. Similarly, the NDL does not preclude strategic default triggered by "unwillingness to pay" considerations (see section 2.1.3) (Mendoza and Oviedo, 2008).

The Natural Debt Limit (NDL) is the upper bound placed on government debt ratios, following the precautionary-savings literature for private agents' debt limits (see Aiyagari, 1994) (Mendoza and Oviedo, 2008). The NDL arises when financial markets are incomplete and the government does not have access to state-contingent debt instruments to smooth its expenditure during bad states of nature (Mendoza and Oviedo, 2008).[14]

Reinhart, Rogoff and Sevastano (2003) find that sovereign debt thresholds are highly country-specific. The IMF suggests distinct thresholds of debt sustainability based on debt-servicing ratios and public debt ratios, yet these do not relate to EMU countries due to the critical effect of external debt

[13] The Mendoza and Oviedo (2008) model breaks down the primary balance into government revenue and expenditure and relates credible commitment about debt repayment to the credibility of fiscal rules in place under a stochastic general equilibrium framework. Fiscal rules are outside the scope of this thesis.

[14] The proposal for state-contingent GDP-linked bonds in Chapter 5 is a means of increasing this limit by enhancing market completeness.

denominated in a foreign currency. In the EMU, the Maastricht Treaty sets a uniform criterion requiring the long-run convergence of member states to a 60% government debt-to-GDP ratio. In the light of the low-interest-rate environment and very high public debt ratios, recent policy initiatives have called for a revision of this criterion into higher levels of critical sustainable debt ratios.

2.1.3. Theoretical Models of Sovereign default

Theoretical models of sovereign default are broadly divided into default that arises due to strategic reasons ("willingness to pay") versus default due to the inability to meet debt servicing obligations ("ability to pay"). Cost-benefit analysis based on an intertemporal budget constraint is implied in relevant political economy models.

i. Why do sovereigns repay their debt? "Willingness to pay" versus "ability to pay"

Given the lack of a sovereign bankruptcy court and associated enforcement power on sovereign debt contracts, economists have pondered over the reasons why sovereigns repay their debts. Two distinct explanations have been offered in the literature, which Bulow and Rogoff (2015) divides into two strands accordingly: On the one hand, the *'reputational approach*,' initiated by the work of Eaton and Gersovitz (1981), suggests that repayment will occur according to a reputational equilibrium based on some incentive-compatibility constraint, as the sovereign will be willing to maintain a reputation of repayment to continue tapping international capital markets and, thus, to smooth consumption across states of the world. On the other hand, the *'direct punishments' approach* of Bulow and Rogoff (1989a, 1989b) notes the limited empirical validity of the theoretical framework of Eaton and Gersovitz (1981) and suggests that direct sanctions ought to be applied in the case of non-repayment to the sovereign to induce repayment, particularly during good states of the world.

According to the *reputational approach*, the sovereign will repay its debts to avoid building a reputation for default and to avert the possibility of an associated loss of market access. Reputation for repayment operates as "reputational collateral," creating the incentives for repayment and the enforcement of sovereign debt contracts (Bulow and Rogoff, 1989a). In this framework, the sovereign will *strategically decide* whether or not to repay its debt according to its incentive-compatibility constraint, based on which it trades off the consumption-smoothing benefits of market access (and thus of a reputation for repayment) against the costs of debt service (Drazen, 2002). According to Bulow and Rogoff (1989), it is the *threat* of sanctions that suffices for the "reputational approach" to work rather than actual penalties (Bulow and Rogoff, 1989). The critical debt limit in such models is based on the observed volatility of output or unobserved risk aversion levels (Bulow and Rogoff, 2015).

Grossman and Van Huyck (1988) offer an extension of this 'reputational approach' framework, incorporating the possibility of 'partial default'. They show how a sovereign who trades off the short run benefit of debt repudiation against the long-run costs arising due to the loss of a reputation for repayment will always have an incentive for 'excusable' partial default in some bad states of the world (Grossman and Van Huyck, 1988). In contrast, higher debt repayment is envisaged in good states of the world as the marginal utility of consumption is decreasing (Bulow and Rogoff, 2015). In their model, lenders distinguish between "excusable partial default" arising due to adverse state-contingencies and "unjustifiable repudiation" (Grossman and Van Huyck, 1988). Therefore, this line of literature models default as a strategic decision related to a sovereign's *willingness to pay (strategic default)* rather than solely its *ability to pay*. In the empirical literature, Tomz and Wright (2007) find evidence of reputation effects in trade relations and financial markets.

Nevertheless, the strategic default framework is problematic when applied to empirical evidence, as it suggests that default occurs due to the lack of willingness to repay based on a value maximization problem that weighs the costs of default against the costs of debt service (a form of cost-benefit analysis). This line of reasoning could erroneously lead to the conclusion that the sovereign will only default in good times, when market access is not required for consumption smoothing. This would occur due to the model's depiction of default costs as a fraction of output: as output is higher in good states, higher default costs occur in good states compared to bad states (See Appendix A2.3).

Secondly, the identity of the creditor is irrelevant in reputational models, a fact which has been shown not to match real outcomes (Bulow and Rogoff, 2015). Thirdly, the consumption-smoothing basis of reputational models suggests increased borrowing when income is more volatile, whereas in reality sovereigns are better positioned to tap capital markets when income is more stable (Bulow and Rogoff, 2015). Lastly, the reputational approach does not allow for an explanation of debt buybacks or debt-to-equity swaps involving third-party (official sector) funds, which in contrast are plausible under the direct-punishments approach in Bulow and Rogoff (1989b) (Bulow and Rogoff, 2015).

Building on the above critique, *inability-to-repay models* (Bulow and Rogoff,1989; Sachs and Cohen, 1982), show that the enforcement of sovereign loans in small countries (small in the sense that they do not affect world interest rates) requires the imposition of direct sanctions. Unless *direct costs* are involved, the sovereign may still default on external debt, despite the associated reputational costs, since reputation cannot imply the complete and permanent exclusion from capital markets in the presence of "cash-in-advance" contracts[15] (see Appendix A2.2). In addition to the loss of market access, examples of direct costs include trade sanctions, geopolitical considerations, exclusion from monetary union membership or other regional arrangements, and the curtailing of access to other sources of funds.[16]

ii. *The "Sovereign-Default Puzzle": Is Default a Strategic Decision of the Sovereign or is it a Decision of the Markets?*

Cohen and Villemot (2012) note that a major problem with theoretical models is that both the frequency of default and debt levels outstanding depend on a single parameter: the cost of default. The above question has served as the benchmark distinguishing between *'willingness to repay'* versus *'ability to repay'* theoretical models.

Cohen and Villemot (2012) suggest that a change in the sequencing of decision-making with respect to default would resolve the problem as follows: Unlike the standard assumption that given a set of

[15] Bulow and Rogoff (1989) have criticized the empirical validity of the Eaton and Gersovitz (1981) model, through the introduction of so-called 'cash-in-advance' contracts: As a form of insurance, the sovereign will always have an incentive to make an upfront payment on a contract which will make state-contingent payments in the future. The rational sovereign will, thus, always prefer to honour the cash-in-advance contract, which will provide higher consumption in future states against making a current repayment on its debt and honoring the reputation contract (Bulow and Rogoff, 1989).

[16] For example, in 2015, European creditors insinuated that a Greek default could imply the exit from the EMU and the European Union, or that structural funds would cease to flow to Greece.

constraints, the sovereign decides whether or not to default, "*default is a decision that is modeled to be taken by financial markets*."[17] The choice of timing of events is critical to the model. The eruption of the crisis is modelled via a Poisson process.[18] In essence, the Poisson component of the process mimics the exogenous risk of being hit by a confidence shock with real and lasting negative consequences, which may only be restored if no default occurs. When the price of debt is low, Poisson shocks will always generate a default, as also suggested by self-fulfilling models *à* la Cole and Kehoe (1996, 2000). Effectively, the Poisson jump acts in a fashion akin to the "sunspots" (see section 2.1.4), giving rise to the dynamics that lead to the "bad" equilibrium.

As an implicit cost-benefit-analysis is central to liquidity crises and 'ability to pay' models, the following section summarizes the empirical findings in the literature on the costs of default involved in the cost-benefit-analysis of the sovereign and recognized by financial market expectations when pricing sovereign risk premia.

iii. The Costs of Sovereign Default

Given the cost of debt repayment, the sovereign will have an incentive to default in all states of the world, except if there are high output costs associated with default (see, *inter alia*, Alfaro and Kanczuk, 2004).

The output costs of default have been extensively studied by empirical research. Based on two hundred years of data, Borensztein and Panizza (2008) present empirical evidence on sovereign default costs according to a four-fold classification: *reputational costs*, costs of sovereign default on the *banking sector, political costs* on authorities, and costs due to the *exclusion from capital markets*. Overall, the authors hold that "default costs remain somewhat vaguely defined, and difficult to quantify" (Borensztein and Panizza, 2008). Noting that output contraction often occurs prior to a

[17] This formulation rules out the notion of "strategic default", which the authors, however, deem to be practically unrealistic, with the exception of Ecuador in 2009 (Cohen and Villemot, 2012).
[18] Cohen and Villemot (2012) develop a Levy Process of sovereign debt, namely, a combination of a Brownian motion process with a compound Poisson process, whereby it is the Poisson process of infrequent yet discrete jumps which generates defaults.

credit event, Levy-Yeyati and Panizza (2011) suggest that large output losses may be induced even *by the mere "anticipation of default* rather than the default itself" (Levy-Yeyati and Panizza, 2011).

Reputational costs have mostly been associated with the breakdown in trade. Using a gravity trade model, Rose (2005) finds that Paris Club renegotiations are associated with an 8% per annum 15-year decline in bilateral trade. In contrast, using industry-level data, Borensztein and Panizza (2006), find that the effect of default on export-oriented industries is short-lived.[19] Arteta and Hale (2006) find evidence that sovereign debt crises are accompanied by lower levels of foreign credit to domestic private firms.

Sovereign default has also been associated with *banking crises* and the banking sector may operate as an amplification channel of the costs of default. Borensztein and Panizza (2006) find that the probability of a banking crisis conditional on sovereign default in the previous year is 14%, as opposed to 3% for the unconditional probability. Given that banks hold large amounts of sovereign bonds in their portfolios, sovereign default imposes a direct balance sheet cost on banks, which in turn may undermine their solvency position, particularly when combined with a bank run (Sturzenegger and Zettelmeyer, 2006).

The *political costs* of sovereign default on political parties, finance ministers and top executive public figures are considered the most long-lasting among sovereign default costs (Borensztein and Panizza, 2008). Using 1980-2003 data for the percentage of votes for the ruling coalition in the elections preceding and succeeding a default, ruling coalitions are shown to have lost votes in all countries, except for Ukraine (Borensztein and Panizza, 2008). On average, the decrease in electoral support was 16 percentage points, while in 11 out of 22 episodes, the chief executive changed during or after the

[19] Borensztein and Panizza (2008) attribute the difference to the channels via which default is shown to affect trade: although the theoretical debt literature suggests that default is associated with the imposition of restrictive measures to investors, there exists little historical evidence of quotas or embargos on defaulting countries. Instead, given the more sophisticated and anonymous nature of modern capital markets, more recent models assume that default is linked to the credit quality of exporting firms, and particularly, the imposition of capital or exchange controls, which in turn make credit less available and more expensive (Borensztein and Panizza, 2008).

year of the default episode (Borensztein and Panizza, 2008). Similarly, Borensztein and Panizza (2008) find that more than 90 percent of finance ministers lose power in the 18 months following a default episode, a turnover which is even higher for dictatorships compared to democracies. The presence of high political costs leads to a twofold opposite response: first, high political costs increase the sustainability of public debt by increasing the country's willingness to repay; yet second and opposite, high levels of political costs lead to delays and to 'gambles for redemption' which only serve to amplify the economic costs of default (Borensztein and Panizza, 2008).

Schmitt-Grohe and Uribe (2017) explain that the *loss of access to capital markets* is costly in that it prevents the current account from smoothing consumption over time in response to shocks in aggregate demand. However, unlike the assumption underlying the reputational costs approach to sovereign repayment, evidence suggests that exclusion from capital markets in the aftermath of default is not permanent. Following the conclusion of a sovereign debt restructuring, financial markets do not provide discriminatory access to sovereigns, according to their default history (Borensztein and Panizza, 2008). For instance, Gelos et al. (2004) find evidence that countries defaulting in the 1980s were able to regain access to international capital markets within approximately as little as 4 years (Borensztein and Panizza, 2008). Richmond and Dias (2009) distinguish between full and partial defaults, finding an average exclusion of 5.4 years for partial default and of 8.4 years for total default. The short-lived exclusion for Argentina is contrasted to the approximately decade-long exclusion for Ecuador (Richmond and Dias, 2009).

Given reaccess to capital markets, empirical studies have probed into the *impact of default on a sovereign's borrowing costs.* Borensztein and Panizza (2008) distinguish the following three groups of papers: A first group of papers find that default history did not bear a significant impact on sovereign spreads in the late 1990s; a second group of papers, including Eichengreen and Portes (1995), which find evidence of a 20bp increase; and a third group of papers, including Flandreau and Zumer (2004), who find that the post-default spread increases by 90 bp in the year following default yet decreases rapidly over time.

Further detail on modelling choices for the cost of sovereign default is provided in Appendix 2.3.

2.1.4. Multiple Equilibria Models and Self-fulfilling Crises

Economic literature has long observed the phenomenon of self-fulfilling crises. Models with *multiple equilibria* have been developed for that purpose. Multiple equilibria models are rational expectations models relating the effect of market expectations and fiscal fundamentals. Typically, multiple equilibria rely on the existence of at least two equilibria over a zone of fundamentals: a 'good equilibrium', in which the pricing and quantity of debt is such that debt rollover (or debt repayment) is enabled; and a 'bad equilibrium', in which pessimistic creditor expectations about the sovereigns' willingness and/or ability to repay, become self-fulfilling, thus generating the market conditions in which the optimal choice for the sovereign is to default. [20]

Such models move from the intertemporal notion of solvency, which is solely based on fiscal fundamentals (see Section 2.1.1) into an implied current-period gross financing needs (GFN) approach, in which the effective interest rate on debt and liquidity concerns become central. According to this approach, market expectations (based on some perceived probability of default by risk-neutral investors in capital markets) place a risk premium on government debt issuances, such that borrowing costs may become sufficiently high as to prohibit debt rollover. In that case, expectations precipitate a liquidity crisis, which in turn culminates into sovereign default. Rather than focusing on a 'tipping point' for the government debt ratio (debt limit-based sustainability, see section 2.1.2), this line of literature alludes to immediate debt-servicing concerns. *Multiple equilibria* models are consistent with *rational expectations*, i.e. bad equilibria are possible even in the absence of behavioral effects such as herding behavior or panic effects.

The majority of theoretical papers model self-fulfilling crises as a credibility and time-inconsistency problem of the government, or as a coordination problem between agents (inter-creditor lack of

[20] A very simple model of sovereign debt crises is offered by Romer (2012, pp. 632-639). Concluding remarks on this model pave the way for a model a la Morris-and-Shin (1998a), as in Chapter 3, by alluding to the role of higher-order beliefs'.

coordination, or intertemporal creditor coordination); alternatively, multiple equilibria are the outcome of some random variable, a *sunspot.*[21] [22]

The literature on self-fulfilling debt crises originated in political economy setups with time-inconsistent fiscal policies and has evolved into more complex multi-period DSGE models. As the DSGE methodology is outside the scope of this thesis, DSGE models will only be discussed with respect to their main findings, rather than for their methodological components.[23]

The literature on self-fulfilling crises emerged in the aftermath of the Mexican peso crisis in 1994 and made use of currency crisis model insights, particularly those of the second-generation models, following Obstfeld (1994). Typically, self-fulfilling crises originate over a zone of questionable fundamentals but their outcome may be unrelated to changes in fundamentals. Self-fulfilling crises are set in motion through a pessimistic belief which makes lenders more suspicious, thereby requiring a higher risk premium, or inducing lenders to curtail their purchases of the sovereign's bonds. Higher costs of debt service, when coupled with a pressing repayment schedule for the sovereign may lead to default, even if repayment capacity was not questionable at first. Investor herding and frequent massive sell-offs observed prior to default exacerbate the situation as do spikes in the repayment profile and large sums of short-term debt during such periods.

Critical to liquidity crises in self-fulfilling models is the inability to roll over debt. For this reason, a model's choice of timing of actions within a period is important, as models will generally require new debt to be issued prior to old debt being retired. Multiple equilibria models connect self-fulfilling beliefs with fundamentals, such that over a zone of questionable fundamentals different outcomes may occur for debt repayment, once the self-fulfilling expectations mechanism has kicked in. [24] The

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[21] Sunspots are extrinsic payoff-irrelevant random shocks which influence economic activity and lie at the heart of multiple equilibria models.

[22] The latter two sources of multiplicity (intercreditor coordination and sunspots) will be elaborated upon in the theoretical model in Chapter 3.

[23] Chapter 3 seeks to bridge the concept of 'sunspots' usually applied in the DSGE literature, with an alternative game-theoretic setup more pertinent to reduced-form models.

[24] Chapter 3 will elaborate on this issue.

following subsections offer a brief overview of a limited number of seminal papers, based on which the literature on self-fulfilling debt crises has evolved.

i. *Self-fulfilling Crises and Policy Time Inconsistency-Inability to commit to next-period taxes*

Calvo (1988) developed the first two-period model of debt repudiation with multiple equilibria for the interest rate: in the 'good equilibrium', investors require the risk-free rate from the sovereign, and debt repayments are met; in the 'bad equilibrium', investors require a risk premium and interest payments accumulate, inducing partial default and rendering the debt unsustainable. In Calvo's model, inability of government policy to pre-commit to raising future taxes generates self-fulfilling equilibria. (see Figure A2.1 in Appendix A2.4). Calvo (1988) prescribes a role for interest rate ceilings on new government bond issuances, such that when interest rates exceed a predetermined level, no more debt is sold to ensure a unique and sustainable equilibrium. Therefore, Calvo (1988) alludes to the role of a *maximum sustainable interest rate* and suggests a policy solution in response.

The potential for two equilibria in Calvo (1988), with distinct welfare implications, points to the government's inability to commit to future policy (future tax raises) as a source of the multiplicity of equilibria. The attribution of multiple equilibria results to *fiscal policy time inconsistency* coincides with a rich line of literature in political economy. For example, Alesina, Prati and Tabellini (1989) suggest maturity extensions as a measure to enhance time-consistent fiscal policy choices to rule out the default equilibrium in favor of a "rollover-and-eventual-repayment" equilibrium.

ii. Rational Liquidity Crises in Sovereign Debt-Credibility and Reputation

Detragiache (1996) describes two main channels via which market expectations with respect to the liquidity position of the sovereign may underpin the multiplicity of outcomes in the market for sovereign debt: first, pessimistic financial market beliefs drive up the risk premium charged by financial markets, thus prohibiting debt rollover (as in Calvo, 1988); second, lower proceeds from a bond sale, worsen the liquidity position of the government, thus reducing investment, which in turn affects future output and raises the probability of default in the following period (Detragiache, 1996).

As a solution, Detragiache (1996) suggests that the government builds "a reputation for being a 'good risk' over time" through the adoption of credibility-enhancing policies, as following Diamond (1989), reputation effects may induce time-consistent behavior by debtors.

An additional source of multiplicity of outcomes relates to financial market disruption effects. As such, Detragiache (1996) recommends that the bond-issuing sovereign should reserve the right to declare a bond auction void "automatically" in the event that some "minimum price rule" is not attained (Detragiache, 1996).

iii. Sunspots and the Maturity Structure of the Government Debt

Following Calvo (1988), *Cole and Kehoe (1996, 2000)* developed DSGE models of self-fulfilling crises, focusing on liquidity crises along the lines of the Diamond and Dybvig (1983) model for bank runs. Using one-period debt, the basic framework of modern sovereign debt models is established: the sovereign borrows and decides whether to repay or to default. Given a continuum of possible equilibria in the self-fulfilling zone, an exogenous random shock with respect to fundamentals, namely a *sunspot variable*, triggers default. Default occurs due to the effect of the sunspot and high levels of one-period debt maturing at the end of the period. Maturing debt cannot be refinanced due to exclusion from financial markets, thereby leading to a liquidity crisis, which, in turn, precipitates default even if the country's fundamentals are solid. Cole and Kehoe (2000) attribute self-fulfilling crises to short average debt maturity. Similarly, Cole and Kehoe (1996) show that the Mexican crisis may not have occurred had the average maturity of debt been 16 months instead of 9 (Villemot, 2012). They posit that an ex-ante maturity extension can reduce the size of the 'crisis zone'.

In the *Cole and Kehoe (2000) model*, expectations affect the level of interest rates, which in turn interact with the level of debt outstanding and the maturity structure to generate default. Two origins of self-fulfilling crises are distinguished based on the identity of the agent whose fears induce default: *financial markets fears and government fears of default*, resulting in domestic investors' fears. In the former case**,** 'bankers' (who correspond to international capital markets) fear that the government will not be able to sell its debt in the next period with a positive probability, thus, expect default and do not lend to the sovereign.[25] In the second case, the government's own fears of default induce domestic consumers' fears, who in turn cut back on the level of real investment, lowering future output and, thus, increasing the probability of a future financial crisis.[26] This feedback effect between government and financial market expectations of default is given an alternative treatment in Chapter 3 of this thesis, following Jeanne and Masson (2000), based on the movement of some critical default threshold for fundamentals.

Critically, the Cole and Kehoe (2000) model of self-fulfilling crises warns that the standard prescriptions against *credibility* problems, such as increasing the cost of default ex ante by increasing the economy's dependence on external trade, may in fact prove even more detrimental to the status quo if the possibility of a crisis is not averted.[27] The authors conclude that "the only way to avoid a debt crisis is to avoid the conditions on fundamentals that make [debt crises] more possible: in particular, relatively high levels of debt with a short maturity structure" (Cole and Kehoe, 2000). Faced with the probability of a self-fulfilling crisis, Cole and Kehoe (2000) suggest that the optimal fiscal policy response is to run fiscal surpluses and pay down the debt. In the case of liquidity crises, Cole and Kehoe (2000) caution against the effect of the usual credibility-enhancing policy measures suggested to highly indebted countries, as these increase the costs of default without necessarily affecting the probability of a debt crisis.

The implication of the model is that there exists some range of fundamentals proxied via debt level bounds, in which fundamentals interact with expectations, giving rising to doom-loop effects, which are exacerbated by the effect of shocks (sunspots).[28]

[25] Therefore, in Cole and Kehoe (1996, 2000) a coordination failure among current and potential new creditors can occur in the present and future periods (Chamon, 2007).
[26] In determining a so-called 'crisis zone' for self-fulfilling crises, Cole and Kehoe (2000) make use of the realization of two random sunspot variables, ζ and ξ for *financial markets fears* and *domestic consumers' fears* respectively.
[27] Other insights generated by the model concern the following: given the direction of causality from expectations to interest rates, a peg in the interest rate will simply induce no government lending by private agents; good governments, in the sense that they are patient or that they favour private consumption over government consumption are more likely to be in the crisis zone (Cole and Kehoe, 2000).
[28] Chapter 3 borrows the concept of a crisis zone of fundamentals for the characterization of multiple equilibria. However, rather than focusing on the role of the government debt maturity structure, Chapter 3 provides an

iv. *Multiple Equilibria due to Coordination Failures*

Chamon (2007) extends the *multiple equilibria* framework to show that the 'bad equilibrium' can be avoided via changes in the rules of the game as it arises due to a *coordination failure*, a critical insight for ensuing literature. In fact, Chatterjee and Eyigungor (2012) explicitly define self-fulfilling rollover crises based on coordination failure: "A self-fulfilling rollover crisis is default arising from a coordination failure, wherein if all lenders continue to lend, the sovereign will continue to repay, but *if each lender suspects that other lenders will not extend new loans* and therefore refuse to lend in anticipation of a default, then the sovereign defaults" (Chatterjee and Eyigungor, 2012). According to this line of research, in the presence of some small uncertainty about debt repayment, if all creditors could agree on providing financing at low rates, the default outcome would be prevented. If, however, investors fear that other investors will not provide financing at low rates, then investors would be obliged to follow their peers and charge a higher interest rate to avoid losses. Thus, a coordination failure originating from *investors' beliefs about other investors' actions* is at the heart of this central account of self-fulfilling crises, also maintained by Cohen and Portes (2004).[29]

Chamon (2007) proposes the addition of a *state-contingent clause, based on which if the number of bond subscribers lies below some threshold, the contract is cancelled.* State-contingent bonds with a participation constraint ensure the emergence of the 'good equilibrium'. In a two-period model, focusing on cases of 'solvent but illiquid' creditors, state-contingent debt contracts are used as a preventive measure against self-fulfilling liquidity crises arising due to creditor coordination failures, by eliminating the possibility of debt runs (*Chamon, 2007)*. The required assumption for this model is that a critical mass of investors is attained (*Chamon, 2007)*. This is precisely the reason why investment banks underwrite sovereign bond issuances instead of the sovereign engaging in auctions: to ensure that a critical size of issuance is reached and to avoid the uncertainty effects on the interest

explanation for the process via which market expectations affect the default/repayment decision, albeit not in a general equilibrium framework.

[29] Chapter 3 exploits this coordination failure by elaborating on investor belief process formation.

rate that could prevail otherwise. Chamon (2007), thus, builds a model of state-contingent bids based on participation constraints, which works to the effect of removing the impact of 'strategic uncertainty'.[30] The operation of strategic uncertainty will be highlighted in Chapter 3.

v. Confidence Crises

Villemot (2012) further extends the Chamon (2007) framework by examining another type of self-fulfilling crisis triggered by a confidence shock, which is undeterred even if Chamon's state-contingent mechanism is in place. Villemot (2012), thus, studies another channel of crisis propagation, a 'confidence crisis', whereby a confidence shock can "destroy" a country's fundamentals, even if the country does not default.

Villemot (2012) distinguishes between two states of nature for the economy, which he names "normal times" and "trembling times". He constructs an innovation term, which takes on different values based on whether an innovation shock occurs (with some probability p and q respectively) depending on whether the economy is in the "normal" or "trembling" state, equivalently.

The No-Default Case

According to Villemot' s (2012) model, during "normal times", the innovation term represents a confidence shock, which operates over and above a negative growth shock. The confidence shock η_t follows a Poisson-like process:

$$\eta_t = 0 \; with \; probability \; 1 - p$$

$$\text{or} \quad \eta_t = -\mu_z \; with \; probability \; p$$

The effect of the confidence shock is to push the economy to the "trembling times" state, whereby investors have lost confidence on the sovereign (Cohen and Villemot, 2012). Investors then bet

[30] Chamon (2007) explicitly notes that the framework is "robust" to 'higher-order beliefs' a la Morris and Shin (1998a).

against real economy fundamentals, yet they may revise their expectations if the sovereign displays responsibility and does not default (Villemot, 2012).

Similarly, during “trembling times”, the innovation term represents a positive shock which may “reverse” the real negative consequences inflicted on the economy by low investor confidence. The country may, thus, “recover from the tremor of the confidence shock with probability q (which is typically much higher than p)” (Villemot, 2012):

$$\eta_t = 0 \; with \; probability \; 1 - q$$

$$\text{or} \qquad \eta_t = \mu_z \; with \; probability \; q$$

Following μ_z , Villemot (2012) assumes that growth is “restored” to “pre-crisis levels” such that the economy is back to “normal times” (Villemot, 2012).

The Default Case

If default occurs during normal times, its effect is similar to that of a confidence crisis, namely a shock of magnitude ε_{t+1}^{z}= - μ_z is applied (Villemot, 2012).

If default occurs during ‘trembling times’, then the sovereign can no longer return to pre-crisis output levels (Villemot, 2012). However, it is assumed that the country does not undergo an additional negative shock (Villemot, 2012).

Villemot (2012), thus, constructs a two-fold Poisson process, distinguishing between cases whereby a confidence shock leads to default and cases in which it does not, in effect replicating the mechanics of a transitory and a permanent shock.[31]

[31] In Villemot’ s (2012) words: “a confidence shock acts like a ‘trembling hand’ event: it shakes the economy for a while. If during such an episode the country defaults, then the trembling shock becomes permanent and no recovery takes place. When instead the country defaults while being in good times, the default creates its own confidence shock form which the economy does not recover (except for the fact that the growth loss dies out naturally over time, since z_t is a mean—reverting process)” (Villemot, 2012).
Villemot (2012) notes the following differences of his Poisson-like model to Hamilton’s (1989) Markov-switching model for GDP: Firstly, although both models display different mean growth rates across regimes, Villemot’ s (2012) “trembling” state involves a temporarily lower mean (because of mean reversion), whereas Hamilton’s model implies a permanently lower growth rate in the bad state. Secondly, the Cohen and Villemot

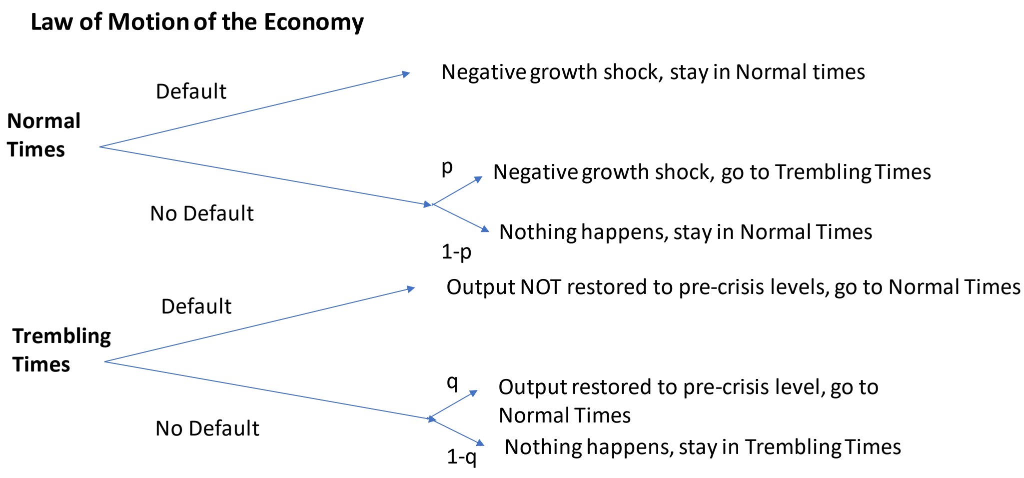

Figure 2.2. Law of Motion of the Economy, Source: Cohen and Villemot (2012)

Villemot (2012) suggests that the key solution to self-fulfilling crises is thus commitment to an amount to be repaid to the investor by the sovereign in the following period, instead of an announcement of the amount to be borrowed in the current period. Investors thus follow by requiring some appropriate level of interest rate today, or equivalently an amount they wish to lend today, as opposed to investors requiring some amount to be repaid tomorrow (Villemot, 2012). Under this framework, the returns of individual investor participation in government bond sales are not determined by other investors' actions.

vi. *"Gambling for Redemption"*

Self-fulfilling crises are also examined with respect to the government's incentives, particularly for consumption smoothing during recessions when the temptation to "gamble for redemption" is large. [32] The phrase "gambling for redemption" is used to depict a situation whereby the consumption-smoothing incentive "dominates" the debt-reduction incentive (Conesa and Kehoe, 2017). In a model inspired by the Eurozone debt crisis, Conesa and Kehoe (2017) examine the conditions and fundamentals based on which the government decides whether to increase the amount of new debt or

(2012) model entails an endogenous switch between regimes, as opposed to the exogenous switch in Hamilton (1989).

[32] Evidence on the historical avoidance to take fiscal action against default may also be taken from Reinhart and Rogoff (2010), whereby governments are shown to delay fiscal adjustment to the point of default due to their belief that "this time is different" (Reinhart and Rogoff, 2010).

to cut back to avert a self-fulfilling crisis. In this model, the incidence of a recession leads to a decline in government revenue, which in turn determines the risk of a self-fulfilling crisis. Unlike the Cole and Kehoe (2000) model, the authors question whether, in recession, the optimal fiscal policy response to the probability of a self-fulfilling crisis is to cut back on debt; alternatively, they may prefer to 'gamble for redemption', going into deficits and raising the public debt outstanding and the probability of default. Conesa and Kehoe (2017) suggest that when third-party loans are available, as under EMU membership, the Cole and Kehoe (2000) model whereby self-fulfilling crises arise solely due to rollover risk does not apply, since liquidity assistance could resolve the crisis.

vii. Models of Multiple Equilibria and Sovereign Debt in the EMU

The literature on multiple equilibria in the context of sovereign debt crises within the EMU is relatively novel and is based on models of currency crises. The EMU status is distinguished from general models of external debt in Emerging Market Economies, as the government debt of EMU member states is characterized by a low percentage of debt issued in a foreign currency. In addition, EMU member states lack monetary policy autonomy, which is a critical feature for policy response in a balance of payments crisis.

Arghyrou and Tsoukalas (2011) project the dynamics of currency crises models onto the mechanics of the Greek sovereign debt crisis. They argue that although fiscal policy was unsustainable in the case of Greece, as required for the first-generation currency crisis model,[33] sovereign default is in reality a less frequent phenomenon than the collapse of a currency peg, such that first-generation models may not offer sufficient insight (Arghyrou and Tsoukalas, 2011). Furthermore, as noted by Gros (2012), first-generation currency crisis models of speculative attacks on highly indebted countries may not be valid, as the usual trade off between monetizing the debt against raising taxes for debt service does not apply to a currency union. In contrast, the second-generation currency crisis model[34] developed by

[33] According to the first-generation crisis model, a devaluation of a currency is the outcome of a speculative attack on currency peg for a myopic government pursuing unsustainable fiscal expansion, ultimately resulting in the depletion of foreign currency reserves (Arghyrou and Tsoukalas, 2010).

[34] Second-generation currency crisis models suggest that the decision to defend or abandon a currency peg depends on the outcome of a loss minimization, in which the rational government trades off the credibility cost of default against the macroeconomic cost of maintaining the peg due to an exchange-rate misalignment in

Obstfeld (1996), is more insightful. Arghyrou and Tsoukalas (2011) apply this model by translating the 'credible exchange rate peg commitment' into a credible commitment by Greece regarding its future EMU participation. They note that the "decoupling" of Greek spreads from those of other peripheral countries in the aftermath of the November 2009 budget balance announcements corresponded to a "mutation" of a crisis of fundamentals into a confidence crisis regarding Greece's commitment to the EMU against the probability of a so-called Grexit (Arghyrou and Tsoukalas, 2011). Arghyrou and Tsoukalas (2011) also apply Krugman's (1998) third generation crisis[35] model to Greece, by suggesting that Greek accession to EMU was initially perceived to convey an "implicit bailout guarantee" to investors in Greek bonds (Arghyrou and Tsoukalas, 2011). A subsequent lack of convergence and reforms on the part of Greece, combined with the "constructive ambiguity" stance of Germany, which was interpreted as a lack of credible commitment on the part of the guarantor of Greece's repayment capacity, gave rise to multiple equilibria dynamics. A "double shift in expectations" occurred, such that both Greece's commitment to the EMU and Greece's ability to service its debt became questionable in February/March 2010 (Arghyrou and Tsoukalas, 2011). The model proposed in Chapter 3 of this thesis may be reconciled with Arghyrou and Tsoukalas (2011) if the stance of 'constructive ambiguity' (whether on the part of Germany in 2010, or on the part of the Greek government in 2015) is modelled to generate information noise about fundamentals, which in turn leads to the uniquely bad outcome in our model. Therefore, a model as in Arghyrou and Tsoukalas (2011) may be used to explain how the noisy error term emerges in Chapter 3 of this thesis.

terms of Purchasing Power Parity (PPP) (Arghyrou and Tsoukalas, 2010). Below some critical threshold of exchange-rate overvaluation, maintenance of the peg is optimal, whereas devaluation is optimal above it. In second-generation models, expectations interact with fundamentals, such that two loss functions emerge due to the endogeneity of the cost of defending the peg with respect to financial market expectations: a relatively steep section, corresponding to non-credible peg commitment and a flat section, corresponding to credible commitment to the peg. Thus, multiple equilibrium exchange rates may arise within a critical zone (Arghyrou and Tsoukalas, 2010). See Jeanne (2000) for a taxonomy of second-generation currency crisis models.

[35] According to the third-generation currency crisis model, high international liquidity and government guarantees, which are extended to improperly supervised financial institutions to finance speculative investments imply that a currency crisis occurs in tandem with a broader financial crisis (Arghyrou and Tsoukalas, 2010). A gradual revelation of less "than best-case scenario" leads to the unravelling of investment projects, decline in confidence in banks, drops in asset prices and increasing needs for bailout money (Arghyrou and Tsoukalas, 2010).

Similarly, *De Grauwe (2011)* uses a multiple equilibria framework to compare an EMU member state (Spain) against a 'standalone' country (the UK) to show that irrespective of solvency and debt dynamics, due to the absence of a lender of last resort, monetary union members become susceptible to self-fulfilling liquidity crises along the lines of Calvo's 'sudden stops', yielding a so-called 'bad equilibrium'. In turn, due to the degree of financial integration, a liquidity crisis in the sovereign bond market is likely to translate into a banking crisis. At the same time, the difficulties entailed in using automatic stabilizers serve to effectively reduce EMU member states to the status of Emerging Economies, plagued by the so-called "original sin" (Eichengreen et al., 2003, namely an inability of fiscal policy to stabilize business cycle dynamics). In contrast to the loss minimization entailing fixed and variable costs in the Arghyrou and Tsoukalas (2010) model, De Grauwe (2011) develops a simple model of the cost-benefit-analysis on sovereign default. Costs of default are modelled to be fixed, corresponding to the reputation loss and subsequent loss of market access. Multiple equilibria arise due to the existence of two curves of benefits of default:[36] a benefit curve for default which is anticipated by investors and a benefit curve for unanticipated sovereign default (De Grauwe, 2011). The steepness of the unanticipated default benefits curve depends on the initial debt level, the efficiency of the tax system and the size of external debt (De Grauwe, 2011).[37] Using three solvency shocks of different sizes, as in the *Arghyrou and Tsoukalas (2010) model*, a zone of 'indeterminacy' emerges for the intermediate size shock, as both a default and no-default equilibrium are possible at the same time. *De Grauwe (2011)* cautions against the large degree of uncertainty regarding the probability of default and associated market pricing and expectations, as it leaves room for market sentiment effects (De Grauwe, 2011). Thus, the presence of uncertainty could potentially be interpreted as a call for behavioural insights or market sentiment effects by future research. Crucially, due to its simplistic graphical depiction, unlike second-generation currency crisis models, De

[36] In contrast to the currency union member state, De Grauwe (2011) claims that multiple equilibria are less likely for a stand-alone country which can issue its own currency and can allow its central bank to take appropriate liquidity actions to avoid default. In that case, there is only one benefit curve (De Grauwe, 2011).
[37] A higher initial debt level, a less efficient tax system and a larger proportion of external debt, which is assumed to be associated with less domestic political opposition against default, are associated with a steeper benefit curve from default.

Grauwe's (2011) model fails to explicitly model the interaction of expectations and fundamentals and does not distinguish between liquidity and solvency crisis dynamics.

Gros (2012) develops an analytical model of multiple equilibria for sovereign default for a member of a currency union, unable to print money in the currency in which their debt is denominated. Under this framework, indeterminacy of outcomes and the possibility for multiple equilibria arise due to the indeterminacy of risk premia, which may, or may not, render high levels of debt unsustainable. Market expectations of the government's ability to service its debt underlie the level of risk premia and ultimately become self-fulfilling in terms of debt sustainability. Unlike earlier literature of the 1980s, Gros (2012) models the repayment decision to be gradual, dependent on the cost of required tax revenues and on the cost that may be imposed by creditors. A 'threshold effect', similar to previous models 'fixed costs' portion is considered, as well as a remaining trade off past this threshold, resembling the 'variable costs' portion of previous models. In addition, and beyond the previous cases, Gross (2012) explicitly models a degree of 'haircut' imposed on creditors within the social loss function. Gros (2012) also distinguishes between the certainty and uncertainty case, alluding to more complex multi-period models of decision-making with political parties and elections mediating between the time when the interest rate is set (current period) and the period during which the government decides whether or not to default and how much of a haircut to impose on creditors. Under this framework, the interaction of expectations and the feedback loops between higher risk premia and a higher probability of default are explicitly taken into account. Interestingly, the introduction of uncertainty in Gross's (2012) model serves to reduce the probability and range of multiple equilibria.

Across the above models, critical thresholds are used to determine the range of multiple equilibria. In turn, equilibria arise, either via a direct intersection of expected costs against expected benefits, in the presence of some shock, or through the outcome of a cost (or loss) minimization function. Crucially, even though the largest share of public debt in the euro area is denominated in euros, which is the domestic currency for member states, the loss of monetary policy autonomy and the adoption of the common currency implies that debt may be subject to similar dynamics as those affecting the external debt of Emerging Market economies (De Grauwe, 2011). Therefore, further policy solutions are called for, such as looser collateral requirements by the ECB, a common lender of last resort (Gross,2012; De Grauwe, 2011), the issuance of joint Eurobonds, as suggested by De Grauwe (2011), among many. Both Gros (2012) and De Grauwe (2011) call for future research into the market sentiment or behavioral aspects and for the modelling of irrational 'panic' behavior on market expectations and its effects on the range of multiple equilibria.

viii. A Simple "Escape Clause" Model for Sovereign Debt-Jeanne and Masson (2000)

Bruneau et al. (2012) criticize the simplicity of the structural models of self-fulfilling crises offered by Argyrou and Tsoukalas (2010), Conesa and Kehoe (2017) and De Grauwe (2011) due to their lack of clarity on how spreads are determined. Bruneau et al. (2012) argue that the above models merely model a shift from an optimistic regime of market sentiment into a pessimistic regime of market sentiment without any analysis about the underlying mechanism.

Bruneau et al. (2012) and Do Bernardo (2016) apply the Jeanne and Masson (2000) escape clause model of the probability of exiting a peg to the Eurozone sovereign debt crisis. The advantage of the Jeanne and Masson (2000) model is that it is in a linearized reduced form, which is more appropriate for econometric applications. Bruneau et al. (2012) extend the linearized model by allowing both the constant and the coefficients of fundamentals to vary (Bruneau et al., 2012). In their model, multiple equilibria arise due to shifts in investor expectations from optimistic to pessimistic regimes, as investors sell government bonds thereby increasing the interest rate and hence also the benefit of default. Default expectations are self-fulfilling because a high probability of default increases the net benefit of default, thus justifying the higher probability of default (Bruneau et al., 2012). The Jeanne and Masson (2000) model adaptation to debt crises will serve as the basis of the framework in Chapter 3.

2.1.5. Linking Solvency to Liquidity for Debt Sustainability and Sovereign Risk

In the light of the above discussion, debt sustainability (or sovereign risk) is a long-run assessment of solvency yet it also involves the short-run per-period assessment of liquidity concerns based on Gross

Financing Needs (GFNs).[38] Assessing liquidity needs is notoriously difficult, as borrowing needs are highly uncertain and depend on fickle market beliefs (as will be shown in Chapter 3). However, gross financing needs are key into the preparation of medium-term projections for debt sustainability. Debrun et al. (2019b) comment on the extension of the scope of the definition of debt sustainability to incorporate liquidity concerns in addition to public solvency requirements.

Public policy models of sovereign debt have shown that theoretical models of sovereign default may be utterly disconnected from the realities of Debt Sustainability Analysis (DSA). A major difference between the two concerns the number of assumptions and state-variables driving scenarios in DSA models, as well as the ultimate judgement of debt sustainability based on Gross Financing Needs (GFNs) in addition to the level of Public Debt Outstanding.

i. Slow-Moving Debt Crises: Linking Intertemporal Solvency and Current-Period Liquidity

In typical models of self-fulfilling crises, the emergence of a self-fulfilling crisis is triggered via a sudden shock, either in the form of a Poisson jump as in Cohen and Villemot (2012) and Villemot (2012), or via the realization of a payoff-irrelevant random variable: *a sunspot.* In contrast, still within the multiple equilibria framework, an alternative theory suggests that debt crises may be viewed as *slow-moving* events, according to Lorenzoni and Werning (2013, 2019). In slow-moving debt crises, the effect of shocks is persistent and the debt moves from a region of multiple equilibria (possible ex ante) into a steady state of either the good outcome (repayment) or the bad outcome (default) (Lorenzoni and Werning, 2013, 2019).

Slow-moving debt crises are distinguished from self-fulfilling rollover crises in that in the former, despite a jump in government bond prices due to a higher probability of default, default takes time to materialize. In contrast, in rollover crises, default is the immediate aftermath of a “run on the

[38] Gross Financing Needs or Gross Financing Requirements relate to the total financing requirement of the indebted government in each period. Gross Financing Needs are calculated as the difference between government sources of funds (the primary balance surplus, the proceeds of privatization or new debt issuance) and uses of funds (borrowing needs involving the repayment of maturing debt and other fiscal-space related considerations). In recent years, the IMF’s new approach to debt sustainability is based on templates which link Gross Financing Needs and Debt-to-GDP ratios, encompassing both short-run and long-run sustainability.

country's debt" (Lorenzoni and Werning, 2019). A second difference relates to the fact that self-fulfilling crises are typically transitory, whereas slow-moving crises of fundamentals, despite some immediate trigger due to single-period pessimistic expectations, cause persistent damage to country fundamentals (Lorenzoni and Werning, 2019). The economy is entrapped in the bad equilibrium (Lorenzoni and Werning, 2019).

Lorenzoni and Werning (2019) build a model in which the dynamics of debt, interest-rates and default are driven by insolvency. "Slow moving debt crises" are to be viewed as "*complementary"* to rollover crises for the interpretation of turbulence in sovereign debt markets (Lorenzoni and Werning, 2019). In this model, the multiplicity of equilibria against a uniquely bad equilibrium depends on the shape of a 'Debt Laffer Curve', namely a curve depicting the revenue collected by the government upon debt issuances, which in turn is used to meet its current maturing debt obligations and to satisfy the government budget constraint. In this model, the time-dimension is crucial as the distinction between long-term and short-term maturity debt implies that current-period debt repayment may be lower in the presence of long-term debt (Lorenzoni and Werning, 2019). Within a single-period framework, multiple equilibria are possible if the Debt Laffer Curve is not single-peaked: both a low-debt stock steady state and a high-debt stock steady state are possible (Lorenzoni and Werning, 2019). The stability of the equilibrium depends on the equilibrium not being located in a portion of the Debt Laffer curve where the slope is negative.[39] An unstable equilibrium is indicative of default (Lorenzoni and Werning, 2019).

In an attempt to bridge the difference between the stock of debt outstanding and current-period financing needs, Lorenzoni and Werning (2013) differentiate between two types of *creditor coordination failures* which in turn give rise to two distinct debt Laffer Curves: the *"issuance Laffer curve"* and the "*stock Laffer curve"* (Lorenzoni and Werning, 2013). The effect of the *issuance Laffer curve* depends on a coordination failure among current period investors and the government, as a

[39] If that were the case, lower revenue for the same amount of debt being issued would correspond to declining bond prices and increasing risk premia due to excess supply, which would continue up to the point where the debt issued would correspond to a zero probability of repayment and a bond price equal to zero (Lorenzoni and Werning, 2019).

coordinated bidding up of the current revenue proceeds for the government would have sufficed for the government to meet its budget constraint and for investors to recover their investment (Lorenzoni and Werning, 2013). The *stock Laffer curve* relates to an intertemporal creditor coordination failure: Had investors who invested in the government debt at time t and in the past coordinated to reduce the face value of the debt at t+1, they would have received a higher expected repayment as the market refinancing condition would have eased the government in covering its financing needs (Lorenzoni and Werning, 2013). Long-term debt reduces the value of pre-existing debt (debt dilution) but it alleviates the current-period budget constraint. Lorenzoni and Werning (2013) thus comment that "a country may still very well be on the decreasing side of the stock Laffer curve and yet still be on the increasing side of the issuance Laffer curve" (Lorenzoni and Werning, 2013).

The permanent damage to fundamentals results from the fact that the multiplicity of equilibria is only possible ex ante, i.e. prior to the revelation about whether a sunspot shock has occurred; thereafter, model dynamics are deterministic and may converge to a steady repayment state or to a steady default state, as the size of the region between the two extreme regions is reduced (Lorenzoni and Werning, 2019). Depending on the percentage of long-term debt in the maturity structure, the government ends up in either the safe or the crisis region. Jumps across the two regions (of a good steady state and a bad steady state) depend on the sunspot shock. Prior to the sunspot, multiple equilibria are possible; after the effect of the shock, a unique equilibrium is identified (Lorenzoni and Werning, 2013, 2019)

ii. State-Contingent Debt Contracts as a Remedy Against Default

As a remedy against the costs of default and as a precaution against the break-down of debt sustainability, a number of policy solutions have been recommended. A mixture of *ex ante* preventive measures and *ex post* solutions is available. Ex ante, fiscal rules have been envisaged into government budget plans and fiscal coordination is required by EMU member states to ensure long-run debt sustainability and solvency, as originally envisioned and required by the Maastricht Criteria.

Policy solutions to ward against self-fulfilling crises include, inter alia, the imposition of capital controls to avoid capital flight and 'sudden stop' phenomena, the lengthening of maturities (e.g. Cole and Kehoe, 2000), state-contingent debt contracts (see Chapter 5), lenders of "first resort" (Cohen and Portes, 2004) or automatic credit line availability at the moment of crisis as currently available by the International Monetary Fund (IMF) or the European Stability Mechanism (ESM) through the Precautionary Conditions Credit Line (PCCL) and Enhanced Conditions Credit Line (ECCL), interest-rate ceilings in government auctions, and state-contingent participation bids in debt contracts (Chamon, 2004). These have often been criticized as "too little, too late" for the restoration of liquidity and sustainability. "Slow-moving debt crises" (Lorenzoni and Werning, 2019) are potentially the outcome of such deliberation delays, indicative of the long-lasting effects of brief liquidity crisis episodes on sovereign fundamentals.

Given the possibility for a sovereign to unilaterally default (fully or partially) on its debt obligations, sovereign debt is effectively a state-contingent claim. State-contingencies are driven by state-contingent debt-servicing capacity of the sovereign and state-contingent market-pricing effects due to *financial market expectations and the role of uncertainty shocks*. Therefore, given incomplete markets, some form of *state-contingent solution is required* to shield against uncertain debt repayment outcomes.

This thesis focuses on an alternative *ex ante* contractual solution against debt-destabilizing shocks to economic growth, thus enabling state-contingent debt servicing capacity irrespective of the degree of uncertainty in the future distribution of economic growth. Chapter 5 analyzes the implications of insuring against low future growth outcomes via the introduction of GDP-linked bonds.

2.2. Sovereign Risk and The Determinants of Sovereign Spreads

This section examines the determinants of the market-based proxy of the probability of default, sovereign spreads, also an arbiter of debt sustainability. Section 2.2. is developed around the main questions raised by relevant research: What is the most appropriate proxy for sovereign default risk? What are the determinants of government bond yield spreads for the EMU and for Greece, in particular? What is the relative importance of each determinant? Are there changes in the effect of such determinants over time? If so, which dates may be identified as structural breaks, thresholds or regime switches? An evaluation of the answers to the above questions will shed light to the context, purpose and empirical strategy followed in Chapter 4.

Based on the above questions, section 2.2 is structured as follows: section 2.2.1 explains the choice of the dependent variable used as a proxy of sovereign risk; sections 2.2.2 and 2.2.3 extensively cover the literature on the determinants of government bond spreads in the Eurozone and in Greece, respectively; section 2.2.4 ranks the contribution of determinants to sovereign spreads based on empirical findings; section 2.2.5 reviews regime-switches and changes in the effect of determinants to sovereign spreads.

The scope of this section is limited in terms of economic theory, as the focus rests at the empirical insights and methodological techniques that bridge theory with data. Although our empirical model is dedicated to Greece, this review will cover related studies of other EMU countries as well, as only a very small number of papers have been devoted to the determinants of Greek government bond yields per se.[40]

[40] Notwithstanding their critical contribution to the development of relevant literature, previous studies of the determinants of government bond yields in Emerging Markets during the 1980s and 1990s, external debt crises have been excluded from this review due to the different macroeconomic profile and EMU membership of Greece, which involves distinct pricing behavior. Similarly, in spite of the critical theoretical and methodological contributions made by US studies on the effects of fiscal fundamentals on interest rates, the review has only incorporated more recent findings by researchers of EMU public debt.

2.2.1. The Dependent Variable- A Proxy for Sovereign Default

The empirical study of sovereign risk and default has traditionally focused on two main dependent variables: long-term government bond yields and Credit Default Swaps (CDS), defined either in levels or in terms of a differential from the relevant benchmark (i.e. as ‘spreads’).

Government bond yields, or *yield to maturity,* represent the average rate of return for an investor who purchases government securities and holds them until maturity. In essence, the yield to maturity (YTM) corresponds to the interest rate that may be used to equate the price of a security to the present value of its future cash flows (Bodie et al., 1989). According to the expectations theory of term structure, long-term yields contain an additional *term premium* to compensate investors against the higher levels of uncertainty associated with long-term bonds repaid in more distant periods compared to short-term bonds (Bodie et al., 1989). Yield spreads represent the difference between the yield on the government bond of a country with that of same tenor by a benchmark country. In the context of the Eurozone, the yield of the Deutsche Bund serves as a relevant risk-free benchmark for the calculation of yield spreads.

Credit Default Swaps (CDS) are Over-The-Counter (OTC) derivative instruments, stipulating the quarterly payments by the buyer of CDS to the seller for the contingent claim in the event of sovereign default (Aizenman et al., 2011). Although the definition of sovereign default and the events that ‘fire’ CDS payments have been the topic of debate at the International Capital Markets Association (ICMA),[41] CDS are among the standard proxies for sovereign default risk in the literature. Aizenman et al. (2011) have argued that CDS spreads constitute a superior statistic to interest rate spreads for empirical work due to their timeliness on market-based pricing, the avoidance of difficulties regarding time-to-maturity and due to their non-embedding of inflation expectations. They thus isolate default risk. However, Sturzenegger and Zettelmeyer (2005) note that CDS may be used as measures of default risk but not as proxies of the probability of default, since their price depends

[41] For example, the Greek Private Sector Involvement (PSI) ignited discussions about the definition of sovereign default based upon which CDS instruments would make payments to investors.

both on the probability of default and on expected recovery. Favero and Missale (2011) further caution that CDS differentials also depend on liquidity considerations and counterparty risk.

As noted by Fontana and Scheicher (2010), the 'basis', or difference between CDS spreads and the spreads on the underlying bonds, has been non-zero in the Eurozone after 2010. Differences between the two measures have been attributed to the limits of arbitrage and to the decline in investor appetite for more credit-risky instruments, such as CDS, as opposed to a stable quest for yield in government bonds (Fontana and Scheicher, 2010). The CDS market has been shown to be more easily manipulated by speculative investors, exacerbating the liquidity crisis for Greece, Ireland, Spain and Portugal in the first half of 2010 (Calice et al.,2013).

The relevance of developments in either of the above two variables for the study of market-based sentiment as opposed to fundamentals since the creation of the EMU has been amply documented.[42] For instance, Codogno et al. (2003) and Bernoth et al. (2004), among many, note the importance of the onset of the EMU with respect of government bond market pricing. Similarly, data confirm the widening of sovereign bond spreads vis-à-vis Germany in 2008, implying a reassessment or risk by capital markets and a differentiation of eurozone country risks in response to the transmission of the US financial crisis. Research has also documented a differentiation in risk patterns, proxied by government bond spreads, following the eruption of the eurozone sovereign debt crisis in late 2009. Studies proxying sovereign risk based on CDS premia include Calice et al. (2013), Delatte et al. (2012), Fontana and Scheicher (2010),[43] among many. Palladini and Portes (2011) apply cointegration analysis to show that in equilibrium, sovereign yield spreads and CDS spreads in six EMU countries between 2004 and 2010 are equal.

The vast majority of recent papers documenting a disconnect of market pricing from fundamentals over the financial crisis and Eurozone debt crisis period of 2010-2012 uses long-term government

[42] An overview of Eurozone yield developments is provided by Baker et al. (2016b) and Lane (2012).
[43] Fontana and Scheicher (2010) is a seminal paper comparing the explanatory effect of EMU sovereign risk via the bond and CDS markets of ten Eurozone countries in 2006-2010. They find that since September 2008 common factors have driven pricing in both markets and that CDS spreads have exceeded government bond spreads, which they attribute to "'flight to liquidity' effects and limits to arbitrage" (Do Bernardo, 2016).

bond spreads as the dependent variable. Examples include De Grauwe and Ji (2012), Di Cesare et al. (2012), De Santis (2015), Dewachter et al. (2015). In line with this research choice, this chapter will use the spread of the Greek 10-year government bond yield from the yield of the relevant German Bund as a dependent variable.

2.2.2. Determinants of Government Bond Yield Spreads

A plethora of papers have been written since the 1980s on the determinants of government bond yield spreads.[44] Government bond yield spread studies have been grouped in other literature reviews according to the following methodological criteria: single-country studies against panel-data studies; research on the short-run versus long-run determinants (e.g. Poghosyan, 2012; [45] Gibson et al., 2012; Csonto and Ivaschenko,2013; Beirne and Fratzscher, 2013); affine term structure models[46] against regression models; constant-coefficient models versus time-varying approaches. In the context of the EMU, an alternative grouping could be based on the time of writing (and corresponding time-period covered): studies written prior to the US financial crisis against studies written during/after the crisis. Vast heterogeneity is exhibited in the length of time series and countries included in relevant studies, such that caution is required prior to conclusions.

Related literature has followed distinct groupings of the determinants of government bond yields, the broadest of which is as follows*: debt sustainability variables* (e.g. government debt-to-GDP ratio, government debt-to-tax revenues, government primary deficit as a percentage of GDP); *external sector variables* (e.g. external debt-to-GDP, the current account balance-to-GDP); *competitiveness*

[44] Depending on the characteristics of the economies and crises in question, different fundamentals have been incorporated in models. For example, external imbalances and the level of economic growth were shown to be critical during the 1980s and 1990s external debt crises in Emerging Market economies, while later studies of the United States have shed light on the role of fiscal fundamentals.

[45] In studying the determinants of sovereign bond yields in advanced economies, Poghosyan (2012) distinguishes between the short-run and long-run determinants of *real long term yields* using panel cointegration techniques, which allow the sovereign's short-run cost of funds to deviate from long-run fundamentals.

[46] Affine models were extended to defaultable bonds by Duffie and Singleton (1999) and Duffie (2002). Subsequently, Ang and Piazzessi (2003) developed a model with macroeconomic fundamentals, while Dai and Phillippon (2006) and Laubach (2011) extend the framework to include fiscal variables. Building on earlier work on affine term structure models, Borgy et al. (2011) develop an advanced microfinance algorithm to estimate the joint no-arbitrage affine term structure model for Eurozone yield curves. The advantage of this method is that it exploits information regarding the entire maturity structure of sovereign yield spreads (Borgy et al.,2011).

variables (e.g. the Real Effective Exchange Rate, Unit Labor Costs*); the level of economic growth* (GDP growth, the unemployment rate, leading indicators of industrial activity); *liquidity*; and *international risk aversion* (e.g. the VIX index, or the spread between US AAA corporate bonds with respect to the US 10-year treasury); and more recently, *political uncertainty* (e.g. the Economic Policy Uncertainty Index). A three-fold grouping along the lines of fiscal risk, liquidity risk and global risk aversion is also gaining currency in the literature, as the above factors explain most of the variation in government bond yield spreads (e.g. Attinasi et al., 2009). Additional determinants considered by the literature include the effects of contagion and the fragility of the Eurozone and associated market perceptions of the probability of a euro-breakup (De Grauwe, 2011; De Grauwe and Ji, 2012). This review will group the determinants of government bond yield spreads into four broad categories: *fiscal policy variables, non-fiscal macroeconomic fundamentals, liquidity, and uncertainty variables.*

i. Fiscal Policy Variables

Fiscal sustainability has stood at the foreground of discussions of debt sustainability, as virtually all studies of sovereign risk include one or more variables for fiscal risk. Notably, Borgy et al. (2011) devote their entire paper of government bond yield spreads to the effect of fiscal variables and conclude that the effect of fiscal factors, especially of government debt, may account for the larger portion of the increase in spreads since 2008. They also explain that the lack of synchronicity in spread reactions across the Eurozone after Lehman is largely attributed to differences in fiscal soundness.

According to Ardagna et al. (2006), a deterioration in public finances affects medium and long-term yields via three main channels: first, under an inelastic supply of savings, financing the budget deficit requires public sector funds which raise the real interest rate; second, increases in public debt raise the credit risk premium; third, public deficits fuel concerns about inflation or exchange-rate expectations. Di Cesare et al. (2012) argue that the literature largely ignores the above distinction in empirical work and use reduced-form regressions to obtain estimates of the effect of fiscal variables on interest rates. A positive relationship is evidenced between public debt and interest rates for the United States and Europe, with relevant coefficients being larger, though not uniform, across Eurozone countries.

In contrast to the more recent literature which is firm on the existence of a fiscal risk premium, earlier papers of the EMU present mixed evidence:[47] Codogno et al. (2003), Faini (2006), Bernoth et al. (2004), Bernoth and Wolff (2008), Manganelli and Wolswijk (2009) and Schuknecht et al. (2009) show that fiscal risk was an important factor of credit risk, while Hallerberg and Wolff (2008) conclude that fiscal variables played only a limited role in the determination of sovereign risk, as credit risk declined after the introduction of the euro. Later studies (Giordano et al.,2012; Favero and Missale, 2011; Schuknecht et al.,2010) agree on the significant role of fiscal fundamentals for sovereign risk in the Eurozone, yet note that their effect is heterogeneous across countries, time-varying and non-linear.

More recently, Afonso et al. (2015) note that credit risk[48] is usually captured via indicators of *past or projected future fiscal performance*. Thus, while fiscal and credit risk is not identical, the two are often confined in the literature under the implicit assumption that credit risks emanate primarily from the sustainability of public finances. Indeed, various papers have attested to the additional risks incurred due to a looser fiscal policy stance (Ardagna, 2004; Afonso and Rault, 2015) or due to changes in fiscal policy expectations (Elmendorf and Mankiw, 1999).

Borgy et al. (2011) note that the appropriate choice of relevant fiscal variables for each country is open to debate. The most commonly used fiscal variables are the debt-to-GDP ratio (Borgy et al., 2011; De Grauwe and Ji, 2012, among many)[49], the fiscal balance ratio (Dell' Erba and Sola, 2011; Baldacci and Kumar, 2010; Afonso, et al., 2015; Amira, 2004; Laubach, 2009; Akitoby and Stratmann, 2008), debt-service ratios, such as interest-payments-to-GDP (Bernoth et al.,2004), indicators of transparency and governance (Bernoth and Wolff, 2008), fiscal track record interaction

[47] Haugh et al. (2009) provide an extensive survey of 'stock' versus 'flow' variables which determine government bond yield spreads and conclude that early empirical evidence is mixed.
[48] In general, credit risk may be defined as the additional yield required by investors to be compensated for the probability of non-full recovery of their investment in the event of partial or full default. As such, credit risk incorporates all cases under which the sovereign borrower may not be able to make full repayment under the agreed bond or loan covenants (Haugh et al.,2009). Credit risk also incorporates inflation risk, as governments may opt to inflate away a portion of their debt burden.
[49] De Grauwe and Ji (2012) probe for the effects of market sentiment against debt-to-GDP ratio, which appears to be the main indicator of fundamentals.

dummies[50] (Hough et al., 2009). Aizenman and Jinjarak (2010) first proposed the use of a *"fiscal space" variable*, defined as the government debt-to-total tax revenue ratio[51] or as the deficit-to-tax-revenues ratio, as an indicator of debt-servicing capacity. This *fiscal space* variable has also been used by Aizenman et al. (2011), De Grauwe and Ji (2012) and Giordano et al. (2012). Bernoth et al. (2006) claim that debt service ratios with tax revenues in the denominator are superior indicators as they are not directly monitored by the Stability and Growth Pact (SGP) and are thus less prone to manipulation on the part of governments. Such indicators may also reflect black market activity and the ability of the government to raise tax revenues. In addition to the above, Haugh et al. (2009) use the expected change in pension expenditure as a share of GDP between 2010 and 2050, [52] while others have considered fiscal announcements and credit ratings.[53]

Fiscal variables are used either in current values, or as differentials from a benchmark to match the definition of yield spreads of the dependent variable. In line with findings by Gale and Orszag (2002) and by Laubach (2003, 2009) for the US, increasingly, empirical studies find that the effect of *expected* rather than current deficits is significant against long-term interest rates on government bonds for the EMU (Haugh et al.,2009; Attinasi et al.,2009). Expected fiscal variables are used to capture the forward-looking nature of financial markets and the pricing of sovereign bonds. Early EMU studies using expected fiscal variables[54] are Heppke-Falk and Hufner (2004), Attinasi et al.

[50] Haugh et al. (2009) find that the effect of debt service ratios on spreads is non-linear and is amplified by the fiscal track record variable and general risk aversion. This amplifying effect has been most acute in the case of Greece and Italy. In reverse, the benefit of a good fiscal record was amplified on spreads for Finland.
[51] *Fiscal space* is a variable that captures both a stock and flow dimension of debt servicing capacity and is deemed to be a superior indicator for debt sustainability. In essence, it corresponds to the number of years of tax revenues required to service the debt and conveys more information than the simple debt ratio, as countries with seemingly innocuous debt ratios may be unable to raise sufficient tax revenues to pay down their debt (Aizenman et al., 2011).
[52] Expected increases in future pension expenditures are found to be substantial contributors to spread increases, particularly in the case of Greece, but also for Ireland, Portugal, Belgium and Spain (Hough et al., 2009).
[53] Credit ratings (Manganelli and Wolswijk, 2009) and fiscal announcements have been used as indicators of fiscal risk, particularly in the form of "negative announcements" (Afonso et al.,2012). However, de Grauwe and Ji (2012), and Giordano et al. (2012), caution that credit ratings are best omitted from relevant empirical work to avoid endogeneity bias, as they tend to react to changes in government bond yields and other fundamentals. Similarly, Afonso et al. (2015) note that although sovereign credit ratings are significant explanatory variables for spreads, their contribution is limited when compared to macroeconomic and fiscal fundamentals.
[54] Expected fiscal variables are taken from the forecasts of the European Commission and account for the fact that financial market investors are forward-looking.

(2009), Laubach (2009), Haugh et al. (2009).[55] More recently, Barbosa and Costa (2010), Favero and Missale (2011), Afonso et al. (2013, 2018), among many, have also incorporated fiscal forecasts. Gibson et al. (2012) construct an indicator of fiscal budget revisions based on revisions in the quarterly forecasts of the European Commission for Greece ("cumulative fiscal news indicator").

While both the debt-to-GDP and the government budget ratio may theoretically affect spreads, there exists some controversy with respect to the inclusion of both variables in empirical work. On the one hand, Codogno et al. (2003) and Haugh et al. (2009) find that both the deficit to GDP and debt-to-GDP ratio are significant for euro area spreads. On the other hand, earlier studies find that the impact of public debt is quantitatively lower to that of public deficits (Faini, 2006; Laubach, 2009). In-between the above two points, Afonso et al. (2015) claim that sovereign fiscal risk operates via the fiscal balance, but that since March 2009, countries with high levels of projected public debt have received larger fiscal risk penalties by investors. Afonso et al. (2013) show that the increase in spreads is attributed primarily to the expected budget balance for most EMU countries, except for Greece, where credit risk operates via the expected debt channel. Borgy et al. (2011) caution that the inclusion of either the deficit-to-GDP, the debt-to-GDP and debt service, the most commonly used fiscal variables in relevant literature, may lead to substantial endogeneity bias. They also note that the effect of the above variables is "rather modest" when government bond maturities are not short and do not command frequent refinancing (Borgy et al.,2011).[56] Similarly, in their Threshold Regression (TR) model of sovereign spreads, Bruneau et al. (2012) include the government debt ratio and exclude the fiscal deficit ratio to avoid multicollinearity. Favero and Missale (2011) find that debt and deficit are both significant only for Greece.

An interesting link between the debt-to-GDP ratio and the government budget ratio is provided by Baldacci and Kumar (2010), who however, study Emerging Market economies. They suggest that in

[55] Haugh et al. (2009) find that higher expected fiscal deficits drive increases in spreads during the 2008-2009 period for all countries and especially for Ireland.
[56] On this note, Borgy et al. (2011) distinguish between total debt issuance by countries such as Germany, France and Spain, which in 2010 stood at levels below 10 percent, with those of Italy and Greece, which reached 17 percent. They note that the endogeneity problem is particularly acute for Greece, Portugal and Ireland at the time close to the announcement of their EFSF programs due to refinancing concerns.

the presence of permanent shocks to public deficits, the coefficients of public debt and public deficit with respect to government bond yields are related, such that an increase in the debt-to-GDP ratio by one percentage point may be associated with an increase in the deficit ratio by 1/(1+g) percent, where g represents the rate of nominal GDP growth.

In addition to the significant linear effects of fiscal variables, empirical studies have provided substantial evidence of nonlinearities in the fiscal effects on long-term government bond yield spreads both by earlier and later research. Non-linearities involve square terms, interaction terms of fiscal variables with other determinants of government bond yields, or with time-dummies, and threshold effects.[57] Haugh et al. (2009), De Grauwe and Ji (2012), Bruneau et al. (2012) and Giordano et al. (2012), and more recently Pamies et al. (2021), among many, suggest that fiscal variables, and particularly the government debt-to-GDP ratio, are often included in squared terms to account for nonlinearities. Square terms imply that at higher levels of debt, investors become more jittery with respect to further increases in indebtedness and are justified on the grounds that the government's decision to default is discontinuous, such that the probability of default increases substantially with higher debt-to-GDP ratios. Interacting determinants with fiscal variables include liquidity variables, global risk aversion (e.g. Favero and Missale, 2011; or, for peripheral countries during the earlier years of the EMU, Pagano and von Thadden, 2004)[58], a binary dummy for fiscal track record (Haugh et al, 2009) and time dummies (Bernoth and Erdogan, 2010).[59]

Empirical research on the effect of fiscal variables on the pricing of government bonds in the EMU has also considered whether markets provide evidence in favour of a fiscal disciplining role against instances of irrational herding behaviour and 'animal spirits' unwarranted for by fundamentals. Notwithstanding the looseness of relevant definitions, this question is central to the dynamics across

[57] For example, Faini (2006) shows that sensitivity of yields with respect to GDP increases above a threshold (100 percent of GDP is used). The sensitivity of yields above this threshold increases by between 2.5 to 4 bps for every percentage point increase in the debt-to-GDP ratio.

[58] Favero and Missale (2011) show that countries whose fiscal fundamentals are weak are also more exposed to changes in global risk appetites.

[59] Bernoth and Erdogan (2010), who examine the time-variation in the relationship between government bond spreads and fundamentals, find that the importance of fiscal fundamentals and global risk aversion gradually subsided yet fiscal fundamentals became relevant once again two years prior to the collapse of Lehman Brothers and reached their pinnacle during the Eurozone sovereign debt crisis period.

multiple equilibria. Among earlier papers, Heppke-Falk and Hufner (2004) provide evidence of the role that expected fiscal balances play in explaining French and German risk premia on government bond yields in the EMU, such that markets are in line with fiscal discipline. Bernoth and Wolff (2008) and Schuknecht et al. (2009) also point to that direction, while the findings of Manganelli and Wolswijk (2009) suggest otherwise. According to the consensus view, during the first years of the EMU, spreads' undershooting of fiscal fundamentals serves as evidence against the ability of financial markets to impose fiscal discipline.[60] In contrast, at the peak of the debt crisis, spreads vastly overshot their fundamentals, thus implying exaggerated discipline which in effect worked to the detriment of fiscal soundness, inducing liquidity effects. A primary example is the case of Greece in 2012. Giordano et al. (2012) find that core countries were not affected by the post-Lehman financial turmoil beyond what their fundamentals would have dictated, while after mid-2012, they benefited from the Eurozone sovereign debt crisis, in line with the claims of investor flight to quality (Afonso et al., 2013). In contrast, peripheral countries, such as Spain, Portugal and Ireland, witnessed a revision in the pricing of their government bonds in 2010, with premia peaking after 2012 and Italy's spreads bearing a heavy onus from contagion due to its high levels of indebtedness.

For a survey of the political economy literature of why fiscal policy may lead to unsustainable deficits and high levels of public debt, which in turn affect sovereign spreads as detailed above, see Romer (2012) and Drazen (2002b), *inter alia.*

ii. Macroeconomic Fundamentals

As national fiscal policies operate within the broader macroeconomic environment, investors also consider macroeconomic fundamentals in their pricing of sovereign risk. Alessandrini et al. (2012) show that in relation to the reassessment of risk for highly indebted countries after the structural break

[60] According to Laubach (2011), "it is difficult to avoid the impression that default risk was underpriced prior to 2008" given that the average Greek and Italian spreads were approximately 25bps and for Portugal 15bps. It is important to ask whether we can identify a threshold or estimate the nonlinear process by which the interest rate effects of fiscal policy become amplified" and the "time-varying sensitivity of EMU government bond spreads to fiscal conditions."

in 2010, poor fundamentals, such as low labor productivity, may be responsible for debt concerns irrespective of the level of fiscal responsibility displayed by the country in question. Empirical studies incorporating macroeconomic factors in the study of EMU spreads include, among many, the following: Alessandrini et al. (2012); De Grauwe and Ji (2012); Maltritz (2012); Giordano et al.(2012); De Grauwe and Ji (2012); Bruneau et al. (2012), Afonso et al. (2013); Afonso et al. (2015). This chapter groups macroeconomic fundamentals into the following categories: indicators of the level of economic activity and indicators of external imbalances (current account, competitiveness, inflation differentials).

Economic Activity

Higher levels of economic growth are associated with higher debt servicing capacity, yet also imply that the cost of reneging on debt payments is higher (if modelled as a percentage of output), and vice versa. In the context of the Eurozone, whereby default entails additional political costs, the relationship of economic growth to spreads is presumed to bear a negative sign. This is in line with standard economic theory, and Blanchard (2019), as increasing levels of government indebtedness need not be a concern to the extent that the rate of growth in the economy is sufficiently high compared to the level of interest rates.

Multiple papers provide evidence of the significance of economic activity to perceptions of sovereign risk in the EMU. For the post-August 2008 period, Giordano et al. (2012), and Afonso et al. (2015) find a negative sign in the relationship between economic growth and sovereign spreads. Similarly, De Grauwe and Ji (2012) explain that lower levels of economic growth imply enhanced difficulties in raising the tax revenues required for debt service. Afonso et al. (2013) find that the GDP-growth rate is significant only for Greece and Spain among EMU countries and only during the period of the debt crisis.

Other proxies for the overall state of the economy included are the one-period lag in the GDP-growth rate, or Industrial Production, which is a leading indicator in the formation of investors' expectations (Giordano et al., 2012). The annual growth rate of industrial production has often been included as a proxy for economic growth and for the state of the business cycle (Bernoth et al.,2004; Afonso et al.,2013). Bruneau et al. (2012) proxy economic activity based on the unemployment rate to avoid collinearity with the debt-to-GDP ratio. Hilscher and Nosbusch (2010) and Afonso (2010) have also proposed using the level of GDP and GDP per capita. Noting that financial markets are forward-looking, Afonso et al. (2018) incorporate the logarithmic difference of the Economic Sentiment Index for the country in question against that of the benchmark, i.e. Germany.[61] Lastly, based on the Fisher effect, interest rate differentials (and, thus, the spread of the long-term government bond yields of an EMU country to that of Germany) may be linked to the inflation differential between the country in question and Germany.

External Imbalances

The current account variable may take on either a positive or negative sign, depending on whether the economy in question is facing solvency risks. Most studies point to a negative relationship between the current account balance and government bond yield spreads. Increasing current account deficits need to be financed by capital inflows and increases in net foreign indebtedness, which may undermine the government's ability to finance its external obligations, as commented by De Grauwe and Ji (2012). This increase in total (private and official sector) net foreign indebtedness is likely to increase default risk for the government as higher default risks in the private sector tend to have a negative effect on economic activity, leading to decreased government revenues and ballooning budget deficits. Similarly, when the source of the increase in net foreign debt is government expenditure, higher debt service ratios result in higher default risk (De Grauwe and Ji, 2012). Paradoxically, current account surpluses may also be associated with increased sovereign risk. Countries with positive current account surpluses may be facing net external capital outflows, such that capital flight concerns or an inability to borrow from abroad may be lurking in the background. This interpretation is offered by Maltritz (2012), who finds a positive sign for the current account with

[61] The literature is divided as to whether the ESI reflects macroeconomic fundamentals as opposed to agents' expectations thereof, as the ESI is survey-based and reflects both current conditions and expectations of prospective economic developments. For example, unrelated to sovereign risk, Nowzohour and Stracca (2017) classify ESI into uncertainty variables.

respect to spreads. Linking the results of the two studies, positive signs in the relationship between the current account balance and government bond yields may point to periods of liquidity crisis and negative signs may relate to long-term solvency issues (Giordano et al.,2012).

Lower levels of competitiveness have been associated with increased levels of sovereign risk. In the EMU, the absence of the possibility of an actual exchange rate revaluation risk in the EMU entails that other measures of price competitiveness must be controlled for. Competitiveness is empirically accounted for via labor productivity (Alessandrini et al., 2012), unit labor costs (Bruneau et al.,2012) and the real effective exchange rate (REER) (Afonso et al., 2013). A real appreciation of the effective exchange rate or an increase in unit labor costs are associated with a deterioration in the external position of the country and increased sovereign risk. According to the Uncovered Interest Rate Parity (UIP), the interest rate differential between two countries should be equal to the relative change in the exchange rate between the two countries over the same period of time. Therefore, long-term government bond yield differentials from the benchmark could be examined as differences in real effective exchange rates between the country in question and Germany. Arghyrou and Tsoukalas (2011) and Arghyrou and Kontonikas (2012), Afonso et al. (2013) provide a theoretical and empirical interpretation of the relationship between the effective exchange rate and spreads, respectively. De Grauwe and Ji (2012) consider the real effective exchange rate to be an apt "early warning variable" for competitiveness, used as an indicator of future current account deficits and thus of debt concerns, when pointing towards a real appreciation.

Gibson et al. (2012) provide an account of the Greek financial crisis based on the relationship between Greek sovereign spreads and external imbalances by incorporating relative prices as a measure of relative appreciation (given the fixed exchange rate against Germany).

iii. Liquidity Risk

Liquidity risk encapsulates the possibility of investor capital losses in the event of early liquidation and of price reductions due to limited transactions (Afonso et al., 2015; Arghyrou and Kontonikas, 2012). During times of increased macroeconomic uncertainty and financial market volatility, investors are more likely to unwind their asset positions, decreasing demand and raising liquidity costs (Barbosa and Costa, 2010). Barbosa and Costa (2010) suggest that a security's liquidity premium should be associated both with its *expected* liquidity but also with *unanticipated changes* in liquidity, at a national and international level.

Liquidity risk is relatively difficult to measure and there exists no single consensual measure of liquidity. Different indicators have been used in the literature to capture the various dimensions of liquidity risk (Barbosa and Costa, 2010). Empirical studies of liquidity risk include one or multiple variables related to liquidity.

Proxies for liquidity risk in the literature may be divided into direct and indirect measures of liquidity (Barbosa and Costa, 2010). Direct proxies include the bid-ask spread[62] (Barrios et al., 2009; Favero et al., 2010), turnover ratios, the average number of transactions, the maximum number of transactions or outstanding government debt as a measure of depth for sovereign bond markets (Attinasi et al., 2009), as well as the ratio of transaction costs and volume available for trade, as an ask-side market depth indicator (Barbosa and Costa, 2010). For indirect measures of liquidity, Bernoth et al. (2004), Barbosa and Costa (2010), among many, use the relative share of government bonds issued by a country compared to total government debt issuances in the Eurozone. Similarly, Giordano et al. (2012) and Bruneau et al. (2012) apply the percentage of a government's debt outstanding with respect to total Eurozone debt outstanding. Indirect liquidity measures have the advantage of not being associated with the limitations of one particular trading platform. Codogno et al. (2003) incorporate multiple liquidity variables and find that trading volume is a first-best measure, when compared to the bid-ask spread and turnover ratio.

In general, liquidity effects on spreads are found to be largely heterogeneous in size across countries (Gomez-Puig (2006), Beber et al. (2009), Ejsing and Sihvonen (2009), Attinasi et al. (2009), Barrios et al. (2009), Haugh et al. (2009) and Gerlach et al. (2010)). The findings of the literature of the explanatory power of *liquidity risk* on spreads is mixed: While the vast majority of papers conclude in

[62] Attinasi et al. (2009) caution against a disadvantage of the use of the bid-ask spread as it is not truly exogenous as it depends on market features.

favour of a role for liquidity risk in the pricing of EMU government bonds, another set of empirical studies attests that no such relationship exists. For example, a number of pre-crisis empirical studies (Bernoth et al., 2006; Schuknecht et al., 2010) find that liquidity risk does not bear a significant effect on sovereign spreads. Gomez-Puig (2006) finds that liquidity, especially market size, drives bond yields, though admitting to a complementary role for default risk. Manganelli and Wolswijk (2009) estimate that liquidity variables are responsible for approximately half the change in spreads when interest rates are high. Haugh et al. (2009) find evidence of the contribution of liquidity to the rise in Irish and Finnish government bond yields in 2008-2009. They also show that in June 2009, core countries benefited from approximately 30bps lower spreads due to greater liquidity compared to smaller EMU countries. Favero and Missale (2011) reconfirm this result for Finland.

In between the above two extremes, other studies exhibit qualified acceptance for the effect of liquidity risk on sovereign spreads. Codogno et al. (2003) find that liquidity affects interest rate differentials yet that its role is driven by global risk aversion. Similarly, Favero et al. (2010) point to a role for liquidity only once interacting with the aggregate risk factor. For the early EMU years, Bernoth et al. (2004) show that although liquidity variables, such as the ratio of a country's debt outstanding to that of the Eurozone,[63] contribute to explaining EMU spreads, its explanatory power vanishes after the onset of the EMU. Similarly, for the early EMU era, Bernoth and Erdogan (2010) are of the view that liquidity premia are irrelevant after the onset of the EMU due to the increased interdependence of financial markets in the Eurozone, whereby transaction costs were rendered irrelevant for investment decisions. In contrast, Afonso et al. (2015) find that during the financial crisis, namely between the summer of 2007 and spring 2009, lower levels of debt issuance by Eurozone member states were associated with lower spreads, yet, the opposite relationship held after March 2009, thus pointing to time-varying signs for liquidity risk.

The depth of local markets and fiscal soundness may also interact with the pricing of liquidity risk. According to Borgy et al. (2011), in large countries with well-developed markets and sound fiscal

[63] Most relevant studies use the indirect proxy of government debt issued by a country compared to total EMU government debt outstanding.

fundamentals, liquidity effects are milder (Favero (2010), Beber et al. (2009) and Haugh et al. (2009)). However, in countries with small sizes of debt outstanding relative to the total euro area government bond market, such as Greece, Portugal and Ireland, liquidity remains an important contributor to spreads.

Related literature has been dichotomous on the relative size of liquidity effects on sovereign pricing after the crisis. Among many, Beber et al. (2009) point to an increased role for liquidity following the US financial crisis. In contrast, Favero et al. (2010) argue that the role of liquidity diminishes during periods of crisis and posit an alternative theory in justification of their view. According to this theory, crisis periods are characterized by a more constrained menu of alternative investments such that investors may flock to sovereign bonds as safe havens. Later studies have shown how liquidity has had a mild effect for more fiscally sound core countries in the Eurozone, while it acquired increasing importance for countries such as Greece, which were deemed to be on the verge of a liquidity squeeze. Thus, the interaction of liquidity risk with the degree of fiscal soundness has emerged as an answer to the above dichotomy both for the earlier EMU period (Pagano and Von Thadden, 2004; Gomez-Puig, 2006[64]) and in later years.

Other interaction terms affecting the pricing of liquidity risk in EMU government bonds are the degree of financial integration and overall capital markets development of the issuing country. Pagano and Von Thadden (2004) suggest that liquidity may interact with default risk and that a distinction between current and expected illiquidity is required. According to this view, expectations of an increase in future transaction costs, potentially due to a liquidity shock, act as amplifiers of sovereign default risk. In contrast, high current transaction costs act as a break against investor appetite to sell government bonds, such that they minimize the risk of sovereign default.

[64] Interactions between liquidity risk and fiscal fundamentals have also been documented in empirical literature, though by a limited number of studies. For example, Gomez-Puig (2006) explains that relative market size levels across nine EMU countries between 1996 and 2001 may have impacted spreads, as spreads of smaller-market size countries overreacted to increases in debt ratios.

A limited number of more recent studies have linked liquidity risk premia in sovereign spreads to the European Central Bank's response to the Eurozone debt crisis. Attinasi et al. (2009) find that the ECB's lowering of the main refinancing rate in response to the crisis played a significant role in the narrowing of spreads. Baker et al. (2016b) control for the role of monetary policy, i.e. for the effect of the short-term nominal interest rate on government bond yields, using forward-looking measure of expectations of overnight interest rates. They find that the expected path of the short-term nominal interest rate is a significant long-run determinant of government bond yields, especially for Northern Eurozone countries. As such, the loosening of monetary policy in the Eurozone has contributed to the decrease in sovereign bond yields in Northern states. Apart from lowering interest rates, Afonso et al. (2018) document the impact of extraordinary monetary policy actions on the sovereign spreads of the Eurozone periphery. These actions include the Securities and Markets Programme (SMP) and the Outright Monetary Transactions (OMT) since 2012 and the QE programme since 2015. The impact of both SMP and OMT has also been studied by Gibson et al. (2016), while Altavilla et al. (2015) examines the effect of the announcement of OMT on sovereign spreads. Afonso et al. (2018) account for the size of the "securities held for monetary purposes" by the ECB as well as for the impact of the Main Refincing Operations (MRO) rate. Pamies et al. (2021) probe into the explanatory power for spreads by the "Public Sector Purchase Programme" related to the Eurosystem's aggregate purchases of government bonds in secondary markets (Pamies et al., 2021). Event studies (*inter alia*, Godl and Kleinert, 2016) have confirmed the easing impact of ECB announcements, such as Mario Draghi's 2012 famous "Whatever it Takes" speech, on Eurozone sovereign spreads. Lastly, ECB purchases of government bonds may also reduce the extent of long-term crowding out of private capital by budget deficits, thus reducing the impact of deficits on long-term interest rates (Baker et al., 2016b).

iv. Uncertainty Variables

Global Risk Aversion

Global risk (or international risk) has been found to be a major determinant of government bond yields in the Eurozone. It is identified in empirical literature as the first principal component in

Principal Components Analysis (PCA)[65] of the determinants of sovereign spreads and is the main source of time-variation in spreads, usually captured via a time-varying constant (Assman and Boysen-Hogrefe, 2012). Global risk is distinguished from other determinants of sovereign spreads for not being country-specific.

International risk has been modelled empirically using one or more of the following proxies: the seven-to-ten year US corporations spread for BBB rated bonds (Codogno et al.,2003; Gerlach et al. , 2010), the Ted spread (namely the spread between the 3M LIBOR against the US T-Bill rate) (Gerlach et al.,2010), the Refcorp spread (Gerlach et al.,2010), the Chicago Board VIX[66] measure of the implied volatility of the S&P500 index (Beber et al., 2009; Gerlach et al., 2010; Borgy, 2011; Afonso et al., 2013), though De Santis (2015) has proposed the use of European equity implied volatility[67] as well. More commonly, the spread between the corporate 10-Year bond yield against the yield on US 10-year Treasuries is applied (Codogno et al., 2003; Favero et al., 2010; Bernoth et al., 2004; Haugh et al.,2009; Borgy et al., 2010; Bruneau et al., 2012). Assman and Boysen-Hogrefe (2012) measure global risk as the time-varying component of spreads using a latent variable approach. They use a GARCH time-varying coefficient which is assumed to follow a random walk. Manganelli and Wolswijk (2009) hold that ECB short-term interest rates may be better explanatory variables for the time-variation in spreads yet acknowledge that the financial crisis may not be accounted for using this measure, as spreads during the crisis peaked while monetary policy rates were held at all-time lows.

[65] In fact, as noted by Borgy et al. (2011), Principal Components Analysis often displays that the first principal component, responsible for over 80 percent of the variation in government spreads, is time-varying international risk aversion (Do Bernardo, 2016). Manganelli and Wolswijk (2009) find that the first principal component explains 86% of the total variation in EMU spreads. Similarly, Bufano and Manna (2012) find that the first principal component in the analysis of 10-year swap spreads accounts for over 94% of the variance of spreads for the period up to 2008: q3 and rises at the end of 2008 and early 2009, reaching a peak in the second half of 2011. This first principal component has been shown to correlate with proxies for "risk appetite" or "risk aversion" (Laubach, 2011).

[66] The VIX is a common proxy for international risk aversion. It is derived using the volatilities implied by 30-day puts and calls on the S&P500 index and is, thus, a forward-looking measure of volatility. It has been deemed to be the "investor fear gauge" as it tends to spike during periods of financial market upheaval (Whaley,2008).

[67] However, the precise focus of De Santis (2015) is the measurement of Eurozone redenomination risk.

International risk appears to have been relevant to government bond yields during the first more tranquil years of the EMU. Codogno et al. (2003), Geyer et al. (2004) and Manganelli and Wolswijk (2009), Sgherri and Zoli (2009), Favero et al. (2010) are among the first group of studies to confirm this. The effect of international risk was intensified with the crisis (Haugh et al.,2009; Barrios et al., 2009), particularly for countries with higher debt ratios (Cadogno et al.,2003). Later papers (Attinasi et al., 2009; Bernoth and Erdogan, 2010; Gerlach et al., 2010; Schuknecht et al., 2010; Favero and Missale, 2011; Maltritz, 2012) also attest to such findings.

Empirically, the effect of global risk is documented primarily using interaction terms with other variables. A number of studies confirm the interaction of the international risk factor with fiscal performance (Arghyrou and Kontonikas, 2012; Bernoth and Erdogan, 2010; Barrios et al., 2009; Haugh et al., 2009; Manganelli and Woslwijk, 2009 and Schuknecht et al., 2010), thus also explaining the time-varying significance of fiscal variables. Favero and Missale (2011) show that countries whose fiscal fundamentals are weak are also more exposed to changes in global risk appetites, thereby providing evidence of the interaction of fiscal variables with the international risk factor and cross-sectional heterogeneity. Afonso et al. (2015) confirm the decoupling of risk across core and periphery countries in the Eurozone since 2009. Schuknecht et al. (2010) show that Denmark, Finland and the Netherlands, which displayed strong fiscal fundamentals at the onset of the crisis benefited from lower spreads as a result of the crisis, while markets penalized Greece, Ireland and Portugal due to their weak fiscal performance, which accounted for more than half of the increase in spreads during the crisis. Haugh et al. (2009) find that the increased levels of risk aversion observed since the onset of the crisis have magnified the effect of fiscal variables in a non-linear fashion, particularly those of the ratio of debt service to tax revenues and of expected fiscal deficits. Giordano et al. (2012) include an interaction variable between a fiscal variable (debt-to-GDP) and global risk aversion for periods after mid-2011. Laubach (2011) attests to nonlinearities in the effect of risk aversion of spreads and hints at the possibility of feedback loops in the EMU: an increase in risk aversion, ceteris paribus, drives up spreads, which in turn increase the debt burden and deficit, further pushing up the spread.

Favero and Missale (2011) interpret the global risk variable to be equivalent to the interaction between fiscal fundamentals with other EMU countries' spreads. In particular, Favero and Missale (2011) construct a new factor, called "global spread", which is a global weighted average of spreads, whereby weights for each country's spreads are determined based on similarity in fiscal fundamentals, which in turn entail projected debt-to-GDP and deficit ratios. Favero and Missale (2011) show that for Italy, contagion accounts for as much as 200 basis points of the increase in spreads. Their study of the Eurozone shows that fiscal fundamentals affect sovereign risk only once interacting with other countries' spreads. As such, the above may be indicative of the presence of two regimes for the effect of contagion on sovereign CDS spreads. Bruneau et al. (2012) attribute shifts in market sentiment to contagion originating from Greece to the periphery.

Three main sources of global risk have been studied in the EMU spreads literature: banking risks, Eurozone breakup risk and EMU contagion risk. International sovereign risk has been attributed to international banking risk, confirming the so-called 'diabolical sovereign-bank nexus', particularly following the US financial crisis. For example, Acharya et al. (2011) note a transfer of global financial risk to the sovereign bonds market via bank bailouts (Afonso et al., 2015). While there is large cross-country heterogeneity in the magnitude of this nexus, Afonso et al. (2015) distinguish three main channels for the transmission of international banking risk into sovereign debt: firstly, via a decrease in the availability of bank credit; secondly via the fiscal costs of contingent liabilities involved in the recapitalization of financial institutions; and thirdly, via the announcements of bank bailouts. Similarly, Gerlach et al. (2010) comment on the significance of the interaction between the international risk factor with the size and structure of national banking systems, singling out two primary channels for such an interaction: the role of government as a lender of last resort for bank recapitalizations; and, in line with Adrian and Shin (2009), via the increased fiscal risks generated when equity-to-asset ratios of banks deteriorate. Mody (2009) shows that only after the collapse of Lehman Brothers does fiscal exposure to the financial sector explain spreads.

Arghyrou and Tsoukalas (2011) provide an alternative explanation for international risk, according to which the pricing of sovereign risk was altered during the crisis due to a change in private investors' expectations with respect to the probability of sovereign default or exit from the euro.[68] This is confirmed empirically by Di Cesare et al. (2012), who attribute the difference between predicted fundamentals-based yields and actual yields to the emergence of a new common risk factor, the risk of a breakup of the euro and of subsequent "fears of reversibility of the euro". Indeed, in 2012 market participants started forming scenarios of the risk of a Eurozone breakup. For example, a June 2012 UBS poll of 80 Central bank reserve managers showed that the risk of a euro-area breakup was perceived to be the largest risk for the global economy over the following 12 months, while 75% of respondents was confident that one country would leave the eurozone (Financial Times, 2012). Similarly, financial and regular media and online searches were flooded with concerns about a Eurozone breakup. Relevant Google keyword searches peaked in early December 2011 and in May and June 2012 (Di Cesare et al., 2012). Euro area yields were thus perceived to contain a convertibility premium, as also mentioned by the President of the ECB, Mario Draghi in 2012 (Di Cesare et al., 2012). De Grauwe and Ji (2012) study a similar determinant, which they name 'fragility of the Eurozone' and which is not a direct explanatory variable but emerges via a comparison of models for Eurozone economies and stand-alone countries. De Grauwe and Ji (2012) confirm that the post-crisis increase in significance for the real effective exchange rate and fiscal fundamentals occurred only for Eurozone economies, thereby validating the view of a Eurozone fragility risk. Similarly, De Santis (2015) find evidence of redenomination risk, arising from the perceived risk of the Eurozone breakup as a driver of sovereign spreads

"Residual redenomination risk" is related to default and exit from the Eurozone. Afonso et al. (2018) capture "residual redenomination risk" through the Sentix euro break-up index, which is a survey-based index of private and institutional investors' predictions about "at least one country leaving the EMU within twelve months" (Afonso et al., 2018). Furthermore, Afonso et al. (2018) interpret high

[68] Market whims for Eurozone government bond pricing have often been associated with the discussion of the breakup of the eurozone, and related prophecies of Grexit, Italexit, etc. In a currency area, due to the impossible trinity, member states relinquish the capacity to issue debt in a currency directly under their control. In line with this claim, De Grauwe and Ji (2012) find that during the onset of the Eurozone debt crisis in 2010-2011, a substantial portion of the increase in spreads for Greece, Ireland, Portugal and Spain was unrelated to fiscal fundamentals.

levels of sovereign spreads in the aftermath of the ECB's Outright Monetary Transactions (OMT) announcement as 'residual redenomination risk' for the panel of countries under study.

Global risk has also been closely linked to contagion or spill over effects in international capital markets. Certain studies distinguish the examination of contagion from international risk, others seem to tacitly blur the distinction between the two, while some comment on contagion being responsible for the unexplained variance of their empirical models. Elsewhere the distinction between uncertainty, country-specific market risk sentiment, global risk aversion, and contagion becomes blurred. For example, Giordano et al. (2012) include a proxy for global risk aversion (GRA), while at the same time studying two distinct forms of contagion, the latter of which is highly reminiscent in definition to international risk: *idiosyncratic contagion* is the marginal effect of fundamentals on the spread for each country, and *systemic contagion* corresponds to the percentage change in annual variation in spreads which is common across Eurozone countries. Giordano et al. (2012) define *systemic contagion* to be the common time-varying market sentiment once all economic fundamentals are kept constant.

Under an alternative interpretation of contagion, a number of papers argue that the portion of sovereign risk which is not explained by economic fundamentals may be partially attributed to contagion effects. For example, Metiu (2012) provides evidence that between January 2008 and February 2012, sovereign risk flew from Greece into Spain and Portugal, which thereafter hit Italy (Di Cesare et al., 2012). De Santis (2012) also finds evidence of contagion, particularly with respect to investors flocking into safe havens. [69]

Lower levels of contagion are confirmed for the pre-crisis era in the EMU (Attinasi et al.,2009; Sgherri and Zoli, 2009; Barrios et al., 2009; Haugh et al., 2009; Arghyrou and Kontonikas, 2012; De Santis, 2012; Favero and Missale, 2011) while later studies provide evidence for contagion originating from lower-rated sovereigns (Caceres et al., 2010; Arghyrou and Kontonikas, 2012; De Santis, 2012; Favero and Missale, 2011) (Afonso et al., 2015). Favero and Missale (2011) show that for Italy,

[69] Safe haven phenomena have also been documented by Caceres et al. (2010) and Beber et al. (2009), as investors increase their demand for the more liquid assets.

contagion accounts for as much as 200 basis points of the increase in spreads. Their study of the Eurozone shows that fiscal fundamentals affect sovereign risk only once interacting with other countries' spreads. As such, the above may be indicative of the presence of two regimes for the effect of contagion on sovereign CDS spreads. De Santis (2012) attests to the role of contagion effects in the development of the EMU sovereign debt crisis.

More recently, Afonso et al. (2018) decompose the VIX into two components: *realized volatility* of the S&P 500 and a *volatility risk-premium* of the S&P 500 that reflects the difference between implied volatility (risk-neutral expected volatility) and realized volatility. Afonso et al. (2018) consider this volatility risk premium to be a proxy of general risk aversion, motivated by the relevant methods applied in equity markets by Bollerslev et al. (2009) and Bekaert and Horoeva (2014).

Political Uncertainty

The Eurozone debt crisis provided the impetus for research on the effects of political uncertainty on sovereign bond market pricing. Departing from the common panel data studies on the political and institutional determinants of Emerging Market and Advanced Economies sovereign credit spreads, which traditionally have included, inter alia, constitutional effects, political stability, and cross-country governance indicators published by the World Bank, [70] this line of EMU research studies the concept of *political uncertainty*. Although *political* uncertainty has been distinguished from *policy* uncertainty (see Pastor and Veronesi, 2011a),[71] noting the inherent difficulty in the measure of

[70] Political risk has been measured as the Political Risk Rating by the PSR Group, an ICRG composite qualitative risk rating based on a scale of 0 to 50. This measure has been used in panel studies of emerging markets (eg. Csonto and Ivaschenko, 2013).
[71] Pastor and Veronesi (2011a) study the effect of government policy uncertainty on stock prices. They distinguish between two distinct types of uncertainty: *policy uncertainty*, which relates to the uncertain impact of government policy on private sector profitability, and *political uncertainty*, which relates to the private sector's perception of uncertainty regarding potential changes from the current government policy. In a Bayesian framework for the effect of economic policy uncertainty on equity risk pricing, they define *policy uncertainty* as the standard deviation of agents' (the government and the investors) prior beliefs regarding the impact of policies on profitability, while *political uncertainty* is the standard deviation of the impact cost of a policy change to investors, which occurs in the aftermath of some threshold analysis by the government about whether or not to replace a policy rule with a new rule.[71] Bayesian updating due to both types of uncertainty induce movements in the threshold.

political uncertainty, recent studies have availed themselves of the Baker et al. (2016a) proxy of the *Economy Policy Uncertainty Index (EPU).*

The literature on the financial market effect of this variable is nascent and shallow, despite the linkages of seminal theoretical asset pricing models to Knightian Uncertainty (Knight, 1921). In the context of equity capital markets, Pastor and Veronesi (2011) find that stock price declines are larger following the announcement of political changes which include an element of surprise. Similarly, Pastor and Veronesi (2013) find empirical evidence for a political risk premium, arising due to the effect of political shocks on investors beliefs about future government policy choices. Using EPU, they show that political uncertainty is state-contingent, as it is higher during periods associated with worse economic outcomes.

In an empirical study of the effect of political uncertainty on Eurozone CDS spreads using Principal Components with panel data, Manzo (2013) associates major political events of the Eurozone debt crisis (such as the announcement of the first Eurozone bailout for Greece or dates of relevant EuroSummits) to increases in CDS risk premia. Similarly, Pastor and Veronesi (2013) find that financial market investors, when pricing equity and government-related debt instruments, require compensation in the form of an additional risk premium for exposure to policy uncertainty, particularly with respect to major political news and events such as the outcome of elections.

More recently, Handler and Jankowitsch (2018) conduct event studies of government bond pricing in the Eurozone using a number of distinct event dates and event windows, to provide additional evidence of the impact of policy uncertainty on financial market pricing, both in the runup and in the aftermath of event dates associated with political uncertainty.

Policy uncertainty is also critical for the detection of the influence of trading volume on sovereign spreads. Handler and Jankowitsch (2018), controlling for events associated with high uncertainty find that measures of trading activity/liquidity[72] are *negatively* associated with government bond yields

[72] Liquidity measures include, *inter alia*, cumulative trading volume, net bids, the Amihud (2002) illiquidity measure, Roll’s (1984) measure.

during deteriorating economic conditions. In contrast, the collapse of financial market mispricings (bubbles) is accompanied by a *positive* association of risk premia and trading volumes (Brooks and Katsaris, 2005). Reconciling the above, empirical evidence confirms the concurrent effect of trading volume activity (short sales) and uncertainty in the pricing of government bonds and relevant associations may be state-contingent.

2.2.3. Determinants of Greek Government Bond Yield Spreads

A relative dearth is noted on studies devoted to the study of Greek sovereign spreads as time series compared to the large number of panel studies of EMU spreads which also include Greece. This section will combine the insights and findings on Greek spreads offered by the Arghyrou and Tsoukalas (2011), Gibson et al. (2012) and Chionis et al. (2016) with panel-data-based findings on Greek spreads.

In an attempt to develop a simple model of the Greek debt crisis and abstracting from the formulation of a structural empirical model, Arghyrou and Tsoukalas (2011) study the pre-bailout era (2000-2010), breaking it down into six periods based on global financial market developments and changes in Greek government bond yield spreads over the German Bund: i. During 2000-summer of 2007, Greek participation in the EMU led to a convergence in sovereign bond yields, giving rise to a spread of 25bps for the 10-year GGB; ii. In the summer of 2007, the onset of the US subprime crisis contributed to a rise in the average spread for the 10-year GGB to 65bps; iii. A third period covers the peak of the global credit crunch, spanning Sept. 2008 to March 2009, accompanied by spreads of 285bps on average for the Greek 10-year bond; iv. Between April 2009 and Aug. 2009, the easing of the global financial crisis led to a de-escalation of the spread on the GGB to an average level of 121bps; v. Marginal increases in the Greek government debt are portrayed in the fifth period (Sept. 2009-Nov. 2009), marked by mildly higher spreads (120-130bps), with spikes around three major events: the 4/10/2009 snap election, the mid-October 2009 budget deficit revision from 6% to 12.7% GDP and the mid-November budget submission; vi. In the runup to the first bailout package, between

November 2009 and 22/4/2010, spreads reached an average of 586bps (Arghyrou and Tsoukalas, 2011).

Among single-country studies focused on Greece, Gibson et al. (2012) and Chionis et al. (2016) are the sole papers distinguished for their empirical contributions on the determinants of Greek government bond yields. In their study of the imbalances that led to the outbreak of the Greek debt crisis, Gibson et al. (2012) use a Vector Error Correction Model (VECM) to study the relationship between fundamentals and 10-year government bond yield spreads since 2001. They find evidence of both overshooting and undershooting, defined as instances where the distance "between actual and predicted spreads lies outside the standard error bands of residuals" (Gibson et al., 2012). Gibson et al. (2012) show that spreads deviated from their fundamentals-based values during two periods: between the end of 2004 and mid-2005, when spreads overshot fundamentals; and since May 2010, when actual spreads were 400bps higher than the level predicted based on their model. The increase in spreads was built up since mid-2009 and is mostly attributed to "fiscal surprises". In the long run, relative price differences (competitiveness) are the largest determinant of Greek government bond spreads: one standard deviation increase in Greek prices compared to those in Germany, increase spreads by 225 bps on average. This is followed by economic activity, the cumulative impact of fiscal news, and oil prices. Economic fundamentals studied include fiscal variables (government debt-to-GDP ratio, deficit-to-GDP ratio), a fiscal news variable incorporating "real-time fiscal data", or accumulated forecast revisions; competitiveness indicators (real exchange rate, trade-to-GDP and current-account-to-GDP), the level of economic growth (using the Bank of Greece's monthly coincident indicator of economic activity). Interestingly, the price of oil has been included, as unlike other advanced economies Greece is an oil-dependent economy.[73]

More recently, Chionis et al. (2016) study the determinants of Greek government bond yields prior to and after the crisis, distinguishing between "market-driven" and macroeconomic variables and find that the debt-to-GDP ratio, the budget deficit, inflation and unemployment were the main

[73] The effect of the price of oil was found to be minimal.

determinants of 10-year government bond yields. They posit that both common and country-specific factors influence spreads. Markets have generally overshot fundamentals in their pricing of Greek sovereign risk after the crisis. Prior to the first rescue package for Greece, inflation and unemployment appeared to be the most significant drivers of 10Yr GGB yields. During the crisis, the fiscal deficit became significant, but the effect of economic growth was insignificant. The authors interpreted the above as evidence that fiscal consolidation was most appropriate for Greece.

The vast majority of empirical papers study Greece within a panel of EMU countries and not as a standalone country. For instance, Afonso et al. (2013) find that the pricing of Greek sovereign risk occurs primarily via the expected debt channel. A very pronounced increase in the relevant coefficient of debt with respect to spreads occurred in 2011, while liquidity risk (proxied via the bid-ask spread) and global financial risk (as proxied by the logarithm of the VIX) also increased in importance after 2011. Unlike Chionis et al. (2016), Afonso et al. (2013) find that economic growth is statistically significant for Greece during the debt crisis period.

2.2.4. Relative Factor Contributions to Spreads

Large discrepancies are demonstrated among empirical findings of the relative contributions of each determinant of sovereign spreads. The majority of papers point towards the pre-eminence of international risk among sovereign risk pricing factors in the EMU. Principal Components Analysis is regularly used for deciphering the role of each factor. A common finding in the literature is that the international risk factor is the first principal component, accountable for over 80% of the total variation in spreads (Borgy et al., 2011).[74] Codogno et al. (2003) find that global risk is more important than liquidity risk, while Geyer et al. (2004) find support for the effects of international risk for Austria, Belgium, Germany, Italy and Spain yet noting no liquidity risks. Similarly, in their study of the time period corresponding to the financial crisis, Attinasi et al. (2009) find that, on average,

[74] Borgy et al. (2011), thus, hold that this renders the study of country-specific determinants of government bond yields, such as national fiscal policies, a highly difficult task.

international risk aversion is the main contributor to changes in spreads, followed by the expected fiscal position, liquidity proxies, and finally, fiscal announcements.

Borgy et al. (2011) focus on fiscal risk in large countries with well-developed markets and do not attribute as much importance to liquidity risk as do other papers at the time, such as Favero (2010), Beber et al. (2009) and Haugh et al. (2009). However, they caution that for countries with small sizes of debt outstanding relative to the total euro area government bond market, such as Greece, Portugal and Ireland, liquidity remains an important contributor to spreads.

Barbosa and Costa (2010) show a change in the relative importance of the determinants of sovereign spreads in the beginning of 2007, such that both the sensitivity of spreads to factors changed but also the role of different factors was altered. They find that prior to the collapse of Lehman Brothers, the global risk factor was responsible for most of the variation in spreads, contributing as much as 70 percent of the change in spreads (Barbosa and Costa, 2010). After the onset of the crisis, country-specific fundamentals ("idiosyncratic factors") became increasingly important (accounting for over 50 percent of the average spreads level between September 2008 and December 2009), with liquidity factors being critical during the first months after the financial crisis, and macroeconomic factors taking over in importance as a heterogeneous country credit risk became more relevant during the EMU debt crisis (Barbosa and Costa, 2010).

Alternative methods of gauging the relative importance of determinants for sovereign spreads include comparisons of the significance and size of model coefficients or the variance decomposition in VARs. Furthermore, based on PCA, Attinasi et al. (2009) develop formulas for the absolute and relative contributions of factors.

Time variation in the contribution size of factors is examined via time dummies (De Grauwe and Ji, 2012). For the financial crisis time period (2007-2009 data), Attinasi et al. (2009) find that, on average, international risk aversion contributes to changes in spreads (56%), followed by the expected fiscal position (21%), liquidity proxies (14%), and finally, fiscal announcements (9%). For France, liquidity is the most important determinant of spreads (43%). Liquidity was relatively high in contribution for Italy (29%), the Netherlands (20%) and Belgium (17%). Barbosa and Costa (2012) find that the relative importance between credit and liquidity risks is time-varying and may depend on structural changes and the position in the business cycle.

Combining all the above factors, Barbosa and Costa (2010) conclude that sovereign credit risk premiums affected primarily countries with higher expected budget deficits and countries in which public debts had been higher and whose international investment position was worse prior to the crisis. In addition, international financial risk acted as an amplifier of liquidity and credit risk premia during the crisis, while liquidity premia were especially magnified in countries with smaller sovereign bond markets.

2.2.5. Parameter Instability in the Determinants of Sovereign Risk

Evidence of structural change in the determinants underlying the pricing of sovereign risk in the euro area, and for Greece in particular, as captured by a relevant country-dummy for Greece, has been presented by Giordano et al. (2012). They find that core EMU countries were not affected by the post-Lehman financial turmoil beyond what their fundamentals would have dictated, while after mid-2012, they benefited from the eurozone sovereign debt crisis, in line with the claims of investor flight to quality. In contrast, peripheral countries, such as Spain, Portugal and Ireland, witnessed a revision in their pricing in 2010, which peaked after 2012, with Italy's spreads bearing a heavy onus from contagion due to its high levels of indebtedness.

Gibson et al. (2012) apply the Kalman filter to distinguish between a time-varying component of market sentiment in the Greek government bond yield spread from the respective German government Bund yield. Controlling for dummy variables related to the announcement dates of ratings downgrades, they show a substantial variation in the market-sentiment component of Greek government bond yield spreads over the time sample considered.

Barbosa and Costa (2010) also confirm the change in the relative importance of the determinants of sovereign spreads in the beginning of 2007, such that both the sensitivity of spreads to factors changed but also the role of different factors was altered. Barbosa and Costa (2010) find that prior to the collapse of Lehman Brothers, the global risk factor was responsible for most of the variation in spreads, contributing as much as 70 percent of the change in spreads (Barbosa and Costa, 2010). After the onset of the crisis, country-specific fundamentals ("idiosyncratic factors") became increasingly important (accounting for over 50 percent of the average spreads level between September 2008 and December 2009), with liquidity factors being critical during the first months after the financial crisis, yet macroeconomic factors taking over in importance as a heterogeneous country credit risk became more relevant to the EMU debt crisis (Barbosa and Costa, 2010).

Empirical research points to evidence of structural breaks in the relationship between economic fundamentals and sovereign spreads. However, there is little consensus in the literature on the precise timing of such breaks. For example, Alessandrini et al. (2012) show that a structural break occurred in 2010, when the pricing of risk for highly indebted countries was reassessed upwards. Assman and Hogrefe (2012) select January 2001, corresponding to the adoption of the euro by all countries and March 2009, as the date of the eruption of the euroarea sovereign debt crisis. Afonso et al. (2015) consider two structural breaks: one in August 2007, representing the onset of the financial crisis as in Arghyrou and Kontonikas (2012) and Attinasi et al. (2009) and one in March 2009, indicative of the mutation of the global financial crisis into a European sovereign debt crisis. The latter date also coincides with the revision of macroeconomic data by DG ECFIN, which spread the alarm for the size of the Greek budget deficit. Gerlach et al. (2010) point to the following dates of structural breaks: June 2006, February 2009. Barbosa and Costa (2010) locate a regime change in the first five months of 2007. Aizenman et al. (2011) find that a structural break occurred during 2008-2010 for CDS spreads, as during that time, the pricing of CDS was 'largely decoupled' from fiscal space fundamentals, decreasing their predictive power from 70-80% to 45-60%, as after the financial crisis, measures of external imbalances provide increasing contributions. De Grauwe and Ji (2012) detect a structural break in 2008 via the Chow Test (both for Eurozone and non-eurozone 'stand-alone' economies) and thus proceed with studying the pre-crisis and post-crisis periods separately. The above dates may serve as guidelines for the timing of known regime switches.

Time deviation in the determinants of government bond yields is dealt by other researchers via restrictions in the time series examined. Certain studies simply concentrate on the financial crisis period thus restricting the time series under consideration. For example, Attinasi et al. (2009) focus on data for July 2007 up to March 2009 only in their quest to reveal the determinants of sovereign spreads during the financial crisis. Alternatively, time series are divided into sub-samples to be studied by distinct models. Schuknecht et al. (2010) who devote their study of the determinants of sovereign spreads to the period of the financial crisis, argue that for euro-area spreads, two phases of the crisis may be distinguished: August 2007-August 2008 (the "turmoil period") and September 2008-May 2009 (the "crisis period"). They find that during the crisis period, the evaluation of fiscal performance by financial markets changed. By decomposing the coefficients for spreads during the crisis period into fiscal and general risk-aversion factors, Schuknecht et al. (2010) find that euro area countries are separated into two groups: those whose bond pricing dynamics benefited from the debt crisis and those with less solid fiscal performance, which stood at the vortex of market fears. Borgy et al. (2011) distinguish between the period after the collapse of Lehman Brothers in 2008 and the 2010-2012 period.

Favero and Missale (2011) provide empirical evidence for changes in the effect of market sentiment over time, modelled as shifts in the global risk variable. They study the following time periods: the full time-sample of 2003-2010 and three subsamples, 2003-2007 or the "low-volatility period", May 2007-August 2009 as "the financial crisis" and September 2009-July 2010 as "the Greek debt crisis" period. During the first period, the interest-rate spreads of Greece and Italy are highly correlated, in spite of market differences in terms of size and liquidity. During the financial crisis period, the Greek spread widened to 300bps while the Italian spread jumped to 150bps, indicating that markets clearly differentiated between the two. Lastly, during the Greek debt crisis period, the Greek spread spiked to close to 1000bps while the Italian bond spread was also affected, reaching almost 200bps, namely levels above the US Baa-Aaa spread.

Giordano et al. (2012) use Time-Dummy variables (one for each year) to capture changes in the pricing of sovereign risk over time. They interact the 2011-dummy with international risk aversion and fiscal variables to determine whether after the onset of the debt crisis, global risk aversion increased the investor community's sensitivity to fiscal fundamentals. Similarly, Aizenman et al. (2011) use a time dummy for each of the three crisis years: 2008, which they identify as the central part of the global financial crisis; 2009, which they call a partial recovery period; and 2010, which they relate to the euro area debt crisis and post-global financial crisis. Di Cesare et al. (2012) also use time dummies and divide their sample into three periods, focusing primarily on Italy: mid-2009 to April 2010; May 2010 to June 2011; and July 2011 onwards, in the aftermath of the PSI and second financial assistance programme for Greece. Their model is thus augmented with three relevant dummies, one for the Financial Crisis (post-September 2008), one for the EMU sovereign debt crisis (post-May 2010), and one for the period after the PSI (post July 2011). They find that since the summer of 2011, the residual of predicted sovereign spreads compared to actual market values has increased for all countries in the panel, with Italy being the most severely penalized compared to its fundamentals. They show that up to November 2011, the debt crisis had predominantly affected Italian spreads. In contrast, in the first half of 2012, Greek macroeconomic imbalances and concerns about Spanish banks were the main drivers of risk, such that Italian yields were stabilized, while Spanish yields surged.

The above papers have implicitly adopted time-varying methodologies yet this has not been the focus of their study. Instead, three papers are distinguished for their focus on euro-area spreads endogenous slope time-variation: Assman and Boysen-Hogrefe (2012), Bernoth and Erdogan (2010), Afonso et al. (2013) and Afonso et al. (2018), all of which find evidence of strong time-variation in the relationship between fundamentals and sovereign spreads.[75] These papers take note of the complex and "continuous nature of structural instability" (Afonso et al.,2013) in the process of spreads determination. Using a time-varying Non-Parametric approach, Bernoth and Erdogan (2010) examine whether changes in euro area spreads can be attributed to changes in macroeconomic fundamentals or to market sentiment and show that coefficients are time-varying. Bernoth and Erdogan (2010)

[75] A number of other more recent papers (e.g. Blagov et al.,2015) have studied the time-variation in euro area spreads. Yet due to their wider focus on other lending spreads (e.g. corporate lending spreads), beyond government bond yield spreads, they have been omitted from this review.

distinguish the following dates in their analysis: end of 2006, as the time when Germany reattained a safe haven status and August 2007, coinciding with the US financial crisis. Similarly, Assman and Boysen-Hogrefe (2012) adopt a time-varying approach to detect the relative size of determinants of spreads for 2001-2011. They use latent processes to model time varying determinants, without resorting to the use of global variables, and show that coefficients, particularly those of market capitalization increased substantially in response to the US financial crisis and that the debt ratio was responsible for most of the variation in spreads between 2003 and 2008.

Afonso et al. (2013) criticize the aforementioned latter two studies for being limited to a panel-based approach, such that no light is shed on country specific heterogeneity in the time variation of the relationship of fundamentals and spreads, as in panel data, country fixed effects are only revealed via the intercept. Therefore, following D'Agostino and Ehrmann (2012), who focus on spreads of G7 countries, Afonso et al. (2013) provide the first country-specific time-varying model of determinants of sovereign spreads for the EMU. Afonso et al. (2013) develop a dynamic version of the general-to-specific (GETS) model (Hendry and Krolzig, 2004) and claim to build the first country-specific model that captures the time-varying relationship between spreads and fundamentals (such as international financial risk, liquidity risk, credit risk).

More recently, Afonso et al. (2018) develop a time-varying parameter risk factor model to empirically examine shifts in Eurozone sovereign bond pricing regimes and to answer whether EMU sovereign bond pricing was driven by fundamentals or whether there was evidence of multiple equilibria. Afonso et al. (2018) apply the Li et al. (2011) Local Linear Dummy Variable (LLDV) non-parametric time-varying coefficient model for panel data. They compare time-varying coefficients of a panel of EMU countries against non-EMU countries, and sub-panels of the EMU periphery with and without Greece and show that stronger time-variation is exhibited in the EMU countries coefficients. Time-varying sensitivity to risk factors, as exhibited through time-varying coefficients is interpreted as evidence of *multiple equilibria* in the presence of macro-imbalances that are associated with self-fulfilling fiscal defaults, induced by perceived changes in the probability of default and of a euro-exit. Their results highlight the role of limited market liquidity in asset price equilibrium indeterminacy.

They show how the European Central Bank's reaction to the crisis through the announcements of ordinary and extraordinary monetary policy measures as well as Mario Draghi's reassuring stance in his famous 'Whatever it Takes Speech' introduced a regime-shift as markets became appeased by the presence of a Lender of Last Resort (LLR). They conclude that monetary policy interventions may introduce regime shifts in bond pricing. [76] Overall, they attest to the presence of three distinct periods for sovereign spreads against Germany: 1999-summer 2007; fall 2007-end 2011/beginning 2012 over the course of which bond price increases are marked; 2012 onwards.

Lastly, a further applied methodological consideration in the literature relates to the question of whether coefficients change gradually over time or at discrete break points (Bernoth and Erdogan, 2010). Following this reasoning, Bruneau et al. (2012) build a Threshold Regression (TR) model, locating their threshold in March 2010 for Eurozone economies, noting that spreads dynamics displayed altered behaviour between October 2009 and October 2010. The advantage of this regime-switching threshold option against the Markov-Switching specification is that the variables inducing the threshold-switching behaviour, and associated time variations, are directly observable.

[76] The stabilizing role of monetary policy interventions through Quantitative Easing (QE) has been examined by Altavilla et al. (2015).

2.3. Sovereign Spreads: Fundamentals or Market Sentiment?

This section introduces the basic concepts and empirical findings, as relevant to the question answered by the empirical model presented in Chapter 4. Section 2.3 is structured as follows: Section 2.3.1 provides a succinct overview of the meaning of market sentiment, its relationship to uncertainty in macroeconomic theory, and of relevant empirical proxies used in applied research. Section 2.3.2 subsequently summarizes the empirical methods and findings of models which distinguish between the contribution of fundamentals to that of market sentiment in the evolution of sovereign spreads.

As the literature on the effect of fundamentals against market sentiment differentiates between the short run and long run determinants of sovereign spreads, section 2.3.3 comments on the methodological applications and findings related to this latter distinction.

2.3.1. A Brief Overview of Market Sentiment in Macroeconomics

Applied and theoretical literature has used several terms to portray the effect of market sentiment on market pricing behavior. ‘Market sentiment’ and ‘market expectations’ have been used interchangeably to describe fluctuations in macroeconomic activity. ‘Animal spirits’ is an additional term used in applied and theoretical models as synonymous to the notion of ‘market sentiment’ or to relate to the irrational component of market sentiment. These concepts are linked in the empirical and theoretical literature with the concepts of *uncertainty*, *ambiguity*, *imperfect information*, *trading liquidity* and *coordination failures*. A distinction between the short run and long run is often associated. Noting the inherent difficulty in defining, measuring and predicting market expectations, empirical studies confound the above and make use of proxies or relevant indices, which however are far from capturing the full spectrum of these terms.

Economic theory has long pondered over the nature of expectations and the mechanisms via which expectations and ‘animal spirits’ affect market outcomes. A cornerstone of Keynes’ (1936) Chapter 12 of the *General Theory of Employment, Interest and Money* is the *distinction between short-term and long-term expectations.* In Keynes (1936), short term expectations depend on the existing stock of capital-assets and the ‘strength of existing consumers’ demand’, whereas long-term expectations are based on "future changes in the type and quantity of the stock of capital-assets and in the tastes of the consumer, the strength of effective demand from time to time during the life of the investment under consideration, and the changes in the wage-unit in terms of money which may occur during its life" (Keynes, 1936). Short term expectations are related to speculative trading behavior and 'liquidity' effects, whereas investment professionals form long-term expectations over fundamentals and hold assets over the long term. Complementary to the narrative of short term versus long term expectations, is a distinction between "*facts"* and *forecasts* of future events which in turn depend on the *a priori* incalculable "*confidence*" in the formation of expectations. Expectations and outcomes are therefore dependent on "mass psychology" and the effect of "a large number of ignorant individuals" whose speculative trading behavior unleashes "dark forces" related to 'liquidity' (Keynes, 1936). Keynes (1936) also incorporates an *element of 'irrationality' in market expectations*, thus standing in the cross-roads of the rational expectations versus bounded rationality and behavioral effects in financial market pricing. Keynes (1936) acknowledges the interlinked role of *uncertainty* and of the maintenance of the stability of the *'state of affairs'* assumed under some 'conventional method of calculation' with respect to financial market expectations. Therefore, Keynes (1936) relates market sentiment to liquidity effects and speculative trading behavior, notes a distinction between facts and forecasts, and relates market expectations to the notion of uncertainty, while implicitly cautioning against some form of market-related state-contingency and instability.

Despite its historically long use in economic writing, *'animal spirits'*[77] *lacks a precise definition*. In macroeconomic theory, 'animal spirits' has attained two distinct meanings: it has been used as the mechanism that generates observed fluctuations and multiple equilibria within a rational expectations framework, yet it has also been interpreted as the source of departures from rationality (Angeletos and La'O, 2013). In rational expectations models, *"self-fulfilling animal spirits"* (Nowzohour and Stracca, 2017) are the *payoff irrelevant extrinsic shocks to 'fundamentals' ('sunspots')*. Animal spirits are thus

[77] Animal spirits have a long history of use in the social sciences, which extends beyond the scope of the empirical chapter. For example, in Capital, Volume 1, Karl Marx (1867) refers to the animal spirits of the worker through which co-operation works to enhance worker efficiency, as man is a 'political' or 'social' animal in the Aristotelian sense.

distinguished from fundamentals, which are defined as "payoff-relevant variables such as preferences, endowments, technologies, and government policies or news thereof" and are used to describe fluctuations in asset pricing behavior (Angeletos and La'O, 2013). Under rational expectations, equilibrium is defined based on the fixed point where market expectations and market outcomes coincide. Self-fulfilling expectations exist when there is no finite solution to the 'fixed point' problem. Examples of seminal papers introducing sunspots and self-fulfilling expectations in multiple equilibria models include inter alia, Azariadis (1981), Benhabib and Farmer (1994), Cass and Shell (1983), Diamond and Dybvig (1983) and Cooper and John (1988). In contrast, Akelrof and Shiller (2010) use *irrational 'animal spirits'* to describe the behavioral aspect of asset prices.

Nowzohour and Stracca (2017), blurring the distinction between *sentiment* and *animal spirits,* suggest a third group of *animal spirits* based on *news-induced sentiment.* According to this view, market sentiment changes are the outcome of *noise signals* occurring due to the presence of *imperfect information* about future fundamentals. Signals of fundamentals are critical to financial models of boom and bust, or those related the collapse of a financial market bubble (Nowzohour and Stracca, 2017).

Regarding the mechanism via which *market sentiment* affects outcomes, the following modelling devices are distinguished: In mainstream models, the main channel through which sentiment operates relates to extrinsic *sunspot shocks,* usually through the addition of a random variable to depict an exogenous payoff-irrelevant stochastic shock. In addition to extrinsic *sunspot shocks, coordination failures offer* an additional transmission mechanism for market *sentiment,* when *sentiment* is broadly defined to capture *animal spirits.* This sentiment-based mechanism is described via the use of *sentiment shocks* by Angeletos and La'O (2013). Noting the possibility of fluctuations in market behavior in the absence of sunspot-type extrinsic shocks, Angeletos and La'O (2013) attribute market outcomes to a special type of shocks, called *sentiments,* which are "akin to sunspots", yet operate under unique-equilibrium economies due to the Keynesian notion *of coordination failure.* In the absence of some aggregate external payoff-irrelevant shocks, *sentiments* are shocks which affect market outcomes through communication and coordination failures related to *trading activity* *frictions.* Such *sentiment shocks* are defined as the extrinsic shocks to *first-order* expectations of economic activity as opposed to the operations of *higher order beliefs*, propagated by the literature starting with Morris and Shin (2000). In contrast to the *sentiment* interpretation of Angeletos and La' O (2013), Morris and Shin (2000) relying on a game-theoretic setup relate the selection of a unique self-fulfilling outcome among a range of multiple equilibria to the effect of *higher order beliefs* arising due to uncertainty about fundamentals (*noise singals*) and a *coordination failure* among speculative traders. Angeletos and La' O (2013) and Morris and Shin (2000) follow entirely different methods and answer different research questions, yet both relate incomplete information and noise signals to some coordination failure in trading activity, which in turn affects *market sentiment* and hence market outcomes under rational expectations.

In empirical research, Nowzohour and Stracca (2017, 2020)[78] define *sentiment* in 'economic matters' as a term "used to describe economic agents' views of future economic developments that may influence the economy because they influence agents' decisions today" (Nowzohour and Stracca, 2017). They further qualify this definition of *sentiment* as being reflective of "rational arguments and facts" but also a "mood of optimism or pessimism" (Nowzohour and Stracca, 2017, 2020), thereby underscoring Keynes' (1931) distinction on the factors driving the *expectations* of yields.

Both rational and irrational *market sentiment* is related to *uncertainty*. Nowzohour and Stracca (2017, 2020) explicitly distinguish between two components of *sentiment: confidence* and *uncertainty*, also broadly alluded to in Keynes (1936). The former is shown to be empirically proxied via *consumer and business confidence survey measures*, whereas the latter is proxied via *stock-market volatility* (proxied via the VIX *index*)[79] and the "newspaper-based index" *Economic Policy Uncertainty* of Baker et al.

[78]Nowzohour and Stracca (2017) provide an extensive literature review of the role of *sentiment* on the business cycle. As this chapter does not build a business cycle model, empirical findings are provided for conceptual purposes.

[79] A more relevant proxy of market risk aversion with respect to the Greek economy could be the KEPE GRIV Index. The measure of uncertainty estimated in Chapter 4 provides an alternative to this metric. https://www.kepe.gr/index.php/en/component/k2/item/1276-griv-index

"The KEPE GRIV Index is an implied volatility index and is calculated on the basis of the prices of FTSE/ASE Large Cap Index options, based on the official new methodology applied by the Chicago Board Options Exchange (CBOE). The index was created by KEPE in collaboration with the University of Patras and Prof. C. Siriopoulos. The purpose of the index is to be the main benchmark for expected future short-term volatility in the Greek stock market. It, hence, reflects uncertainty and confidence shown by investors in the Greek Economy, as reflected in

(2016a). Nowzohour and Stracca (2017) find both contemporaneous and forward-looking correlations of *sentiment* variables with economic outcomes and hence conclude that *economic sentiment* may drive economic activity. This empirical finding serves to corroborate the rational expectations models mechanics.

Confidence and *uncertainty* measures across countries are shown to be interlinked, such that a role emerges for a global factor in *sentiment. Confidence* is defined as "a strong belief in positive future economic developments" (Nowzohour and Stracca, 2017) arising either due to *animal spirits* or *news* and may be further decomposed based on the type of *uncertainty*. This *uncertainty* is defined based on a range of possible future outcomes of economic developments and constitutes a type 1 uncertainty, whereas uncertainty arising due to a lack of knowledge about the future distribution of economic outcomes is classified as a type 2 uncertainty (*ambiguity about the probability distribution*) by Nowzohour and Stracca (2017). This classification of sentiment according to the uncertainty mechanism through which it emerges is in line with the classic Knightian (1921) distinction between *risk* and *uncertainty*, the former of which relates to risks with known probability distributions (the "*known unknowns*"), whereas the latter relates to risks with unknown probability distributions (the "*unknown unknowns*") (Kay and King, 2020). However, this distinction of sentiment based on uncertainty blurs the distinction between rational expectations against the behavioral effects with investor herding or panic. Nowzohour and Stracca (2017) further note that in reality *the two types of uncertainty often operate together*. Therefore, a realistic distinction between the two may not be possible empirically. Type 2 uncertainty may act as an "amplifier of type 1 uncertainty" (Rossi et al., 2016, Nowzohour and Stracca, 2017). Following Kozlowski et al. (2015), Nowzohour and Stracca (2017) note that in the aftermath of the global financial crisis, a structural change has occurred with respect to the uncertainty-source of *sentiment:* agents' perception of the 'nature of uncertainties' has changed, in the sense that *ambiguity* and tail events have become more relevant.

derivative products prices, while providing useful information in the domestic, as well as in the international markets " (KEPE, 2020).

Nowzohour and Stracca (2017) relates to type 2 uncertainty, the unknown unknowns and Knightian Uncertainty. In theoretical macro models, Knightian uncertainty is modelled as 'uncertainty aversion' related to belief distortions and 'maxi-min preferences' as agents try to shield themselves from worst case scenarios. Therefore, the effects of liquidity serve as an amplifying mechanism that reinforces 'flight to quality' effects induced by uncertainty.

2.3.2. Market Sentiment vs Fundamentals: Summary of Empirical Findings of Sovereign Spreads

This section proceeds in reviewing the methodological choices and findings in the empirical literature developed to answer whether sovereign risk pricing has been driven by fundamentals or expectations. The empirical findings presented in this section bundle any subtle distinctions of expectations, animal spirits and market sentiment into a single interchangeable market expectations component of sovereign risk pricing. According to one line of reasoning, expectations, or 'animal spirits' are captured as deviations from model estimates of yields, based off fundamentals. The fluidity of definitions (see section 2.3.1 above) and lack of explicit 'cut-off' debt sustainability thresholds (see Chapter 2.1) underlies the multiple empirical interpretations which have emerged with respect to the "fundamentals" and "expectations" components of sovereign spreads in empirical studies.

In spite of widely different empirical techniques used in the literature, broad consensus has emerged on the following: Firstly, since the formation of the EMU, EMU spreads exhibited a decline and relative undershooting with respect to their fundamentals during the period up to 2007. Thus, for the period prior to the crisis, self-fulfilling market expectations functioned in the opposite direction to the crisis period, leading to an undershooting of spreads with respect to the value that ought to have prevailed based on fundamentals. Arghyrou and Kontonikas (2012) argue that market mispricing of fundamentals occurred due to a "convergence trading hypothesis" according to which investors flocked to periphery bonds in the expectation that the fundamentals of these economies would gradually converge to those of Germany. Increased demand for such bonds proved to be self-fulfilling as it led to the decrease in spreads, even in periods when fundamentals in the periphery deteriorated. In contrast, following the eruption of the US financial crisis, spreads overshot their fundamentals for most euro-area countries. During this period, sovereign risk appears to interact more intensely with global factors, the perception of international risk and contagion. After the spring of 2009, the official ignition of the euro-area debt crisis, was marked by an increased importance for fiscal factors. Investors differentiated between fiscally sound countries and the heavily indebted periphery, overreacting to developments in the fundamentals in the periphery, while a 'flight-to-safety' was demonstrated with respect to core countries.

Due to their direct interest in the effects of the US financial crisis for the euro area, Schuknecht et al. (2012) explicitly ask whether financial market reactions of government debt are in line with model-incorporated debt profile characteristics and fiscal fundamentals. They find that prior to and during the crisis period, euro area spreads were largely consistent with model fundamentals, whereas after September 2008, markets penalized fiscal imbalances more heavily by requiring a higher spread compared to that justified by fundamentals.

Aizenmann et al. (2011) conclude that fundamentals may explain a substantial portion of credit default risk but that "a large component is unpredicted" (Aizenmann et al. (2011)). They attribute this large component to market sentiment, which "follows waves of contagion, overreacting and mispricing the risk of sovereign default" while also noting that the CDS market follows both current fundamentals and expectations of future fundamentals. Di Cesare et al. (2012) construct "fundamental-adjusted" CDS premia and compare them against actual CDS premia to decipher whether CDS premia were driven by other factors.[80]

Similarly, Haugh et al. (2009) conclude that their equations "do not fully explain recent movements in spreads and some mysteries remain", as their model undershoots the increase in Greek spreads in the runup to the crisis and overpredicts French market reactions to fundamentals. They suggest that *information asymmetries* may be more important for the understanding of market reactions for smaller

[80] Di Cesare et al. (2012) proceed in three steps: first, they regress sovereign bonds spreads against sovereign CDS; second, they obtain an estimate of sovereign CDS premia, following Aizenman et al. (2011) estimates of CDS premia; thirdly, they compute fundamental-adjusted bond spreads by repeating the first step and replacing actual sovereign CDS against their fundamental-adjusted values.

countries, such that additional terms regarding the exposure to the financial sector, interest-rate level effects and additional liquidity variables may be required.

In contrast to findings of other papers in this review, Borgy et al. (2011) claim that changes in spreads are not driven by self-fulfilling expectations but instead may be fully accounted for by fundamentals. They find that the first round in the widening of euro-area spreads after the collapse of Lehman Brothers in 2008 was largely synchronized while the period of 2010-2012 was accompanied by wide differentiation, which may be attributed to differences in national fiscal policies and government budget soundness. However, Borgy et al. (2011) caution that they may erroneously be led to the conclusion against the presence of self-fulfilling expectations due to their model's initial explicit exclusion of 'snowball effects' and multiple equilibria, which effectively serves to ex ante rule out feedback effects between interest rates and the level of debt.[81] While model simplicity is critical, the initial assumptions of no snowballing by Borgy et al. (2011) may underlie their conclusion of a lack of animal spirits in financial markets' pricing of sovereign risk.

De Grauwe and Ji (2012) enumerate the following features as evidence of market sentiments turning against a country: i. dramatic changes in the level of spreads concentrated in small periods of time; ii. such changes either cannot be accounted for in total by fundamentals or appear to be disconnected to the evolution of fundamentals; iii. changes in spreads appear in clusters over time. They adopt an alternative method of detecting market sentiment: They omit market-related explanatory variables and instead seek to *capture animal spirits via time-dummies and the fraction of the variance in the model that is not explained by fundamentals.* They use *variance decomposition* to detect the relative importance of fundamentals versus this time-dependent market sentiment. They find that for Portugal and Ireland, the evolution in spreads is determined equally by the sum of fundamentals and equally by time-dummies (market sentiment). In Spain, most of the variance is explained by market sentiment. Similarly, market sentiment explains most of the surge in spreads for Belgium and Italy. In Greece, 70% of the variance is explained by worsening fiscal and macroeconomic fundamentals, while only

[81] The importance of the interest-rate feedback effect has acquired increased prominence in international discussions on debt sustainability analysis. Laubach (2009) provides one of the most widely applied rules for the forecasting of interest rates based on the level of debt-to-GDP.

30% of the variance is due to time dummies (market sentiment). In light of the above, De Grauwe and Ji (2012) suggest that, in addition to Greece, Spain (and potentially Italy and Belgium), could be also facing market dynamics that could lead into a bad equilibrium. De Grauwe and Ji (2012) argue that such phenomena render the role of a lender-of-last resort critical.

In Gibson et al. (2012), the deviation of Greek sovereign spreads from their fundamentals-based level is examined by decomposing the Greek government bond yield into a component which is justified based on market information (against the German Bund yield) and an 'irrational component', which is subsequently proxied via the effect of dummy variables corresponding to the dates of major sovereign credit ratings downgrades[82] for the Greek sovereign. They find that over the course of the S&P downgrade of Greece from A+ to A (14/01/2009-8/12/2009) and from A to BBB+ (8/12/2009-end of sample in 2010), an additional 'irrational' component is statistically significant for Greek sovereign risk. Gibson et al. (2012) conclude that the spread changed by more than would have been explained by the downgrades.

Csonto and Ivaschenko (2013)[83] distinguish between country-specific fundamentals and global financial market factors[84] via panel cointegration, repeated over distinct time samples and groups of countries. By applying panel cointegration to sovereign spreads, they find that in the long run, both country-specific fundamentals (proxied by composite indices of fundamentals)[85] and global market

[82] Gibson et al. (2012) include the following revisions as dummy variables in their model:
D1 (1/1/2000-4/11/2002) for the upgrade of the Greek debt from A2 to A1 by Moody's;
D2 (4/11/2002-16/12/2004) for the downgrade of Greek debt from A+ to A by Fitch;
D3 (14/01/2009-8/12/2009) for the downgrade of Greek debt from A+ to A by Standard & Poor's;
D4 (08/12/2009-end-period) for the downgrade of Greek debt from A to BBB+ by Standard & Poor's. (Gibson et al., 2012). They find that the coefficient of the first two events is not particularly significant but the latter to downgrades are important in explaining the risk premium on Greek government bonds. Using the Kalman filter and daily data, they find a large variance in the state equation and underscore the importance of time variation in the total risk premium (Gibson et al.,2012).

[83] As noted in previous sections, due to the importance of foreign-currency denominated debt, the determinants of sovereign spreads in Emerging Market economies are outside the scope of this study. However, due to the dearth of studies distinguishing between fundamentals and market-sentiment indicators with respect to sovereign spreads, this study is incorporated for methodological purposes.

[84] Global Factors include the VIX (proxy for global risk aversion) and the US fed funds rate (proxy for global liquidity conditions).

[85] The following broad *indicators of country-specific fundamentals* are used rather than explicit determinants of sovereign spreads: Economic Risk Rating; Financial Risk Rating; and an indicator of Political Risk Rating. *Economic Risk Rating* is an indicator extracted from the ICRG (International Country Risk Guide) database and is a "weighted rating of GDP per capita, real GDP growth, inflation, fiscal balance/GDP and the Current Account Balance to GDP" (Csonto and Ivaschenko, 2013). *Financial Risk Rating* is an indicator extracted from

sentiment (VIX and Fed Funds Rate as proxies of global risk and liquidity, respectively) are important in explaining sovereign risk dynamics; in the short-run, only global factors matter. Unlike the methodology applied in this chapter, both fundamentals and market sentiment factors enter the long-run equilibrium relationship with spreads.

Csonto and Ivaschenko (2013) define the degree of spreads misalignment with respect to fundamentals as the difference between actual and model-estimated sovereign spreads. Subsequently, they split the sample into seven periods based on key events that affected global risk aversion and calculate the long-run effect of fundamentals and market conditions, as well as the speed of adjustment, the size and the coefficient of short-run-related misalignment for each period. They find that higher short-run misalignment coincides with 'risk-off' (crisis) periods, whereas lower misalignment occurs during 'risk-on' (exuberance) times.

Beirne and Fratzscher (2013) study Advanced and Emerging Market Economies between 2000 and 2011 to distinguish between the effect of fundamentals and *contagion (a form of market-sentiment)* [86] on sovereign risk.[87] For European countries, Beirne and Fratzscher (2013) show that economic fundamentals[88] are not a good predictor of sovereign risk in the pre-crisis period yet perform better over 2008-2011. Therefore, during the pre-crisis era, market expectations may play a larger role in

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the ICRG (International Country Risk Guide) database and is a "weighted average rating of foreign debt/GDP, foreign debt service/exports, current account/exports, official reserves as months of imports and exchange rate stability" (Csonto and Ivaschenko, 2013). *Political Risk Rating* is an indicator extracted from the ICRG (International Country Risk Guide) database representing a "weighted rating of government stability, investment profile, internal and external conflict, corruption, military presence in politics, religious tensions, law and order tensions, democratic accountability and bureaucracy quality" (Csonto and Ivaschenko, 2013).

[86] "Contagion is defined as the *change* in the way countries' own fundamentals or other factors are priced during a crisis period, i.e. a change in the reaction of financial markets either in response to observable factors, such as changes in sovereign risk among neighbouring countries, or due to unobservables, such as herding behavior of market participants" (Beirne and Fratzscher, 2013).

[87] Beirne and Fratzscher (2013) study sovereign bond yield spreads, CDS spreads and sovereign credit ratings as proxies of sovereign risk. Although *contagion* among countries spreads and emerging market economy sovereign risk pricing is outside the scope of this chapter, this study is incorporated in this review as it distinguishes the pre-crisis and post-crisis contribution of fundamentals to sovereign spreads. In addition, the definition of contagion includes yet exceeds the scope of the definition of market-sentiment variables used in Chapter 4 of this thesis. In Beirne and Fratzscher (2013), contagion is defined to incorporate herding effects ("pure contagion") and regional effects ("regional contagion") over and above the change in investor pricing of the same fundamentals, the so-called 'wakeup call contagion' or 'fundamentals contagion' (Beirne and Fratzscher, 2013).

[88] Beirne and Fratzscher (2013) incorporate the following fundamentals: public-debt-to-GDP ratio, fiscal balance ratio, real GDP growth, the current account balance ratio. The common component (proxy for market sentiment) included is the VIX.

sovereign risk pricing for the panel of European countries. In contrast, they suggest that markets have overpriced Greek sovereign risk after the eruption of the debt crisis, suggesting a larger role for market sentiment during the Eurozone debt crisis. However, Beirne and Fratzscher (2013) caution against quantitative appreciations (in bps) of the degree of financial market mispricing, given the normative considerations involved in calculating the fair value of sovereign risk. As their methodology detects *the change in sovereign risk pricing behavior by financial markets*, the extent and the direction of the mispricing may not be clear.[89]

More recently, Godl and Kleinert (2016) explicitly probe into the distinction between fundamentals and market sentiment in interest rate spreads in the eurozone by applying a panel approach that seeks to bridge a compromise between long-run and very short-run effects, albeit in distinct stages of analysis. Godl and Kleinert (2016) incorporate variables which are relevant to long-run debt sustainability and the intertemporal budget constraint (primary balance ratio, gross government debt ratio, rate of economic growth), but also apply event study methods (very short-term event windows), which are relevant to the propagation of self-fulfilling crisis dynamics in debt capital markets (e.g. time dummies for rating downgrades and for major economic and political events). Despite estimating a model with the variables in first differences, Godl and Kleinert (2016) *explicitly avoid using cointegration techniques over a sample that covers the sovereign debt crisis, due to their belief that the crisis may not be "explained by slow-moving long-run determinants"* (Godl and Kleinert, 2016).

In a second step, they separately study the very short-run effect of market expectations via event study calculations of Cumulative Abnormal Returns on bond *yields* against a benchmark yield at various event dates across crisis countries. Event studies are used as a simple statistical tool to detect the effect of market overreaction of risk premia compared to fundamentals. In a third step, taking note of the critique by Gibson et al. (2012) on the inappropriateness of lower-frequency data when examining changes in spreads during crises, they use OLS regressions of *the change* in daily Greek spreads against three categories of news-events relevant to Greece: national policy news; ECB extraordinary

[89] The counter-factual analysis of Beirne and Fratzscher (2013) assumes the pre-crisis pricing behavior was correct and compares actual post-crisis pricing with that which would have been predicted using pre-crisis data.

policy announcements;[90] sovereign credit downgrades. In particular, Event Dummies are included to estimate the economic importance of the major events.[91] For Greece, they find evidence on the importance of fundamentals but also of country-specific *news events*, such as *changes in credit ratings*, but also of *political uncertainty* effects attributed to austerity measures in 2011, and less so, of positive effects by extraordinary actions of the ECB. Short-run effects and long-run effects are therefore not considered within a unifying model, as in this thesis. The distinction between short-run and long run effects is important in differentiating between solvency and liquidity.

In a recent discussion paper, Pamies et al. (2021) explicitly question whether differences in EMU sovereign spreads may be attributed to fundamentals and provide relevant evidence through alternative estimation techniques. Unlike previous panel data models, Pamies et al. (2021) cover the entire post-2010 (but pre-COVID-19) period. They distinguish fundamentals into macroeconomic, fiscal and institutional groupings and find that despite some country heterogeneity, EMU sovereign spreads are indeed determined by fundamentals. Special attention is devoted to the impact of government debt, which operates through potential growth or institutional quality, as well as through interactions with global risk aversion (Pamies et al., 2021).

Changes in market sentiment have been related to *news announcements, ratings agencies announcements or key fiscal events* and have been estimated via event study methods on sovereign spreads (MacKinlay, 1997), particularly in the literature that ensued from the eurozone debt crisis. In event studies, a short event window is selected around some key event capturing a positive or negative

[90] The extraordinary measures adopted by the ECB during the Eurozone crisis are interpreted to have had a double effect: On the one hand, they improved government solvency with respect to fiscal sustainability fundamentals, as they contributed to the reduction in the effective interest burden on troubled governments while also supporting national banking systems. On the other hand, ECB actions contributed to the easing of self-fulfilling expectations in prevention of bad equilibria in government bond markets (Godl and Kleinert, 2016).

[91] The following events are incorporated: economic forecast revisions by the European Commission; fiscal assistance news (including the announcement of bailouts); the announcement of austerity measures; ECB extraordinary measures (such as the announcement of the Securities and Markets Program (SMP) on May 9th 2010, the Long-Term Refinancing Options (LTRO) on December 8th 2011 and the Outright Monetary Transactions (OMT) in July 26, 2012); the Greek PSI as a single-day event on March 12, 2012; announcement of the European Commission of Excessive Deficit Procedures (EDP); political uncertainty via the dates corresponding to major public protests and difficulties in forming a government in May 2012; event dates relevant to ‘Troika’ reports; the announcement of a referendum on austerity measures in October 2011; the announcement of debt rescheduling on June 21st 2011; downgrades in credit-ratings (Godl and Kleinert, 2016).

news component (announcement of macroecononomic data, forecast revision of fiscal variable, a ratings change, the announcement of a fiscal bailout, the announcement of extraordinary monetary policy reaction, political news, etc.) which, in turn, is shown to be linked to the generation of a statistically significant cumulative abnormal return of the dependent variable compared to historical means. Studies of sovereign spreads in this line of research include, inter alia, Pastor and Veronesi (2013), Kelly et al. (2014), Godl and Kleinert (2016), Handler and Jankowitsch (2018) and more recently, Corradin et al. (2021) (see Chapter 2.2). Relevant studies either incorporate time dummies into regression or calculate the statistical significance of event dates associated with news announcements that are related to fundamentals and induce very short-run effects on market expectations. Therefore, depending on the specification, control variables may include *changes in ratings*, *political uncertainty* measures (EPU)/policy changes/policy summits, *changes in trading activity* (Handler and Jankowitsch, 2018). Such determinants of sovereign spreads are broadly deemed to be short run (Godl and Kleinert, 2016).

The role of expectations has therefore been linked to the distinction between *short-run and long-run determinants* of sovereign spreads, and the associated econometric techniques used.[92] For example, error-correction specifications are applied to capture long-run relationships. Cumulative effects do not matter if agents reverse their expectations such that expectations sum to zero; in contrast, cumulative effects are important if they persistently act in one direction. The distinction between short-run and long-run determinants will be pursued in this thesis, yet an alternative technique (CGARCH) will be followed.

Closely related to the literature on the determinants of government bond yield spreads, an additional interesting question, which also underscores the conceptual complexity of the topic, is whether an overreaction or underreaction of fundamentals is defined to be in line with so-called *'market discipline'*. A broad definition of market discipline relates to the correction of deviations on either side back towards some equilibrium relationship for sovereign spreads consistent with fundamentals.

[92] For example, Poghosyan et al. (2012) devote their study of long-term interest rates to the distinction between short-run and long-run determinants and apply Error Correction methods to a panel of OECD countries.

Alternatively, a narrower definition refers to the market penalization of macroeconomic and fiscal imbalances via the imposition of higher sovereign risk spreads, and thus a higher cost for the sovereign to refinance its debt. This second line of interpretation is asymmetric and is silent on the rewarding of a lack of imbalances, which seem to be taken for granted. There exists a relative scarcity in papers focusing on market pricing of sovereign spreads and market discipline, in spite of the broader discussion on the limits to rationality in financial market and related topics in behavioural finance or the debate on the merits of capitalism. One notable exception relates to Cohen and Portes (2004), who however examine the origin of crises in emerging and low-income economies'[93], and who argue that higher interest rates charged by financial markets on highly indebted sovereigns may push the sovereign into the bad equilibrium through the debt snowball effect, as market discipline has a destabilizing effect on sovereign debt dynamics.

Favero and Missale (2011) probe into the *disciplining role of financial markets* with respect to fiscal fundamentals in the Eurozone. They find that fiscal fundamentals are significant in the pricing of sovereign yield spreads only after accounting for interactions with spreads of other countries. They point to a "discontinuity in the disciplinary role of financial markets": If market sentiment is driven by contagion and factors other than fiscal fundamentals for a period longer than the country can remain solvent, yield spreads appear to be a weaker disciplining device.

Market discipline may be given an alternative interpretation to the two-fold explanation above, based on which it is equated with the sensitivity of markets to public finance outcomes (Attinasi et al.,2009). According to this view, an overreaction of spreads to fundamentals is in line with market discipline, yet an underreaction is not. This position does not define market discipline as the absolute difference between actual market reactions and those that would have been expected based on fundamentals. Instead, the implied market discipline focuses on the debt-servicing costs imposed by higher yields, such that any overreaction will increase the burden for a government's budget, forcing the

[93] Cohen and Portes (2004) do not examine the determinants of sovereign spreads. Instead, they look into the origins of debt crises through the increase in the debt-to-GDP ratio and distinguish the following: crisis of confidence (spreads and currency crisis); crisis of economic policy (primary deficit), crisis of fundamentals (real growth rate). As a precaution against the potential push of market discipline into a confidence crisis, they suggest the automatic availability of contingent credit lines by the IMF (e.g. The Contingent Credit Line CCL).

government to consolidate. As such, this reading of 'market discipline' may implicitly reward procyclical fiscal policies which are unduly restrictive for public investment, as demonstrated in the 'safer' Northern European countries; at the same time, it may be rewarding procyclical policies by profligate governments during times of higher growth, as occurred with the spend-thrift Southern periphery of the EMU, leading to the ignition of the euro area debt crisis. Hence, this asymmetric interpretation of the fiscal disciplining role of markets calls for asymmetric techniques in the study of government bond yield dynamics, on which the literature has been silent.

For sovereign spreads, as with the literature on financial markets mispricing (rational bubbles), evidence of deviations of sovereign bond pricing from their fundamentals-justified price may be linked to *skepticism about the efficiency of markets*, in line with Eichengreen and Mody (2000).

2.3.3. Long-Run Determinants of Government Bond Yield Spreads

Empirically, the concept of long-run equilibrium among variables relates to cointegration techniques. The literature applying cointegration to sovereign spreads is limited, potentially due to the nature of the dependent variable, the sovereign spread, which is a financial metric (and thus market-driven and higher frequency) against macroeconomic and fiscal measures (usually available at quarterly or annual frequency, and only implicitly affected by expectations). In addition, for EMU member states, the implicit assumption under the common currency is that long-term interest rates will converge such that the sovereign spread should be zero. Due to EMU membership and the common currency, expected depreciation is zero. As such, based on the Uncovered Interest Parity, the spread between long-term interest rates should also be zero, over the long-term.[94] Nevertheless, noting the deviation of sovereign spreads from their fundamentals-based values, a limited number of studies have proceeded in applying Error Correction methods to sovereign spreads.

In contrast, cointegration techniques have been applied in multiple studies of fiscal and debt sustainability (see Prohl and Schneider, 2006). The following two studies of sovereign spreads in the

[94] The appendix in De Grauwe and Ji (2012) shows that panel cointegration is rejected for the panel of EMU countries, variables and time-period considered.

EMU are most relevant: Gibson et al. (2012) and Csonto and Ivaschenko (2013),[95] none of which, however, makes any association to the long-run equilibrium dynamics of sovereign debt.

Gibson et al. (2012) study the early period of Greece's EMU membership and early crisis years to develop a cointegrated VAR for the investigation of the long-run determinants of Greek sovereign spreads. In the long run, Greek sovereign spreads are determined by economic activity, relative prices, a cumulative fiscal news indicator constructed based on European Commission forecast revisions, and oil prices, as a measure of the Greek economy dependence on energy imports (Gibson et al., 2012). In a separate equation, Gibson et al. (2012) find evidence of substantial undershooting of fundamentals between the end of 2004 up to mid-2005, and of overshooting after May 2010. However, the selection of fundamentals and literature review of this study of the pre-crisis and early crisis period for Greece is based on external imbalances and determinants of sovereign risk in Emerging Market economies.

In contrast to the cointegrating framework of Gibson et al. (2012), Godl and Kleinert (2016) do not apply a technique that explicitly distinguishes between short-run and long-run determinants of sovereign spreads, nor do they solely focus on Greek sovereign spreads. Instead, the choice of determinants of spreads incorporated in their model reflects the variables in the equation of the intertemporal government budget constraint (see Chapter 2.1), with the sovereign spread included in lieu of the risk-free rate. Explicit reference and derivation of the intertemporal government budget constraint (see Chapter 2.1) is made to validate the selection of fundamentals to be included in the model, given the plethora of determinants detected in empirical literature.

More recently, Pamies et al. (2021) estimate an error correction model (ECM) for a panel of EMU countries and find that over the long-term sovereign spreads are determined by the Net International Investment Position (NIIP), the government debt-to-GDP ratio, government effectiveness, country

[95] The application of cointegration by Csonto and Ivaschenko (2013) is not covered in detail in this chapter, as it is not specific to the EMU and opts for a different classification of fundamentals (using indices rather than variables) and makes use of indicators of country-specific fundamentals, risk and political uncertainty and global financial market conditions as long-run determinants of spreads.

size (a proxy of liquidity) and a crisis dummy. However, cointegration is only applied as an additional technique to other estimation in levels, to address non-stationary behavior of the series.

2.4. Evaluation of the Literature

This literature review has exposed the various measures of debt sustainability and the cost-benefit analysis implicitly applied by governments and financial markets, as relevant for sovereign default. Theoretical models related to multiple equilibria for sovereign debt and for short-run self-fulfilling liquidity effects have been presented to provide a contextual background of the theory that explains debt crises which emerge upon the inability of a government to roll over its debt. The source of such crises has been related to market expectations, which in turn affect the borrowing costs of the government through the risk premium charged. In the context of the EMU, the appropriate metric for the probability of sovereign default is the sovereign spread. Therefore, the literature on the determinants of sovereign spreads has also been evaluated. A separate section has elaborated on changes in such determinants over time and on the state-contingent properties therein. However, both in the theoretical and in the empirical literature, no explicit focus has been placed on the mechanism through which financial markets revise their expectations of sovereign default thresholds leading to jumps across a good and a bad equilibrium. A focus on the role of uncertainty is also absent in relevant literature. This will be addressed in subsequent chapters of this thesis.

Theoretical models of multiple equilibria have related the emergence of self-fulfilling crises to multiple sources, yet such models have predominantly *focused on the domestic fiscal calculus* that leads to sovereign default. These models *fail to account for the impact of uncertainty on self-fulfilling debt crises*, except for occasional inclusions of a random variable as a proxy for the impact of sunspots. Even when confidence shocks are accounted for, *models fail to provide a precise mechanism of the process via which uncertainty affects market confidence* and of the mechanism through which changes in market sentiment affect the outcome within some zone of multiple equilibria. Chapter 3 of this thesis will seek to fill this void by suggesting the innovative application of the most prominent critique of the multiplicity of outcomes in currency crisis models, which explains how, among multiple outcomes, uncertainty can induce a unique bad equilibrium. The equilibrium outcome will thus be made contingent on uncertainty and on a 'maximum sustainable interest rate', thus preserving a link to Calvo's (1988) interest rate caps suggestion. The theoretical model will shed light on the process of financial market belief formation with respect to sovereign risk pricing and will relate the effect of self-fulfilling expectations to definitions of uncertainty, liquidity effects and random shocks. To this purpose, insights from the niche currency crisis model of Morris and Shin (1998a) will be drawn. Similarly, the empirical literature has incorporated proxies of risk aversion or political uncertainty, yet n*o link has been developed between such metrics and regime changes for the sovereign spread.*

This thesis seeks to remedy the following additional limitations of the extant *empirical* literature on the determinants of sovereign spreads: ubiquitous use of a panel-based approach; scarcity of models on Greek government bond yield spreads; a lack of consensus on the definition and empirical strategy to determine 'animal spirits'; a consistent method to decipher short-run expectations-relevant and uncertainty-induced sovereign risk dynamics from long-run market-sentiment; a lack of consensus on the modelling of regime switches in the determinants of spreads; a neglect of asymmetric state-contingent effects on spreads by market expectations; no empirical incorporation of uncertainty, other than in event-studies; little control for the effect of monetary policy reactions to the Eurozone crisis.

Although a plethora of factors have been examined by the literature, the effect of uncertainty, has not explicitly been accounted for in models, other than event studies. Uncertainty has either been neglected or merely attributed to the portion of unexplained variance.[96] For instance, Poghosyan (2012) explicitly criticizes the limits to his model's explanatory power with respect to "difficult-to-quantify" variables, such as policy uncertainty.

Second, a dearth in time-series studies of *Greek* sovereign risk is noted, especially on the question of fundamentals versus expectations, with the exception of Gibson et al. (2012). This thesis provides

[96] Handler and Jankowitsch (2018) is a notable exception.

results on a time-series basis, while also covering the period from 1999 up to the end of 2020, which incorporates the entirety of the Greek sovereign debt crisis as well as the more recent COVID-19 pandemic crisis, in addition to the pre-crisis years. The contribution to the literature, in answer of the role of market-sentiment and uncertainty becomes apparent.

Third, a model of the determinants of Greek sovereign spreads which provides a good fit to actual sovereign spreads over the course of the aforementioned entire turbulent period is to our knowledge lacking on a time-series basis. The estimated model in Chapter 4 fills this void.

Fourth, deficient emphasis has been placed on the distinction between short-term and long-term market-sentiment effects on sovereign risk, especially for Greece. Chapter 4 applies CGARCH-M methods used in financial returns and currency crisis models literature to this end.

Fifth, taking note of the assertion in the literature that debt sustainability is a 'gray area'-more of a composite judgement than a scientific answer-and of the lack of an appropriate real-world probability of default metric for Greece, [97] Greek fundamentals seem to have stood in an intermediate zone between default and debt sustainability. However, to this date, apart from accounts related to the historical imbalances that led to the onset of the Greek debt crisis, no study has elaborated on the market-sentiment versus fundamentals question that links Greek sovereign spreads to crisis regimes. Chapter 3 and 4 seek to distinguish between two overarching regimes- a "good" and a "bad" outcome- and to establish an empirical explanation for the variables that can explain the difference between the two regimes.

Sixth, little reference has been made to the impact on Greek sovereign spreads of the extraordinary reaction of the ECB to the Eurozone debt crisis- except for recent event studies, and for Pamies et al. (2021) and Afonso et al. (2018) who, however, apply panel data. Chapter 4 seeks to remedy this

[97] The Greek government defaulted on its debt only once, though partially, during the Greek PSI in 2012. In addition, it has been excluded from financial markets and has contracted official loans, yet an explicit and meaningful probability variable linked to full-default instances is difficult to construct. The sovereign spread is therefore a more appropriate choice for the study of this twenty-year period.

answer by providing a time-series Greek-specific answer to the impact of the expansion of the ECB's balance sheet, and particularly securities held for monetary purposes, on the Greek sovereign spread.

Seventh, no explicit test has been performed for the impact of the following key events on Greek sovereign spreads: the 2009 revelation of the true size of the Greek budget deficit; the downgrade of Greece into Selective Default status prior to the PSI in 2012; the election of a left-wing party in 2015; the announcement of the Greek referendum in 2015; and the announcement of a COVID-19-induced general lockdown in 2020. The event study in Chapter 4 will fill this void, while also examining the impact of the credit rating downgrade of the Greek government into selective default in 2012.

Eighth, the literature has failed to establish a connection between the public policy literature on state-contingent debt and state-contingent sovereign risk. Instead, ex-ante solutions to debt crises are often constrained to liquidity-enhancing measures. This thesis questions whether GDP-linked bonds that provide insurance against uncertain economic growth outcomes may prove beneficial for cases in which the underlying fundamentals reside in a questionable 'gray' intermediate zone with respect to debt sustainability. To date, no historical counterfactual of Greek debt as in 2010, prior to the first bailout loan, has been offered with GDP-linked bonds.

Last but not least, the following additional limitations are noted, yet are not resolved in this thesis:

The literature also cautions that the massive expansion of implicit or explicit contingent fiscal liabilities (e.g. guarantees to the banking sector) has rendered the explanatory power of traditional fiscal measures relatively weak, as these guarantees are typically not included in debts or deficits, yet they affect the level of interest rates (Attinasi et al., 2009; Ejsing and Lemke, 2009; Laubach, 2011). As such, empirical research may be redirected to the role of changes in the so-called SFA (stock-flow adjustment)[98] of public debt on sovereign spreads.

To date, and to the best of our knowledge,[99] no study of sovereign spreads has explicitly accounted for the role of SFA on the determination of sovereign yields, even though specific components which

[98] Seiferling (2013) provides an extensive analysis of the Stock Flow Adjustment (SFA) term.
[99] Bernoth and Wolff (2008) and von Hagen and Wolff (2006) are among the very scarce studies of the increase in yields induced by the presence of a stock-flow adjustment term. Afonso and Jalles (2019) are singled out for

may enter the SFA (such as pension-related expenditure) may have been controlled for occasionally. Instead, the effect of the SFA is shown in variance decomposition studies of the evolution of the debt dynamics, pitted against the interest-growth differential. However, the low-frequency and small number of SFA reported data against the high-frequency of sovereign yields generates an additional difficulty in the study of this factor. As the quantity of data increases, future research could address this point.

their panel approach to the effect of stock flow adjustment terms on sovereign debt dynamics, but the focus is on the effect of the public debt ratio. Similarly, Weber (2012) shows the impact of the SFA term to changes in public debt in a panel of Advanced, Emerging and Low-Income countries.

Appendix 2.1: Brief Overview of Debt Threshold Rules for Debt Sustainability

Bohn (1998)

In a seminal paper, Bohn (1998,2005) introduced *'fiscal reaction' tests to debt sustainability*. In a general equilibrium setup, debt sustainability is tested using the following single equation model of the conditional response of the primary balance to the level of the debt ratio:

$$pb_t = \beta_0 + \beta_1 \breve{g}_t + \beta_2 \breve{y}_t + \rho d_{t-1} + \varepsilon_t \qquad \textit{(A2.1)}$$

where pb_t is the primary balance at time t, $\breve{g}_t$ is transitory variation in government expenditure, $\breve{y}_t$ is transitory variations in output and d_{t-1} represents the previous-period debt ratio (Debrun et al.,2019b). According to this setup, the sufficient condition for sustainability is that the coefficient of previous-period debt is greater than zero (ρ>0), such that the primary balance reacts to increases in the debt ratio (Debrun et al.,2019b).

The Bartolini and Cottarelli (1994) Condition for Debt Sustainability

The coefficient of the debt ratio in the primary balance reaction function should be larger than the product of the steady-state of growth-adjusted interest rate times a metric of the "non-persistence" of the primary balance ratio:

ρ>Γ*(1-λ),[100] (A2.2)

(Debrun et al.,2019b).

[100] This condition is derived based on the following equations:

$$\Delta d_t = d_t - d_{t-1} = \Gamma_t d_{t-1} - pb_t,$$

$$\Gamma_t = \frac{r_t - \gamma_t}{1 + \gamma_t}$$

and

$$pb_t = \kappa + \lambda pb_{t-1} + \rho d_{t-1}$$

where the primary balance displays persistence ($0 < \lambda < 1$) and ρ is the policy response to changes in the public debt ratio and κ is a constant (Debrun et al., 2019).

This condition is stricter than the conventional rule for debt sustainability, which requires that Γ*>0 (Debrun et al., 2019b).

The criterion in the equation above (ρ>Γ*(1-λ)) is also stricter than Bohn's requirement that ρ>0, as it requires that the debt-stabilizing reaction of the primary balance more than offsets the debt-snowballing effect induced by increasing interest rates (debt snowball effect) (Debrun et al., 2019b).

According to this criterion of debt sustainability, both debt-snowballing and fiscal fatigue are incorporated and the long-run steady state of public debt d* is therefore computed as follows:

$$d^*=\frac{-k}{\rho-\gamma^*(1-\lambda)} \tag{A2.3}$$

(Debrun et al., 2019b).

This long-run steady state of public debt depends mostly on the reaction and limits (fiscal fatigue) of the primary balance, which in turn displays an upper bound as follows:

$$pb_t = \min\left(\kappa + \lambda pb_{t-1} + \rho d_t, \overline{pb}\right) \tag{A2.4}$$

Debt sustainability, therefore, requires that the primary balance lies below this fiscal fatigue limit ($pb_t \leq \overline{pb}$), such that convergence to the steady state of debt is enabled, when government debt is on an increasing path (Debrun et al., 2019b).

Appendix 2.2: Cash-in-Advance Contracts

Upon challenging the 'reputational approach', Bulow and Rogoff (1988) show how 'cash-in advance' contracts, whereby the sovereign makes an upfront payment A_t (the purchase of the contract or asset) in return for a stream of state-contingent payments in the future, with an expected value equal to $E_t \sum_{s=t}^{\infty} \frac{P(\varepsilon_s)}{(1+r)^{s-t}}$, may limit the deterrent effects of direct costs upon default. In fact, insurance against bad states is achieved if the state-contingent payoffs of the asset are negatively correlated with the sovereign's income (Drazen, 2002).

According to this framework, to ensure solvency, the expected present value of future debt service must be lower than the expected present value of the future income stream, namely:

$$E_t \sum_{s=t}^{\infty} \frac{P(\varepsilon_s)}{(1+r)^{s-t}} \leq \kappa * E_t \sum_{s=t}^{\infty} \frac{y(\varepsilon_s)}{(1+r)^{s-t}}, \quad \text{(A2.5)}$$

$$\text{or } D_t \leq \text{k } W_t \quad \text{(A2.6)}$$

where 0≤κ≤1, $P(\varepsilon_s)$correspond to future payments, D_t corresponds to future debt service, and $W_t$is the expected discounted stream of future income (Drazen, 2002).

The risk-neutral investor will require the zero expected profit condition to hold:

$$E_t(P_{t+1}(\varepsilon_{\tau+1})) = (1 + \text{r})A_t, \quad \text{(A2.7)}$$

where $A_t$is a cash-in-advance contract (Drazen, 2002).

In addition, by the definition of the cash-in-advance contract, future payments to the sovereign must be positive:

$$(P_{t+1}(\varepsilon_{t+1})) \geq 0 \text{ for every } \varepsilon_{t+1} \quad \text{(A2.8)}$$

(Drazen, 2002).

Under this setup there will always exist states of nature which are sufficiently good as to induce default (Drazen, 2002). This could occur at some state s, whereby although debt service is lower than the expected discounted stream of income ($D_s \leq$k W_s), it may be higher than the expected discounted stream of income minus the current period income shock $D_s \geq \kappa(W_s - y_s)$ (Drazen, 2002). The sovereign would be better off reneging on debt service and instead using these funds to purchase a sequence of cash-in-advance contracts: $A_t(\varepsilon_s) = P(\varepsilon_s) + \kappa(W_s - y_s)$- D_s using the reneged payment as initial collateral (Drazen, 2002).[101] Therefore, the reputational approach does not ensure a no-default equilibrium.

[101] Drazen (2002) therefore distinguishes between the effects of losing access to capital markets for new debt issuances against a complete loss of market access, whereby the sovereign is not allowed to lend either (financial autarky).

Appendix 2.3: Modelling the Cost of Sovereign Default

When modelling the costs of sovereign default, the standard assumption is that default costs increase with the economy's output or capital stock. This implies that default is more costly during good states of nature, such that incentives between creditors and the borrowing sovereign are aligned.

The effect of direct costs is to discourage default by increasing the level of sustainable debt in equilibrium and reducing the risk premium. In good states of nature, when output (y_t) is high and, thus, costs of default $L^d(y_t)$ are high, direct costs contribute to debt repayment. The following generic formula corresponds to the loss function associated with default costs: [102]

$$L^d(y_t) = \max\{0, a_0 + a_1 y_t + a_2 y_t^2\} \quad \text{(A2.9)}$$

For example, Arellano (2008), setting $a_0 = -\bar{y},\ a_1 = 1$ and $a_2 = 0$, assumes that in bad states of nature, the economy will lose endowment above a threshold $\bar{y}$, according to the following:

$$y_t - L(y_t) = y_t, if\ y_t < \bar{y} \quad \text{(A2.10a)}$$

$$y_t - L(y_t) = \bar{y}\ if\ y_t, \geq \bar{y} \quad \text{(A2.10b)}$$

Arellano (2008) suggests the use of an asymmetric default cost, as defaults during good times are proportionately more costly. Similarly, Aguiar and Gopinath (2006) and Hatchondo et al. (2007) assume that default costs are some linear proportion (λ) of output: $L^d(y) = \lambda y$.

Chatterjee and Eyigungor (2012), instead prefer the quadratic specification, which can be modelled by setting $a_0 = 0$, $a_1 < 0$ and $a_2 < 0$. The quadratic default cost function is shown to match the spread in equilibrium:

$$L^d(y) = a_1 y + a_2 y^2 \quad \text{(A2.11)}$$

Mendoza and Yue (2012) also opt for the quadratic formulation in a model of endogenous default cost.

[102] $L(y_t)$ represent a positive and non-decreasing function loss function associated with the output costs upon default.

Following Bianchi et al. (2012), the output loss following a sudden stop is assumed to be a fraction (λ) of the income loss after default:

$$L^s(y) = \lambda L^d(y) \qquad \text{(A2.12)}$$

In an alternative formulation, Roch and Uhlig (2016) model the cost of default as an exogenous one-time utility cost χ_t directly modelled in the following utility maximization problem for the sovereign:

$$U = \sum_{t=0}^{\infty} \beta^t (u(c_t) - \chi_t \delta_t) \qquad \text{(A2.13)}$$

where β is the policy maker's discount factor, u(·) is a strictly increasing, strictly concave and twice differentiable felicity function and $\delta_t \in [0,1]$ is the decision to default in period t. This stochastic utility formulation is intended to "capture the non-pecuniary costs of defaults such as reputation costs and the role of political factors in sovereign default episodes" (Roch and Uhlig, 2016). [103]

In their acclaimed model of self-fulfilling crises, Cole and Kehoe (2000) model default costs via a drop in productivity. They assume that default induces a fall in productivity (from a level of α_t=1 to some α_t<1 from t onwards, in addition to the loss of market access (Cole and Kehoe, 2000)). The productivity costs of default may be temporary or permanent. When the exogenous real cost of default is assumed to be temporary, the model allows for the government to reaccess capital markets even before returning to pre-crisis productivity levels (α=1).

Based on the Cole and Kehoe (2000) model, productivity declines via two mechanisms: Firstly, the drop in productivity occurs due to disruptions in international trade ('confiscation of goods in transit,' 'seizure of trade-related assets' and the 'loss of access to short-term trade credit from intermediaries') and their ensuing effect on output due to default. This occurs primarily via a reduction in imported inputs to production due to a cutoff from international credit to pay for such imports. Mendoza and

[103] This utility formulation has also been used in personal bankruptcy and mortgage default models, as well as in political economy models. The authors also state that they would have modelled the January 2015 Syriza election result in Greece as an election of a government which is more willing to take on the risk of default compared to previous governments, captured by an appropriate change in χ_t(Roch and Uhlig, 2016).

Yue (2012) follow this line of reasoning in their model, where foreign-produced intermediate goods are impeded by the sovereign's default due to the cutoff from international financial markets.

Secondly, default induces a reputation spillover effect on productivity which in turn induces an output loss. Unlike the standard reputational model assumption of default leading to a damage in the reputation to repay in international capital markets, default may also damage the government's reputation for paying government employees' wages. For this reason, the government's ability to hire workers declines and 'the level of valuable government input into private production is reduced' (Cole and Kehoe, 2000).

A central issue when modelling the cost of default relates to the length of time during which the costs of default are present, namely whether costs are assumed to be transitory or permanent. For example, Mendoza and Yue (2012) and Sosa-Padilla (2014) consider transitory costs, whereas Conesa and Kehoe (2017) suggest a permanent cost to be more appropriate. In quantitative models, mean-reverting properties may be useful to depict transitory costs. For this reason, AR(1) models are used in discrete time and Ornstein-Uhlenberg processes in continuous time.

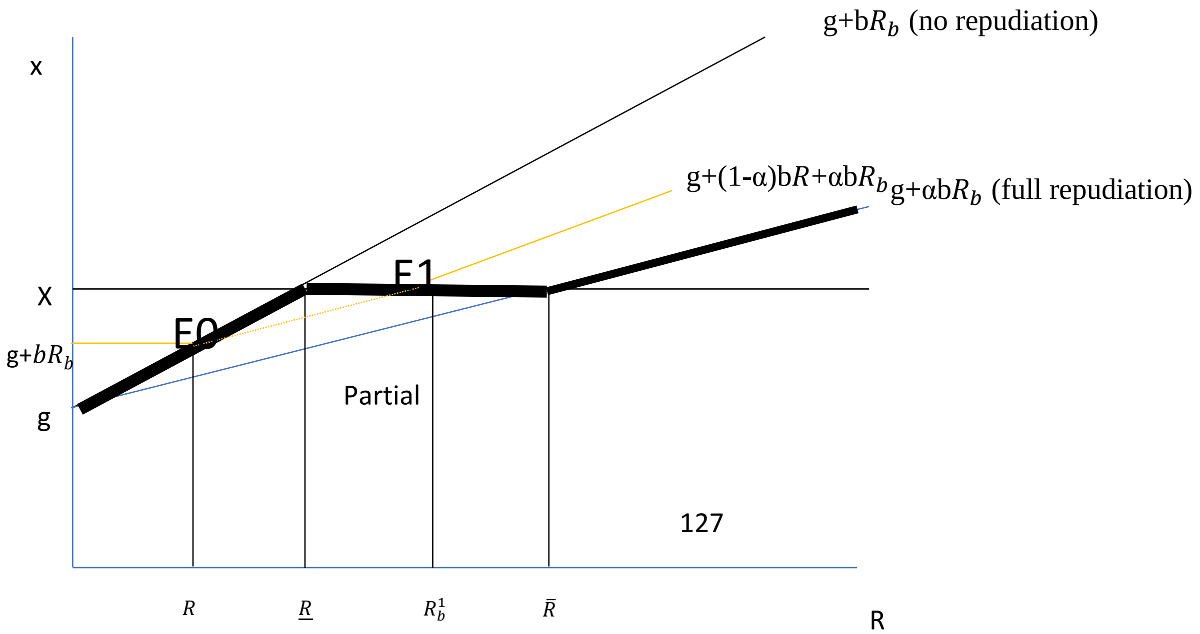
Appendix 2.4: Calvo's (1988) model

In Calvo's model, the government borrows b units of per capita output in period 0, with a grows interest factor R_b from identical consumers/individuals. Thus, assuming a θ percent of bonds will be repudiated, the net interest factor is defined as (1-θ) R_b. In period 1, the government either repays, or repudiates this debt. Consumers may accumulate physical capital under a constant net return R<1. Assuming perfect foresight, consumers should be indifferent between the two types of asset returns such that the two net interest factors should be equal: (1-θ) R_b=R.

Calvo (1988) defines a government budget constraint, in which taxes (x) must be equated to the sum of the interest expenditure (g) (assuming a percentage of non-repudiated debt 1-θ), exogenous government expenditure, and the costs of debt repudiation (αθbR_b) based on a percentage of per capita cost per unit of debt repudiated (α) (Calvo,1988). Assuming a deadweight cost of taxation z(x) which the 'benevolent' government tries to minimize while maximizing consumption in the second period, the government will set taxes based on a period-1 reaction function under debt repayment and a period-1 reaction function under no debt repayment (Calvo,1988). The government must thus select a level of taxes (x) between two straight lines: a line representing the sum of government expenditure plus repudiated debt cost on the one hand (i.e. financing needs upon repudiation) against a line that represents the sum of government expenditure plus non-repudiated debt costs (i.e. financing needs upon no repudiation) (Calvo,1988):

$$g+ab R_b \leq x \leq g+b R_b \qquad \text{(A2.14)}$$

Figure A2.1. Calvo (1988): Determination of government's reaction function in



Source: Calvo(1988)

Based on the chart, the government maintains an unconstrained maximum at x*, which occurs when the interest factor lies between a lower and upper bound ($\underline{R}$, $\bar{R}$) respectively (Calvo,1988). The heavy line depicts the set of best responses, or government reaction function in period 1, given some interest factor R_b(Calvo,1988).

For low interest rates (R≤ $\underline{R}$), debt repudiation is zero (θ=0). For high interest rates (R≥$\bar{R}$), the government repudiates all of its debt (θ=1). Therefore, optimal repudiation in period 1 is an increasing function of the interest rate in period 0 (Calvo,1988). Assuming perfect foresight at time 0 of the conditions at time 1 (ie predictions with certainty), Calvo (1988) defines the following consistency condition:

$$x = g + (1 - a)bR + abR_b \qquad \textit{(A2.15)}$$

which corresponds to the yellow line above. Equilibria are located at the points of intersection between the consistency condition and the government's period 1 best response at each interest factor contracted in period 0 (Calvo,1988).

At equilibrium E0, the interest factor on government debt is equal to the interest on capital R, such that there is no repudiation (Calvo,1988). The government's optimal response is such that it sets taxes as x=g+b R (Calvo,1988). Although the government would want to increase taxes towards x*, this would imply negative repudiation which is ruled out by assumption (Calvo,1988). Thus, at E0 there is no repudiation. E1 is also an equilibrium consistent with partial repudiation (Calvo,1988).

For taxes higher than x*, to the right of E1, there exists no equilibrium, as the consistency condition and government reaction function lines are parallel. Therefore, for R_b>R_b^1, there is no equilibrium (Calvo,1988).

Unique equilibrium occurs where x*=g+b R and R_b^1=R=$\underline{R}$ (Calvo,1988).

Therefore, two, zero and one equilibria are possible: for x*>g + b R two solutions exist: one consistent with no repudiation and one with partial repudiation in which the good equilibrium is always consistent with R, whereas in the bad equilibrium E1, Rb and θ depend on debt levels ; if x*< g + b R, there is no equilibrium; and if x*= g+b R, there exists a unique non-repudiating equilibrium (Calvo,1988).

Calvo (1988) suggest setting interest rate ceilings at R_b and refusing to sell bonds at interest rates above this level to ensure the unique equilibrium at R_b=R.

Chapter 3

A Theoretical Framework for Sovereign Debt Crisis and the Role of Uncertainty

3.1. Introduction

Highly indebted governments may repay their bonds in capital markets yet may also choose to default on their debts or be forced to do so, a decision which seems to be driven by deteriorating fundamentals and has also been linked to confidence crises in financial markets. As such, sovereign debt defaults have offered economists another topic to debate the importance of fundamentals against market expectations, particularly during so-called “self-fulfilling” crises.

Far from attempting to build a narrative of the process via which fundamentals may lead to government default, this chapter focuses on events close to the actual default crisis. Taking note of the well-known result of multiple equilibria in macroeconomics and relevant crisis models,[104] this chapter seeks to explain the mechanism via which a sovereign debt crisis (high sovereign risk) may be triggered. Thus, given some set of fundamentals, we look for the process via which the crisis equilibrium is selected among many.

Recent discussions in policy circles on the sustainability of Eurozone countries’ government debt have centered on the prevalence and effects of ‘uncertainty’. This focus has been warranted by the eruption of exogenous random shocks,[105] such as the COVID-19 crisis, or the pervasive economic policy uncertainty with respect to Grexit during the Greek PSI partial default event.

[104] Multiple equilibria models attained their status in macroeconomics due to the inability of other models to predict the onset of crises or to explain crises which appeared to be unrelated to the underlying economic fundamentals (Morris and Shin, 1998a).
[105] Such exogenous random shocks have always been considered by contract law under ‘force majeure’ clauses.

In the first section (section 3.3), a simple representation of government debt equilibria is portrayed as an explanation for fundamentals-based and expectations-driven equilibria. The application of the Jeanne and Masson (2000) framework, as in Bruneau et al. (2012, 2014) and Do Bernardo (2016) on sovereign debt shows how jumps across multiple stable and unstable equilibria may occur due to changes in fundamentals or expectations. The second section (section 3.4) elaborates on the role of expectation formation in financial markets by borrowing the game-theoretic concept of "higher order beliefs" by Morris and Shin (1998a), readapted from the context of currency crises to a debt crisis in a currency-union country. [106] The 'higher order beliefs' extension broadens the framework to show that when fundamentals lie in the indeterminate region, uncertainty is bound to lead to a unique self-fulfilling outcome. "Higher order uncertainty" has been suggested as an explanation for the behavior of debt capital markets during the spike in Greek government bond spreads shortly prior to the 2012 PSI. Such market behavior implicitly resurrects Keynes' (1936) newspaper "beauty contest" of stock-picking,[107] applied to government bond investments. The third section (section 3.5), follows Jeanne and Masson (2000) and Do Bernardo (2016) in shedding light on the multiplicity of debt equilibria under the impact of an extrinsic random shock, depicted via the concept of "sunspots".

The link and adaptation of two currency crisis models has been selected as a modelling framework for government debt crises due to the study of the timing of a very short-lived period, over the course of which official reported data on fundamentals cannot change by much. Thus, the focus of these models enables the concentration on the effects of market behavior and uncertainty on the crisis outcome, as a complement to the fiscal story that led up to the crisis. Unlike most government debt models, the simplifying one-time game setup used, implicitly allows for a focus on debt-servicing flows, a focus

[106] To date, only Bruneau et al. (2012) and do Bernardo (2016) have suggested this application.
[107] Keynes (1936) compared the pricing of financial markets to a newspaper competition to choose the six prettiest faces among one hundred photographs. The winning competitor would be the person to pick the picture which more closely represented the average preference among competitors, in addition to considering the prettiest face. Similarly, financial market participants should select stocks based on their belief about fundamentals but also using their belief about other participants' average expectation of fundamentals.

common with self-fulfilling debt crisis models and policymakers' emphasis on Gross Financing Needs (GFNs) in Debt Sustainability Analyses.[108]

The model presented in this section contributes to the literature in the following ways: First, it links two seminal papers on currency crises, the Jeanne and Masson (2000) escape clause model and Morris and Shin's (1998a) explanation of the onset of currency crises via the apparatus of higher order beliefs and reapplies their findings in a composite model of the onset of sovereign debt crises. Although Bruneau et al. (2012, 2014) and Do Bernardo (2016) apply Jeanne and Masson (2000) to sovereign debt, no extension along the lines of Morris and Shin (1998a) has been performed. [109] Second, the models used provide scope for a discussion on the role of uncertainty, which has been largely omitted from the majority of sovereign debt crisis studies and has become increasingly relevant. Third, this simple mechanism of sovereign debt crisis may be used to describe more recent events in the Eurozone, such as the Greek PSI or the effect of the early COVID-19-related uncertainty on government bond pricing, *ceteris paribus*. Lastly, the Morris and Shin (1998a) simple setup allows for some endogeneity in the setting of interest rates on government debt, which is critical to government debt dynamics.

This chapter is structured as follows: Section 3.2. provides an overview of related literature; Section 3.3 explains how multiple equilibria are possible for the government debt under common knowledge; Section 3.4 shows how the presence of noise leads to a uniquely bad equilibrium in sovereign debt; Section 3.5 displays the impact of sunspots on the multiplicity of oucomes; Section 3.6 provides concluding remarks.

[108] However, this chapter diverges from this latter strand in the literature, as it abstracts away from external debt dynamics or the behavior of the monetary authority, as typically encountered in relevant models, so as to dedicate its focus to market expectations with respect to fundamentals.

[109] To date, although a portion of the Jeanne and Masson (2000) model has been applied to sovereign debt crises by Bruneau et al. (2012) and do Bernardo (2016), the Morris and Shin (1998a) framework has never used in the context of government debt behaviour. Critically, although some link between the two papers has been suggested by Jeanne and Masson (2000), it has not been performed, for neither type of crisis. Hattori (2004) incorporates the higher order beliefs concept into sovereign debt rollover crises, yet applies a distinct setup, which is based on Morris and Shin (2001) and not on Morris and Shin (1998a), per se.

3.2. Related Literature

This chapter stands at the intersection of multiple equilibria models for sovereign debt crises and currency crises, focusing on the niche section of higher order beliefs to isolate the effects of informational structure as the source of multiple equilibria and of self-fulfilling crises. This line of literature proposes an additional explanation for the “solvent but illiquid” debtor, by applying a coordination failure similar to that of the Diamond and Dybvig (1983) bank run model (Chamon, 2004).

Self-fulfilling crises are distinguished from fundamentals-based crises, as in the latter it is a deterioration in fundamentals and a “sequence of bad productivity shocks” which usually render the debt unsustainable (Chamon, 2004). In contrast, the self-fulfilling literature emphasizes the role of expectations and beliefs propagation in financial markets. In this strand of literature, sovereign default arises due to a coordination failure among current investors or between current and future investors in government bonds, for which they expect a risk premium to be compensated for the coordination risk they face. Intertemporal coordination affects investor beliefs as follows: current investors expect future investors not to buy the country’s debt; the expectation of a future rollover crisis induces current investors not to lend to the country; hence, the initial expectations become self-fulfilling (Chamon, 2004).[110]

Self-fulfilling expectations were first introduced by Calvo (1988) who proved the non-uniqueness of equilibria for two-period domestic debt under a lack of fiscal policy commitment. The occurrence of a confidence crisis automatically induces a regime switch. In contrast, in a model with exchange-rate dynamics Giavazzi and Pagano (1989) add imperfect public information about the government’s preferences in a model where a crisis increases the probability of a regime shift (as opposed to Calvo’s certain regime shift). In this confidence crisis model, ‘sunspot-type beliefs’ induce a speculative attack. Factors that are associated with the probability of crisis include the level of debt outstanding, short average maturities and a concentration of maturities around certain dates. Similarly,

[110] A relevant simple model of sovereign debt crises is provided in Romer (2012, pp. 632-639).

Alesina et al. (1989) were the first to propose a “coordination failure among investors at different dates” (Chamon, 2004). Their model follows a tripartite classification of outcomes based on the deadweight cost of taxation, where two equilibria are possible: a default occurs in the first period or debt is rolled over and repaid in the second period. Cole and Kehoe (1996, 2000) propose an infinite horizon model in which a ‘crisis zone’ is defined beyond some threshold of debt, and in which the default outcome arises when the incidence of some random shock (sunspot) is sufficient to induce a rollover crisis. International investors are assumed to coordinate on this sunspot variable, demanding a risk premium for the probability of default and associated loss in their investment (Chamon, 2004). Maturity structure and the level of private capital stock are critical in addition to the level of debt outstanding. Detragiache (1996) extends the link of such expectations-based models to the real economy by proposing a model with endogenous output. As such, two channels may give rise to the multiplicity of outcomes and result in crisis: the effect of beliefs on debt-servicing costs and financial market disruption. Pessimistic investor expectations about future outcomes increase the risk premium required by bondholders, thereby increasing the debt-servicing burden on the government, precipitating a liquidity crisis via ‘surprise inflation’; alternatively, pessimistic investor beliefs may reduce the proceeds from a government bond sale, inducing the government to cut investment, which in turn, reduces output and imposes a strain on debt dynamics without having directly increased the cost of debt-servicing (Detragiache, 1996). Coordination failures in the presence of multiple small market players reinforce the liquidity crisis in this rational expectations framework (Detragiache, 1996). Chamon (2007) portrays sovereign default as a coordination failure between market participants and explicitly suggests a role for ‘higher order beliefs’(namely, beliefs of each market participant regarding the beliefs of other markets players to the nth order) as in Morris and Shin (1998a).

Chamon (2004) offers a concise review of the self-fulfilling debt crises literature, alongside solutions, such as contingent bids as a remedy for intertemporal investor coordination or state-contingent debt securities and maturity extensions to remedy the time-inconsistency of fiscal policy. Alternative sources of multiplicity in debt equilibria include “rollover multiplicity” (Cole and Kehoe, 2000); or, “Laffer-Curve Multiplicity” (Lorenzoni and Werning (2013, 2019)) whereby there are multiple equilibria for the maximum sustainable debt level. Aguiar and Amador (2013) provide an overview of more recent relevant models and policy solutions. More recently, Auclert and Rognlie (2016), prove the *uniqueness of equilibrium* under an Eaton-Gersovitz (1981)-type model for sovereign debt, and attribute the sources of multiplicity of outcomes in sovereign debt models to modelling assumptions: timing and commitment assumptions, the introduction of long-term debt, the assumption of low international interest rates.

The role of expectations is central in currency crisis models, such as the Jeanne and Masson (2000) ‘escape clause’ or ‘second generation’ approach to currency crises, which follows in the light of Obstfeld (1994) and Jeanne (1997). Jeanne and Masson (2000) is associated with the broad class of “second generation currency crises models”, in which both economic fundamentals and market expectations drive exchange rate dynamics, unlike the first-generation rationale (e.g. Krugman, (1979)) that crises are the outcome of deteriorated fundamentals only. Strategic complementarities in the behavior of financial markets are shown to lead to multiple equilibria and provide the link to the class of models used in this chapter.

Within the broad class of second-generation currency crises models, substantial controversy has arisen with respect to the number of possible equilibria (unique vs multiple), to which the time at which market expectations affect the policymaker’s decision-making (Jeanne and Masson, 2000). In his seminal paper, Krugman challenged the multiplicity of equilibria by showing that when expectations (of devaluation) are formed during a crisis, the outcome is unique. In response, Kehoe (1996) and Obstfeld (1996b) defended the multiplicity of equilibria when devaluation decisions are taken prior to the crisis. The Jeanne and Masson (2000) hybrid reduced form model offers a solution to the apparent puzzle via a “hybrid” reduced-form model of the above, in which both current and previous-period expectations affect outcomes (Jeanne and Masson, 2000). They suggest that although multiple equilibria are not the case with stochastic economic fundamentals or when fundamentals follow a deterministc trend as in Krugman (1996), an “arbitrarily large number of equilibria” is still possible due to the indeterminacy of financial market expectations (Jeanne and Masson, 2000).

While acknowledging the results of the above seminal papers, this chapter is based on a more niche literature which has focused on the role of informational asymmetries with respect to perceived fundamentals in the ignition of financial crises. Noting certain unexplained shifts of investor sentiment in financial markets, or the difficulty in fundamentals-based predictions of the timing of certain crises, this research focuses on speculative beliefs of multiple investors (as opposed to a single representative investor) in anticipation of a crisis. These models show how belief propagation under imprecise information, whether private or public, results in a coordination problem, which ultimately gives rise to a unique crisis or panic outcome. "Information structure" and "market characteristics" drive the multiplicity or uniqueness of outcomes (Hellwig et al.,2006). Investors update their beliefs about whether or not to invest in government bonds based on their expectations about other investors' actions and about their expectations of the state of fundamentals. Morris and Shin (1998a) pioneered this strand of research in macroeconomics for the modelling of self-fulfilling events, based on the game-theoretic results of Carlsson and Van Damme (1993). Morris and Shin (1998a) argue that the multiplicity of macroeconomic equilibria arises due to the simplifying assumption of common knowledge. In reality, common knowledge, as defined in Aumann (1976), never holds.[111] Failure of common knowledge occurs when agents "merely know each other's posteriors" (Aumann, 1976). Differences in posteriors may arise due to differences in subjective probabilities, even when these cannot be directly traced back to differences in information. Kahneman and Tversky (1974) use systematic biases or heuristics to explain the above. Morris and Shin (1998a) challenge that multiple equilibria models of self-fulfilling crises fail to provide an account for the shift in beliefs that sends the economy from one equilibrium to another.

In their first static model of self-fulfilling events, applied to currency crises, Morris and Shin (1998a) show how the breakdown of some imperfection (uncertainty) in the information signals received by financial markets may send the economy to the single crisis outcome. In their model, fundamentals

[111] "If two people have the same priors, and their posteriors for a given event A are common knowledge, then these posteriors must be equal…. In brief, people with the same set of priors *cannot agree to disagree*….When we say that an event is "common knowledge," we mean more than just that 1 knows it, 1 knows that 2 knows that 1 knows it, 2 knows that 1 knows it, and so on." (Aumann, 1976).

follow the multiple equilibria framework of tripartite classification and emphasis is placed in the intermediate 'ripe for attack' region, where the interplay of speculative beliefs and fundamentals leads to the devaluation outcome. Subsequently, Heinemann (2000) challenged the characterization of the equilibrium solution for the limiting case, where informational signal uncertainty approaches zero and presented a "Revised Theorem" for the relevant subsection, such that the switching thresholds are not independent of the critical mass of speculative attacks, even when uncertainty is close to zero. Morris and Shin (1998b) build a more elaborate dynamic continuous-time framework as a theory for the onset of a currency attack, in an attempt to resolve the "indeterminacy in the theory" of the shifts across equilibria. In their model, the actions of multiple diverse economic agents are mutually reinforcing and agents are well-informed about the state of fundamentals, albeit with small informational disparities. Uncertainty about fundamentals leads to some degree of 'indeterminacy in beliefs' which in turn removes the indeterminacy about the crisis outcome. This framework enables some correlation of the crisis outcome with deteriorated fundamentals, yet also shows how the probability of such an outcome increases more than proportionately to the deteriorated fundamentals.

Morris and Shin (2000) extend the discussion on the "indeterminacy in beliefs" to macroeconomic outcomes, noting that indeterminate beliefs leave a role for "sunspots". However, over and above sunspot-induced crises, shifts in beliefs preserve the correlation of outcomes with fundamentals.[112] In a bank-run model, they show how private and public signals received by depositors interact with the state of fundamentals, resulting in a bank run. Rey (2000), unconvinced by the uniqueness of equilibrium, counterargues that the number of equilibria in this setup depends on both relative precision and absolute precision of private and public information signals, which in reality is impossible to gauge. Atkeson (2000) also disputes the basis of the Morris and Shin (2000) argument in that asset prices in a dynamic market economy serve to coordinate the beliefs across heterogeneous agents. According to the Atkeson (2000) critique, market prices serve as public signals which dynamically incorporate all publicly available information. Essentially, this critique reformulates the

[112] In essence, higher order beliefs may substitute for the effect of sunspots in such models; however, the application of higher order beliefs differs from sunspots in that the former preserve a relationship with fundamentals, whereas the latter are assumed to be payoff irrelevant random shocks.

Efficient Market Hypothesis, which the Morris and Shin (2000) setup implicitly challenges, albeit under a rational expectations crisis equilibrium setup.

Using financial market asset pricing by risk averse, short-lived traders, Allen et al. (2003) show how even in a rational expectations model, market prices deviate from those prescribed by the martingale measure of asset pricing; the law of iterated expectations for average beliefs fails under asymmetric information. This failure of public signals in the presence of uncertainty suggests there is scope for a role for noisy private signals, which undergird the higher-order-beliefs crisis-outcome. The authors comment that the weight placed by market participants on the private signal is non-monotonic, as the shorter the timespan or time-to-maturity of a bond, the greater the weight on private signals. This occurs due to a lower number of "layers of average expectations", such that the agent's average forecast resembles increasingly more his own forecast of fundamentals in lieu of the iterated average expectations (Allen et al., 2003).

Naturally, the breakdown of the law of iterated expectations and the role of private beliefs about fundamentals and about the beliefs of others becomes even more pronounced with myopic traders. Tirole (1982) and De Long et al. (1990), among many, have related the myopic traders' forecasting of the beliefs of rational traders to the breakdown of backward induction and the formation of financial market bubbles. As such, the higher order beliefs argument in this line of research (and in this chapter) is bound to be robust and reinforced under a behavioral finance approach to government debt crises. However, as cautioned by Allen et al. (2003), irrationality is not a necessary condition for the higher order beliefs framework to be valid.

The most relevant paper to this chapter -apart from Jeanne and Masson (2000) and Morris and Shin (1998a) - is the application of Morris and Shin (2002b) to sovereign debt rollover crises by Hattori (2004). To the best of our knowledge, this is the only application of the 'higher order beliefs' concept to sovereign debt crises. Hattori's (2004) model is similar to this chapter in its market-based perspective and in its distinction between a case of common knowledge and a case of uncertainty for financial markets. Nevertheless, the application, methodology and insights are entirely different from this chapter, as Morris and Shin (2002b) differs substantially from Morris and Shin (1998a). For example, Hattori (2004) considers two types of investors in government bonds ("specialist" and "final investor"). In contrast, this chapter is not concerned with the actual auction dynamics between the government and primary dealers. Secondly, by applying Morris and Shin (2002b), the relative precision of distinct signals of fundamentals is considered in Hattori (2004), from which we abstract. Thirdly, Hattori (2004) parametrizes a loss function for the government, such that tax considerations enter the game, on which this chapter is agnostic due to the emphasis placed on market sentiment, given some set of fiscal fundamentals. More importantly, a global game setup is developed in Hattori (2004) and a distinction between short-term and long-term debt is the underlying focus, with the ensuing policy implication that an extension of maturities is required to flatten average repayment schedules, and, thus, reduce rollover risk. In contrast, this thesis prefers to abstract from debt management operations and the maturity structure of the sovereign debt profile, in order to isolate the state-contingencies associated with market sentiment and uncertainty. Lastly, unlike our application, Hattori (2004) includes cross-default among categories of sovereign debt and comments on the possibility for debt monetization. In contrast to the above, this chapter focuses solely on trading in secondary markets and abstracts from the government's internal calculus or debt management concerns, as currency union membership and the loss of monetary policy autonomy is the underlying assumption. Our simplifying setup is preferred as it explicitly characterizes two states, common knowledge and uncertainty, and their accompanying features, as most relevant for empirical estimation in the subsequent chapter.

More recently, currency crisis models in this literature have pondered over the role of interest rates, which is to be distinguished from the role of interest rates in this chapter, as we abstract from a consideration of currency effects and of monetary policy. By focusing on the information content of interest rates during currency crises, Tarashev (2003) further elaborates on the process of information aggregation via market prices, using an endogenous 'learning' relationship between private and public information ("endogenous public signal"). Tarashev's (2003) model enriches the analysis on the relative precision of private and public signals. Failure in common knowledge among market participants is generated via informational heterogeneity, as agents avail themselves of slightly perturbed non-identical information sets. The market provides a medium via which agents communicate their beliefs to the market and learn of others' beliefs.

Following the literature on global games and information aggregation (Angeletos et al., 2006; Angeletos and Werning, 2006, *inter alia*), Hellwig et al. (2006) refute the premise of the Morris and Shin (1998a, 2000) apparatus, by elaborating on the Atkeson (2000) critique on the informational role of markets, as applied to the informational role of interest rates. Hellwig et al. (2006) show that the number of equilibria in currency crises depends on market characteristics and not on the information structure. The Morris and Shin (1998a, 2000) uniqueness arises as a special case of strong market-clearing due to a perfectly elastic bond supply at a fixed and, thus, uninformative interest rate, in which case private information signals drive the uniqueness of the outcome (Hellwig et al.,2006). Interest rates affect traders' contingent bids via two channels: first, they influence traders' expectations about the probability of devaluation; second, they affect traders' payoffs from domestic bonds (Hellwig et al., 2006). By endogenizing the interest rate, they refute the claim by Morris and Shin (1998a) that multiplicity or uniqueness arises due to the coordination problem, and instead show that it is the result of multiple market-clearing interest rates.

The debate on the above is reminiscent of the cleavages in the unresolved debate on whether the Efficient Market Hypothesis holds, and if so, under which form. Having observed both the state of pervasive uncertainty in debt capital markets for the Greek government debt, whereby multiple equilibria seem to be a more plausible explanation, and a regime shift in the spreads of Greek government bonds to default levels in 2012, this chapter will seek to provide a simple unifying static setup to describe each of these debt outcomes.

3.3. Multiple Sovereign Debt Equilibria under Common Knowledge

In this section, we provide a setup for fundamentals-based equilibria in debt capital markets. The framework of Jeanne and Masson (2000) for a currency crisis is applied to the context of the Eurozone debt crisis. As in Bruneau et al. (2012, 2014) and Do Bernardo (2016), who were the first to suggest the application of Jeanne and Masson (2000) to sovereign debt, sovereign debt crisis is defined as the increase in the probability of sovereign default, in direct translation of the increase in the probability of devaluation in the Jeanne and Masson (2000) framework. Essentially, the Bruneau et al. (2012,2014) and DoBernardo (2016) application is repeated. In this section, we assume that no external debt considerations are in play, in the sense that all debt is implicitly assumed to be denominated in the domestic currency.[113] Therefore, the model application is best suited to study debt crises in the Eurozone. Moreover, as a simplifying assumption, the interest rate in this chapter relates to the interest rate charged by financial markets on government debt. The simplifying abstraction from monetary policy is justified on the grounds of the surrender of monetary policy autonomy in the currency union. This model also assumes a framework of rational expectations, as in Jeanne and Masson (2000).

Following the notation of Jeanne and Masson (2000), the reduced form of the Net Repayment Benefit of government debt in period t is denoted as the following continuously differentiable function (DoBernardo, 2016):

$$\text{NB}\ (\varphi_t, \pi_t), \tag{3.1}$$

where φ_t corresponds to the aggregate level of exogenous fundamentals affecting the state of the economy π_t reflects the endogenous expected probability of default by debt capital markets (Do Bernardo, 2016).

The Net Benefit NB (·,·) is increasing in fundamentals ($NB_1 > 0$) and decreasing in the probability of default ($NB_2 < 0$) (Do Bernardo, 2016). A higher level of fundamentals is associated with a higher benefit of repayment, an assumption which resonates the predominant modelling choice and empirical result exposed in the literature review, according to which default is more painful during "good states of nature". Also, a lower expected probability of default by financial markets is associated with a higher net benefit from repayment, since as detailed above, lower expectations of default mandate a lower risk

[113] Eurozone debt is used as a simplifying assumption against foreign-currency debt, as the government debt of Eurozone countries is predominantly denominated in the domestic currency of the currency union, the euro. External debt considerations would have required the additional study of exchange-rate dynamics, which would also be largely invalid for the case of a small sovereign borrower in the Eurozone, such as the Greek government, for example.

premium, thus, setting a lower interest rate, which in turn translates into a lower repayment cost for the government, tilting the decision against default and in favour of repayment. Therefore, the default decision rule of the government hinges both on fundamentals and on market expectations of default, which in turn, endogenously, determine the level of interest rates.

For every level of expected probability of default π_t by financial markets, there exists some level of fundamentals φ_t at which markets believe that the net benefit of repayment, as they expect the government to calculate it, is zero (NB (φ_t, π_t)=0). At this point, the government is indifferent between repayment and default (Do Bernardo, 2016). The model does not explicitly state whether default or repayment is selected, though a common simplifying modelling assumption in relevant literature on debt crises assumes that the government shall opt for repayment. Therefore, financial markets form their expectations of default, based on observed fundamentals.

A higher level of fundamentals (φ_t) is implicitly assumed to refer to an improved state for the economy. Fundamentals are stochastic, and are assumed to follow a Markov process with the ensuing transition cumulative distribution function:

$$F(\varphi,\varphi')=\text{Prob}\,[\varphi_{t+1} < \varphi_t \mid \varphi_t = \varphi] \qquad (3.2)$$

(Do Bernardo, 2016).

Financial markets are characterized via the simplistic representative agent assumption. Therefore, π_t, the endogenous expected probability of default, is determined as the average t-period estimate of the probability of default at t+1 across a continuum of agents i ∈ [0,1] such that:

$$\pi_i = \int_0^1 \pi_t^i \, di \qquad (3.3)$$ [114]

(Do Bernardo, 2016). Given the level of exogenous fundamentals φ_t(including past and expected future values thereof), each individual investor in debt capital markets is forward-looking and their subjective

[114] In the higher-order-beliefs interpretation, the expected probability of default will be replaced by the proportion of speculators whose short sales of the government debt based on an equal expectation of default (α(φ)) are sufficient to induce default. This will be subsequently used to show how the final default outcome results from the intersection of α(φ) with the observed aggregate short sale function.

belief about the probability that the government will default in the subsequent period (t+1), is based on a subjective assessment of the net benefit of repayment at time t+1 (Do Bernardo, 2016). This assessment depends on a subjective assessment of future fundamentals but also on an assessment of other investors' future beliefs about the probability of default, according to equation (3.4), as in Jeanne and Masson (2000). Thus, in the next period, investors' expected probability of default, given observed fundamentals will be as in Do Bernardo (2016):

$$\pi_t^i = Prob[NB(\varphi_{t+1}, \pi_{t+1}) < 0 \mid \varphi_t]^{115} \tag{3.4}$$

"Fundamentals-Based Equilibria"[116]

The level at which markets expect the government to default is defined as $\varphi^{*e}(\varphi_t)$, according to the Do Bernardo (2016) translation of the Jeanne and Masson (2000) setup. H (φ^{*e}) corresponds to the point where NB(φ^{*e}, π_t)=0.

Equation (3.4) paves the way for the introduction of Morris and Shin (1998a) higher-order beliefs in the subsequent section, the extension suggested by this chapter.[117] Jeanne and Masson (2000) make the simplifying assumption that agents are rational and have common knowledge of the same information set. Thus, the equation for the expected probability of default by the representative investor in financial markets may be rewritten as follows:

$$\pi_t = Prob[\varphi_{t+1} < \varphi^{*e} \mid \varphi_t]^{118} \tag{3.5}$$

[115] According to Jeanne and Masson (2000), the timing of the formation of expectations is the distinguishing feature of the model that gives rise to multiple equilibria, as opposed to up to three equilibria foreseen in Obstfeld (1996), Velasco (1996) and Jeanne (1997). In the latter papers, expectations are taken at t and the government decision to devalue is taken before the crisis (i.e. at t-1) (Jeanne and Masson, 2000).
[116] The analysis follows the structure and adaptation of DoBernardo (2016), to be expanded subsequently.
[117] This possibility of an extension according to Morris and Shin (1998a) was suggested as a footnote in Jeanne and Masson (2000) for the context of a currency crises yet was not carried out. Bruneau et al. (2012) and Do Bernardo (2016) who were the first to apply Jeanne and Masson (2000) to sovereign debt crises do not provide such an extension. In particular, Jeanne and Masson (2000) note the following: "The assumption of common knowledge is not innocuous. As Morris and Shin (1998) have shown in a recent paper, the absence of common knowledge can remove the multiplicity of equilibria in escape clause models of currency crises" (Jeanne and Masson, 2000).
[118] In contrast to equation 3.5, where the i is dropped, higher-order beliefs imply that the above φ^{*e} would differ across each individual market participant (speculator) i such that π_t^i are also different across i market participants.

Equation (3.5) reads as follows: given the level of current-period fundamentals φ_t, investors' expectations of government default in the subsequent period, are determined by the relationship between future fundamentals and the critical threshold φ^{*e}, below which investors expect the government to default, as in Jeanne and Masson (2000). If next-period fundamentals lie below the critical threshold φ^{*e}, investors will expect the government to default and, thus, affect its cost of repayment by charging a higher interest rate accordingly. Conversely, if next-period fundamentals are above this critical threshold, investors will expect the government to repay its debt obligations.

In turn, following Bruneau et al. (2012, 2014) and Do Bernardo (2016), given these expectations of default by speculators, which depend on investors' critical location of fundamentals with respect to investors' critical threshold φ^{*e}, the government adopts an optimal defaulting policy rule, deciding on whether or not to actually default, according to some trigger level φ^* such that:

for values of $\varphi<\varphi^*$, NB (φ, F(φ, φ^{*e})) < 0, (3.6.1)

namely, for values of fundamentals lower than the government's critical default threshold φ^*, worse fundamentals imply that net repayment benefit is negative and default is the optimal decision rule.

In contrast, for higher values of fundamentals (in excess of the critical default threshold φ^*), the net repayment benefit under improved states of nature is positive, thus, yielding an optimal policy rule of debt repayment as follows:

for $\varphi>\varphi^*$, NB (φ, F(φ, φ^{*e}))>0 (3.6.2)

Since the net benefit function NB(·,·) is a strictly increasing function of fundamentals, $\varphi = \varphi^*$ corresponds to the point at which the government's net repayment benefit is zero and the government is indifferent between debt repayment and default, as follows:

for $\varphi=\varphi^*$, NB (φ, F(φ, φ^{*e})) = 0 (3.6.3)

In a rational expectations equilibrium, the beliefs of investors in financial markets must be rational and materialize. Therefore, the value of fundamentals at which default will actually occur based on the government's policy rule (φ^*), must coincide with the level of fundamentals at which financial markets expect the government to default (φ^{*e}), such that φ^* must be a fixed point of the function H (·) in the notation of Jeanne and Masson (2000) and Do Bernardo (2016):

$$\varphi^* = H(\varphi^*) \tag{3.7}$$

Jeanne and Masson (2000) prove the existence of at least one fundamentals-based equilibrium and provide an explanation about how multiple equilibria may also arise for this critical default threshold φ^*. In particular, since H(·) is an increasing function, there exists "*strategic complementarity"* between market expectations about the government's default decision rule and the rule that is actually chosen by the government (Jeanne and Masson, 2000; Bruneau et al., 2012, 2014; Do Bernardo, 2016). The mechanism via which multiple fundamentals-based equilibria "may coexist," (each arising due to some different government default rule which occurs due to some different critical threshold of fundamentals φ^{*e}) (Jeanne and Masson, 2000), is the following: Investors may revise their expected critical default threshold upwards, such that default is expected, even at better levels of fundamentals. This, in turn, raises the risk premium and cost of repayment for the government, forcing the government to also revise its actual default threshold φ^*upwards. In response to investors' higher expectations of default, the government becomes indeed more likely to default, as its default decision rule prompts to non-repayment, even at higher levels of fundamentals. Therefore, for each level of default expectations, there exists a unique critical threshold for sovereign default and a unique equilibrium (Do Bernardo, 2016). Multiple equilibria may arise due to the interplay of fundamentals and expectations, between financial market participants and the government. This simplistic framework for multiple equilibria, as applied to sovereign debt, serves as an explanation of why expectations may lead to self-fulfilling crises in sovereign debt markets, a result which has been formally treated by a number of seminal papers in the literature (see Chapter 2).

Based on the above analysis, expectations-driven equilibria may arise for the same level of underlying fundamentals due to the different critical thresholds for default, expected by financial markets and subsequently selected by the government. Thus, jumps across such multiple equilibria, occur due to expectations, ceteris paribus. Whether debt ends up in the default region, where $\varphi<\varphi^*$, as opposed to the repayment region (φ>φ*) depends on how this φ* is determined by investor expectations, *ceteris paribus*.

This *ceteris paribus* assumption is essential to the above conclusion on the origins and mechanism of the default decision, which is partially handicapped by an abstraction from other factors that may drive the government's decision-making process, such as ideological preferences with respect to default, the government's more elaborate internal fiscal calculus of the costs and benefits of repayment against default, *inter alia*. In fact, Jeanne and Masson (2000) highlight the critical assumption that the preferences and type of the government do not affect jumps in the critical default level of fundamentals φ*.

For example, during the 2012 Greek PSI,[119] Greek government bond yield spreads skyrocketed over a very brief period of time, during which fundamentals may have been bad, yet the time period during which this spike occurred did not validate any relevant shifts in fundamentals. Applying the above framework, the shift to the (partial) default equilibrium occurred due to a shift to some higher expected threshold for default by bondholders (φ^{*e2}) from a previous level of φ^{*e1} (φ^{*e2}>φ^{*e1}). Thus, although a few days prior to default, actual fundamentals may have "made it" past the original default threshold (φ>φ^{*e1}), as soon as this default threshold was pushed to a level φ^{*e2} above fundamentals ($\varphi^{*e2} > \varphi$), financial markets increased their expectations of default, raising their risk premia, ultimately forcing the government to default, as its own actual maximum sustainable debt threshold φ^{*} moved from φ^{*1} to φ^{*2} ($\varphi^{*2} > \varphi > \varphi^{*1}$) for the same level of fundamentals φ.

There are multiple equilibria (in this Jeanne and Masson (2000) setup) if investors (all at the same time) revise their φ^{*e}; in simple terms, with different default thresholds, there are multiple possible outcomes for the default/repayment decision. For example, when φ^{*e} rises, so will φ^{*}, such that default is expected even at higher levels of fundamentals. Multiple equilibria are possible:

$$H(\varphi^{*})=H(\varphi^{*e}) \tag{3.8}$$

[119] For an account of the Greek Private Sector Involvement (PSI), see Zettelmeyer et al. (2012), Xafa (2013) and Venizelos (2017), *inter alia*.

Thus, an increase in φ^{*e} raises the investors' expected probability of default π_t, thereby decreasing the net benefit from repayment NB by increasing the costs implicitly entailed in the cost-benefit calculation of repayment.

At this point, for the purposes of modelling sovereign debt dynamics, we introduce an additional variable compared to the currency-crisis setup in Jeanne and Masson (2000) and to the application by Bruneau et al. (2012, 2014) and Do Bernardo (2016): the interest rate on government debt.

$$r(\varphi^{*e}) \tag{3.9}$$

An increase in r(φ^{*e}) implies increased costs for the government, therefore, a lower net benefit from repayment, which serves to bring φ^{*} up as well, as default would occur at better fundamentals under a higher interest rate on debt. The interest rate, thus, operates as the mechanism via which the rational expectations equilibrium in (3.8) occurs, which will be used to establish the link to *section 3.4*.

Based on the above, jumps from one equilibrium to the other occur either due to changes in fundamentals or due to changes in expectations (the expected default threshold). Even if fundamentals are constant, multiple $\varphi^{*e}(\varphi_t)$ are possible. Therefore, outcomes depend on which expectation process is followed, as explained by Jeanne and Masson (2000).

3.4 Uncertainty and Higher Order Beliefs

Higher-order beliefs are introduced precisely to explain the process of expectation formation in financial markets once the economy is in some intermediate zone of fundamentals, called the 'ripe for attack region', in which a crisis is precipitated. This framework is used to explain how among the multiple equilibria suggested by models such as the Jeanne and Masson (2000), when in the 'ripe for attack' region and when uncertainty implies unclear market signals, speculators' actions will lead to the unique self-fulfilling outcome of a debt crisis (as proxied by an increase in the probability of sovereign default).

i. Higher Order Beliefs

As in Keynes' (1936) newspaper beauty contest, higher-order beliefs refer to the process via which each investor tries to "guess what other investors try to guess about what other investors try to guess"… (and so on, to the n-th order) "about what other investors guess" about something (usually fundamentals or returns). It is a device which describes the updating of beliefs under rational expectations, based on the reception of some signal (approximate information) (Rangvid et al., 2009). When financial markets are fragmented and heterogeneous signals are possible (uncertainty), the average belief for pricing may differ from each individual investors' belief. Heterogeneity of information implies that the law of iterated expectations does not hold for the determination of average expectations (Rangvid et al., 2009).

Higher-order beliefs[120] models were developed as an additional explanation to self-fulfilling crises described via the multiple equilibria apparatus, as extended to include the mutually reinforcing actions of market participants and the effect of small differences in the information (uncertainty) across such agents (Morris and Shin, 1998a). These two features are shown to remove the 'indeterminacy of beliefs'. As such, contingent on the type of crisis and payoffs assumed in each case, they give rise to policy recommendations in preventing a self-fulfilling crisis. [121]

Higher-order-beliefs have been used to explain bank runs, risky corporate debt and the onset of currency crises, yet no study has focused on government debt, except Hattori (2004). As with sunspots, higher-order beliefs may provide some insight in the answer to the central question about whether equilibria on sovereign debt pricing in crisis arise due to fundamentals or whether expectations and additional external influencing factors may affect the eruption of a government debt crisis. Unlike sunspot-driven

[120]The higher-order beliefs framework was built based on the game-theoretical concept of 'higher-order uncertainty' and the works of Aumann (1976), Rubinstein (1989), Carlsson and Van Damme (1993), Morris et al. (1995). Kajii and Morris (1997) provide a relevant survey. More recently, the market pricing impact of higher-order expectations has been examined by Allen, Morris and Shin (2003), Bacchetta and van Wincoop (2006,2009), Nimark (2008) Banerjee, Kaniel and Kremer (2009), Makarov and Rytchkov (2008), Rangvid, Schmeling and Schrimpf (2009).

[121] For example, the Morris and Shin (1998b) currency crisis model proposes increased 'transparency' in financial markets, highlights the importance of public announcements as remedies to uncertainty in privately held beliefs by market participants, while also showing that capital controls impose transaction costs which limit capital flight and, thus, create some friction to the self-fulfilling onset of a crisis.

outcomes which bear no correlation to fundamentals, higher-order-beliefs would point to an answer for the above question that lies somewhere in-between the two extreme viewpoints.

Morris and Shin (1998b) introduced such higher-order beliefs to re-examine multiple equilibria models. They note that agents' beliefs are indeterminate due to two simplifying modelling assumptions in related literature: 1. Fundamentals are common knowledge; and 2. Agents are certain about others' behaviour in equilibrium (Morris and Shin, 1998b). In turn, these give rise to perfect coordination of actions and beliefs. Morris and Shin (1998b) note that "even a small amount of idiosyncratic uncertainty" may give rise to a "unique set of self-fulfilling beliefs".

Morris and Shin (1998b) critique models of multiple equilibria on two fronts: first, multiple equilibria models do not explain the shift in beliefs, based on which expectations change and the economy jumps from one equilibrium to the other; second, such models fail to provide an explanation of why bad fundamentals are more likely to move the economy to a bad equilibrium.

Thus, higher-order belief models relax the common knowledge assumption by introducing the notion of 'strategic uncertainty' (Morris and Shin, 1998a), namely, uncertainty about other market participants' beliefs about fundamentals as the driving force towards a single crisis outcome. They also elaborate on speculators' payoffs, by including transaction costs in the decision to short sell.

ii. Higher Order Beliefs and Government Debt Crisis

Using the higher order beliefs framework to model the onset of a sovereign debt crisis, speculators[122] decide whether or not to attack the government debt, based on some expectation of the probability of default and associated payoffs to their actions. Higher order beliefs are linked to the notion of uncertainty and make use of the interest rate on the government debt as opposed to the exchange-rate used by Morris and Shin (1998a).

In this section, the expected probability of sovereign default π_t will be incorporated via α, the percentage of attacking speculators whose attack (in turn based on an expected probability of default),

[122] Given the crisis context, this section focuses on the formation and effect of expectations on government debt outcomes. Therefore, government bondholders are replaced by speculators in the analysis.

is sufficient to induce default, and s, the actual short-selling strategy observed. In line with Morris and Shin (1998a) and for notational simplicity, time subscripts will be omitted, as higher order beliefs are used to describe the dynamics in the event space close to government default in a speculative attack.[123]

Two ex-ante thresholds of fundamentals are defined: $\underline{\varphi}$ corresponds to the best state of fundamentals for which default is the outcome with certainty; $\overline{\varphi}$ corresponds to the worst state of fundamentals above which repayment is the outcome with certainty.

At each point in time, the state of the world is revealed (state with uncertainty-state 1, state with no uncertainty-state2); based upon this revelation, a one-shot-game is played. Thereafter, all uncertainty is instantly removed and the game is repeated as the state of the world is revealed again.

Below is an introduction to the basic setup under no uncertainty, upon which the extension of higher order beliefs will be based.

iii. State 1: Common Knowledge (Case of no uncertainty)

In the case of no uncertainty of the level of fundamentals (ie. common knowledge), following the Morris and Shin (1998a) setup, fundamentals[124] are divided into three regions:

i. if φ∈[0, $\underline{\varphi}$], debt dynamics are unstable;

ii. if φ∈[$\overline{\varphi}$, 1], debt dynamics are stable;

iii. if φ∈[$\underline{\varphi}$, $\overline{\varphi}$], debt dynamics imply that the government debt is “ripe for attack” in the Morris and Shin (1998a) terminology. Multiple equilibria are possible in this range.[125] Relating this to the Jeanne and Masson (2000) notation, as applied to government debt above, each point in this region corresponds to some distinct H(φ^{*e}) default threshold. (In

[123] As an extension to the below static framework, the Morris and Shin (1998b) dynamic model framework could be applied to the onset of government debt crises in future research.
[124] Fundamentals are assumed to be distributed in the normalized range of [0,1] where a level of zero corresponds to the worst possible state, whereas a level of 1 corresponds to the best possible state, as in Morris and Shin (1998a).
[125] Lorenzoni and Werning (2019), albeit in a different framework, distinguish the multiplicity of steady states from the multiplicity of equilibria.

this region, we will show that H(φ^{*e}) moves in a self-fulfilling way to the crisis outcome in the case of uncertainty).

From the above, common knowledge implies the potential of multiple equilibria within the 'ripe for attack region'.

Payoffs

The Morris and Shin (1998a) setup requires a more elaborate definition of the Jeanne and Masson (2000) Net Benefit function. In a cost-benefit setup, the value of debt repayment and the cost of debt repayment are defined as follows:

$$V_{repay} - C_{repay}(\alpha, \varphi) \quad (3.10)$$ [126]

The government decides to repay if the value of repayment V_{repay}, exceeds the cost of repayment $C_{repay}(\alpha, \varphi)$ such that the net benefit from repayment is non-negative.

A more elaborate net-benefit rule is introduced using α(φ), the percentage of speculators required to attack the government debt (due to their belief that the government will default) to induce default. In the Jeanne and Masson (2000) framework, this is defined as the expected probability of default on the part of government bondholders.

r(φ) is defined as the level of the interest rate charged on government debt as a function of fundamentals φ. r(φ) is strictly decreasing in the state of the economy, such that improved fundamentals correspond to lower interest rates. r*[127] is also defined as the 'maximum sustainable interest-rate on government debt'. [128] For interest rates above this level, default pressure is induced on

[126] V(α,φ)=C(α,φ) corresponds to NB(α,φ)=0.

[127] In the Morris and Shin (1998a) currency-crisis framework , this variable corresponds to the variable depicting the level of the exchange rate peg (e*). However, r(φ), the 'free floating interest rate charged on government debt' is a decreasing function of fundamentals as opposed to the increasing equivalent-for-analysis free-floating exchange rate f(θ) in the Morris-and-Shin currency crisis framework.

[128] r* corresponds to the level of interest rates, beyond which the government will default. In reality, the critical level of interest rate used in this paper would have best been endogenous and obtained from a relevant Gross Financing Needs analysis in a Debt Sustainability Analysis (DSA) template. It could be linked to the level of average interest rates relating to the 'maximum sustainable debt threshold' in simulations of government debt dynamics. The concept of a short-term 'maximum sustainable interest rate' is not novel (eg. see Calvo (1988)). In this Chapter, we implicitly abstract from the associated time dimension.

the government by speculative attacks. Given the focus on the Eurozone, the framework omits any exchange-rate considerations associated with external debt.

The cutoff points across regions are, thus, defined as follows:

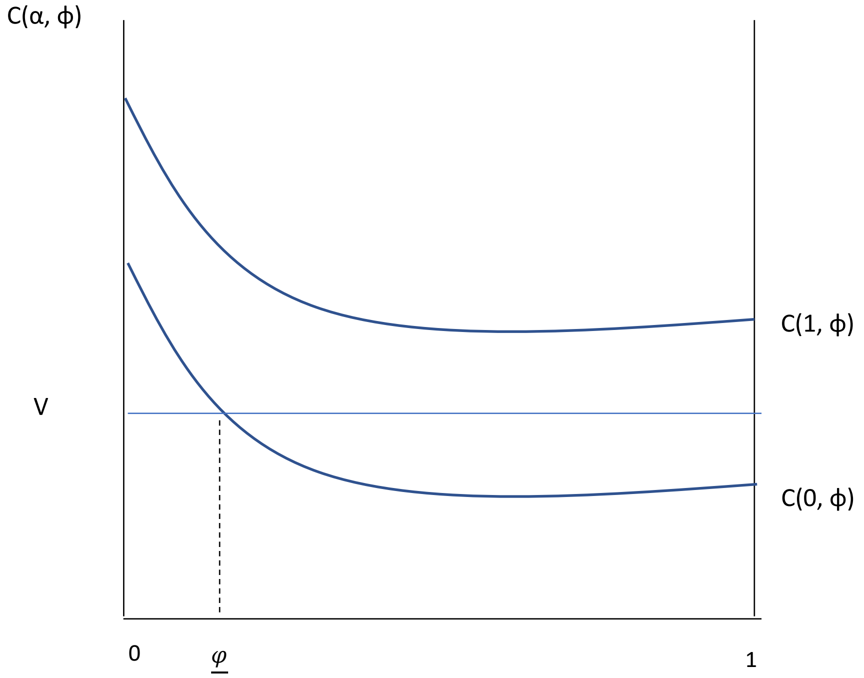
- $\underline{\varphi}$ solves C(0, φ)=V, such that the government is indifferent between repaying and defaulting at this threshold (see Figure 3.1); (this corresponds to the ex-ante repay/not repay threshold)
- $\overline{\varphi}$ solves r(φ)-r*=t, where r(φ) corresponds to the interest rate (which is assumed to be equal to speculators' payoff from attack) and t to some fixed level of transaction costs associated with the attack (see Figure 3.2); (this corresponds to the attack/not attack threshold)

Following Morris and Shin (1998a), the above setup implies that:

C(0,0)>V such that in the worst state of fundamentals, no speculator is required to attack to make the cost of repayment insurmountable for the government;[129]

C(1,1)>V such that even in the best state of fundamentals, if all attack, the cost of repayment implied for the government will exceed the value of repayment;

Figure 3.1: Cost and Benefit of Government Debt Repayment[130]



Cost and Benefit for the government when α=100% and α=0; *Source: Morris and Shin (1998a), adapted to this Chapter*

[129] Fundamentals are sufficiently bad to induce default even in the absence of any transactions-cost-bearing speculative attacks.
[130] Figure 3.1 implicitly assumes that the value of debt repayment is constant over fundamentals.

In the above figure, if all speculators attack, the cost of repayment always lies above the value of repayment. In contrast, if no one attacks, above the critical point $\underline{\varphi}$, the value of repayment exceeds the cost of debt repayment. The region beneath this point corresponds to the above-defined ‘unstable’ region.

		Government	
		Repay	Default
Speculator i	Attack	-t	r(φ)-r*-t
	Refrain	0	0

Table 3.1. Speculator payoffs

In the *Table 3.1* above, r(φ) represents the gross speculator’s yield in the event that a speculative attack is successful and the government defaults; t corresponds to the transaction costs incurred in short sales, which are assumed to be a fixed constant.[131]

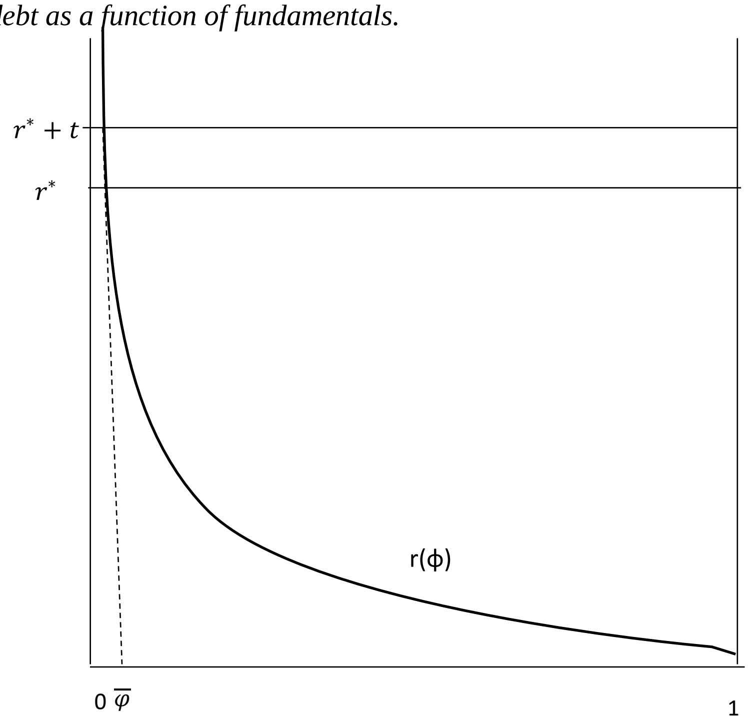
The above table implies that if the speculator refrains from shorting the government bonds, their payoff is zero, irrespective of the actions of the government. If, however, the speculator has launched a speculative attack on the government debt, two options are possible: the attack fails and the government repays its debt, such that speculators only face transaction costs t and no profits; alternatively, if the attack is successful and the government defaults, speculators receive a payoff of r(φ)-r* but also have to pay transaction costs t.

r(1)-r*[132] $<$ t: In the best state of normalized fundamentals (1), the interest rate is sufficiently low compared to the maximum sustainable interest rate on government debt that the speculators’ payoff in the best state of fundamentals is outweighed by transaction costs.

[131] The yield for a speculator shall consist mostly of the price differential captured after shorting the government bonds; for the sake of simplicity, and without a loss of generality for the non-numerical outcomes of this model, this yield r(φ) shall be assumed to be equal to the average interest rate charged on government debt. This assumption is enabled by the fact that under a higher-risk environment, speculators’ yields increase via the rapid decline in government bond prices while the government is also forced to pay increasingly higher interest rates on its debt. In reality, transaction costs may not be fixed and may be related to the interest payments required to be made by speculators. We shall abstract from this relationship to focus on the self-fulfilling mechanics.

[132] This is the level of interest rates corresponding to the best possible state of normalized fundamentals (1). In reality, interest rates will be endogenous to the number of speculators attacking the government debt.

Figure 3.2: The maximum sustainable interest rate and the market-determined interest rate on government debt as a function of fundamentals.



Maximum sustainable interest rate and interest rate; Source: Morris and Shin (1998a), adapted to this Chapter

iv. State 2: Government Debt Equilibria under Uncertainty (Imperfect Information)

This section will examine the impact of uncertainty, defined as imprecision in the information about the state of fundamentals received by each speculator on the multiple equilibria region to show how this region collapses to a single self-fulfilling default outcome due to the impact of higher order uncertainty. Higher-order beliefs are invoked in the analysis.

The game between speculators and the government follows the one-shot setup of the currency attack by Morris and Shin (1998a) as follows:

- Some state of fundamentals in the region [0,1] is revealed;
- Speculators receive a noisy signal of fundamentals[133] $x_i \in [\varphi - \varepsilon, \varphi + \varepsilon]$, based on which they decide whether or not to launch a speculative attack (Attack/Refrain);[134]

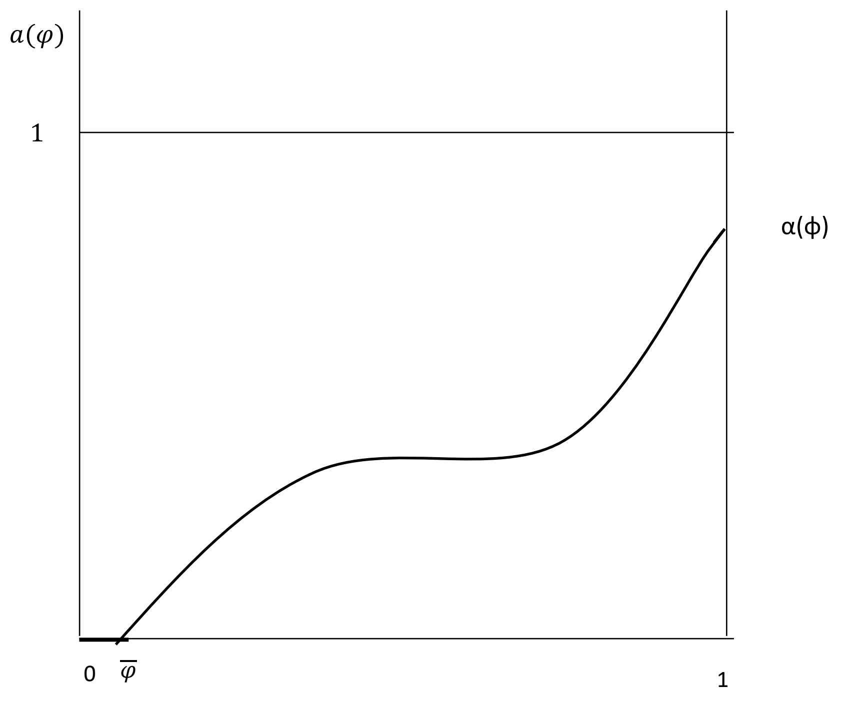
[133] No distinction between private and public signals is made; this could be the topic of a future paper.
[134] The noise in the signal received by financial markets could relate to changes in the political constraints or a lack of transparency on government policy decisions. For example, an application to the Greek debt crisis could relate to uncertainty in demands on the part of Official sector lenders with respect to conditionality in the early stages of the crisis, or uncertainty about the strategy of the government with respect to accepting proposed conditions in early 2015. Therefore, a political economy model could explain (yet not parametrize in this setup), the emergence of noise.

- A percentage α of speculators decide to attack;
- The government observes the state of fundamentals (φ) and the percentage of speculators who attack the debt (α) and decides whether to default or to repay[135];

As in Morris and Shin (1998a), equilibrium consists of strategies for the government and a continuum of speculators, where no player has an incentive to deviate. Solving out the government's final-state game, the focus will lie on the reduced-form game between speculators.

We define α(φ) to be the proportion of speculators whose short sales of government debt are sufficient to induce default at every level of fundamentals, similarly to Morris and Shin (1998a). Clearly, in the unstable region α*(φ)=0, such that default is the prevailing outcome, irrespective of the percentage of speculators who attack.

Figure 3.3: The proportion of speculators whose short sales suffice to induce a default on government debt as a function of fundamentals



The percentage of speculators whose short sales are sufficient to induce default on government debt (as a function of fundamentals); Source: Morris and Shin (1998a), adapted to this Chapter

[135] No distinction is made between partial or full default.

The government's optimal strategy will be to repay if and only if, the observed $\alpha \leq \alpha^*(\varphi)$.

Applying the Morris and Shin (1998a) notation, in the reduced-form game between speculators, we define:

σ(x): the conditional short-selling strategy given signal x of fundamentals;

s(φ, σ(x)): the percentage of speculators who actually attack, given some level of fundamentals φ and some aggregate short-selling strategy σ(x).

Under the assumption that signals x are distributed uniformly over [φ-ε, φ+ε], the percentage of speculators who attack may be written as follows and as in Morris and Shin (1998a):

$$s(\varphi,\sigma)=\frac{1}{2\varepsilon}\int_{\varphi-\varepsilon}^{\varphi+\varepsilon}\sigma(x)dx \tag{3.11}$$

We formally define the event of default to occur at the level of fundamentals at which the aggregate selloff exceeds a critical mass $a(\varphi)$, as in Morris and Shin (1998a):

$$A(\sigma)=\{\varphi|s(\varphi,\sigma) \geq a(\varphi)\} \tag{3.12}$$

Equation (3.12) states that default occurs when fundamentals are such that the aggregate short-selling strategy by speculators exceeds the critical mass of speculative attacks required to induce a default on government debt.

Reduced-form speculator payoffs for a state of fundamentals φ and conditional short sales σ are now redefined as:

$$h(\varphi,\sigma)=\begin{cases} r(\varphi)-r^*-t, & if\ \varphi \in A(\sigma), ie\ in\ the\ event\ of\ default \\ -t, & if\ \varphi \neq\in A(\sigma), ie\ in\ the\ event\ of\ repayment \end{cases} \tag{3.13}$$

Yet, given that speculators do not directly observe the state of fundamentals φ and instead receive a noisy signal x, their payoff ought to be calculated off the posterior distribution conditional on x:

$$U(x,\sigma)= \frac{1}{2\varepsilon}\int_{x-\varepsilon}^{x+\varepsilon}h(\varphi,\sigma)d\varphi = \frac{1}{2\varepsilon}\left[\int_{A(\sigma)\cap[x-\varepsilon,x+\varepsilon]}(r(\varphi)-r^*)d\varphi\right]-t \tag{3.14}$$

Based on this payoff function, a speculator will attack if and only if U(x,σ)>0.

- σ(x)=1, i.e. 'all attack' is an equilibrium if U(x,σ)>0[136]
- σ(x)=0, i.e. 'all refrain' is an equilibrium if U(x,σ)$\leq$ 0.

We repeat the Morris and Shin (1998a) proof for the below theorem applied to a speculative attack on government debt:

Theorem 1: There exists a unique level of fundamentals φ* such that in any equilibrium, under the presence of uncertainty (imperfect information), the government will default if fundamentals lie beneath it, i.e. if and only if φ≤φ* (Morris and Shin, 1998a, adapted to this Chapter).

Lemma 1: Strategic Complementarity

If σ(x) ≥ σ'(x) for all x, then U (x,σ) ≥ U(x,σ') for all x. (Morris and Shin, 1998a, adapted to this Chapter).

Payoffs are increasing in the proportion of speculators who attack (Morris and Shin, 1998a, 1998b). Thus, each speculator's decision to attack is a strategic complement to the other speculators' decision.

Proof

Since σ(x) ≥ σ'(x), then s (φ,σ) ≥ s(φ,σ') for every φ, as in Morris and Shin (1998a).

Using (*3.12*), A(σ) ⊇ A(σ') Morris and Shin (1998a). This implies that the event of default is strictly larger when a larger proportion of speculators follow the aggregate selling strategy to attack.

Using the above, (*3.14*) and the fact the assumption that the interest rate on government debt is non-negative (r(φ)≥0)[137], we follow Morris and Shin (1998a):

U (x,σ)= $\frac{1}{2\varepsilon}[\int_{A(\sigma)\cap[x-\varepsilon,x+\varepsilon]}(r(\varphi)-r^{*})d\varphi]-t \;\; \geq$

[136] Since the investor can guarantee a minimum payoff of zero by refraining from launching a speculative attack on the government debt, speculators will only attack if U(x, σ)>0. Therefore, whenever the expected payoff is positive, all speculators will attack, i.e. σ(x)=100%. In contrast, whenever the expected payoff is negative or zero, speculators will refrain from short sales of government bonds.

[137] The non-negativity of interest rates on government debt is realistic in the runup to a debt crisis.

$\geq \quad \frac{1}{2\varepsilon}[\int_{A(\sigma\prime)\cap[x-\varepsilon,x+\varepsilon]}(r(\varphi)-r^{*})d\varphi]-t$= U(x,σ') (3.15)

Therefore, a greater number of attacks, which in turn, by definition, are based on a higher expectation of default, ultimately results in higher payoffs under attack.

Next, we define k as a fixed number based on which each speculator decides whether or not to attack after having received a noisy signal x. In particular, they will opt for attack if and only if x<k.

Following Morris and Shin (1998a), the aggregate short-selling strategy σ(x) is rewritten using the below indicator function:

$$I_k(x) = \begin{cases} 1, if\ x < k \\ 0, if\ x \geq k \end{cases} \qquad (3.16)$$

Up to this point, a speculator will attack the government debt if and only if he receives a message of fundamentals x which lies below the fixed number k.

Applying Morris and Shin (1998a) Lemma 2 to government debt, the speculators' profits will be decreasing in this k, as payoffs of an attack will be lower when perceived fundamentals are stronger.

Lemma 2:

Morris and Shin (1998a) prove that U(k, I_k) is continuous and strictly decreasing in k.

Lemma 3: Unique Threshold

There exists a unique x* such that in any equilibrium a speculator with signal x attacks the government debt if and only if x<x*.

The switching point x* in Lemma 3 relates to the Jeanne and Masson (2000) perceived default threshold φ^{*e}. However, rather than evoking rational expectations as a reason why the actual threshold of the government's decision to default φ^{*} will be equal to φ^{*e}, higher order beliefs will show how the economy lies with respect to the unique self-fulfilling φ^{*} which is different from x*.

Proof of Lemma 3:

The proof follows directly from Morris and Shin (1998a), as applied to sovereign debt crises. First, the existence of a tipping point x* in the signal of fundamentals received by speculators is proven. Secondly, a symmetrical argument is used to prove its uniqueness.

To prove that there exists some tipping point in the perceived fundamentals, it must be shown that there exists a marginal message about fundamentals k such that the speculators' payoff from attacking is zero: i.e. U (k, I_k)=0 for some k.

Using the fact that U (k, I_k) is continuous and strictly decreasing (from Lemma 2), it suffices to show that for small k, U (·) is positive and that U(·) is negative for large k. This would guarantee that for some k, U (·) would be zero, and a unique threshold would emerge.

- Assume a sufficiently small k, such that k ≤ $\underline{\varphi}$-ε, such that the debt is not in the stable region. The payoff of attack will, thus, be positive U (k, I_k)>0 and the rational speculator would always attack.
- Next, assume a sufficiently large k, such that k≥$\overline{\varphi} + \varepsilon$, such that the debt is in the stable region. The payoff from attack will, thus, be negative U (k, I_k)<0 and the rational speculator would always refrain from attacking the government debt.
- Thus, given that U (k, I_k) is continuous and strictly decreasing, there must exist a unique k where U (k, I_k)=0 and the speculator is indifferent.

The above can be extended for any equilibrium, based on the percentage of speculators who attack, given some uncertain signal about fundamentals x.

Now, we turn to establishing that the solution to U (k, I_k)=0 is given by a unique value of x*, the switching point of perceived fundamentals, following Moris and Shin (1998a).

Two thresholds are defined for noisy imperfect signals of fundamentals: $\underline{x},\ and\ \overline{x}$.

$\underline{x}$ corresponds to the lowest possible state of fundamentals signalled in which some, but not all, speculators attack the government debt:

$$\underline{x} = inf\{x|\ \sigma(x) < 1\} \tag{3.17}$$

Similarly, $\overline{x}$ corresponds to the highest possible state of fundamentals signalled in which some will refrain from attacking but not all, as also explained by transaction costs:

$$\overline{x} = sup\{x|\ \sigma(x) > 0\} \quad (3.18)$$

From the above definitions,

$$\overline{x} \geq\ sup\{x|\ 0 < \sigma(x) < 1\}\ \geq inf\{x|\ 0 < \sigma(x) < 1\}\ \geq \underline{x} \quad (3.19)$$

By continuity, at $\underline{x}$, U $(\underline{x}, \sigma) \leq 0$. (3.20)

From Lemma 1 and (20), U $(\underline{x}, I_x) \leq$ U $(\underline{x}, \sigma)\ \leq 0$. (3.21)

Thus, $\underline{x} \geq x^*$ (3.22)

By symmetry of argument, $\overline{x} \leq x^*$ (3.23)

Therefore, by (3.22) and (3.23), it must be true that $\overline{x} \leq x^* \leq \underline{x}$. (3.24)

Recalling that $\underline{x} \leq \overline{x}$, it must be true that $\overline{x} = x^* = \underline{x}$ (3.25)

We have, thus, followed Morris and Shin's (1998a) argument to show that a unique expected switching point will exist in this 'ripe for attack' region. In the Jeanne and Masson (2000) notation, x* corresponds to the critical expected default thresholds φ^{*e}.

Thus, we may rewrite the indicator function in (*3.16*) using the below indicator function as follows:

$$I_{x^*}(x) = \begin{cases} 1, if\ x < x^* \\ 0, if\ x \geq x^* \end{cases} \quad (3.26)$$

Therefore, in equilibrium, the aggregate short sales (the percentage of speculators who choose to attack) from (*3.11*) is rewritten using the step function I_{x^*} from (*3.26*) as in Morris and Shin (1998a):

$$s(\varphi,\ I_{x^*}) = \begin{cases} 1 & if\ \varphi < x^* - \varepsilon \\ \frac{1}{2} - \frac{1}{2\varepsilon}\ (\varphi - x^*) & if\ \ x^* - \varepsilon \leq \varphi \leq x^* + \varepsilon \\ 0 & if\ \varphi \geq x^* + \varepsilon \end{cases} \quad (3.27)$$

If x* is the perceived tipping point for speculators' decision to attack the government debt against refraining from doing so, all speculators (1=100%) will attack if the level of fundamentals lies beneath this point by more than ε, as this would signal access to the 'unstable region'. Similarly, no speculator (0) will attack if the level of fundamentals exceeds the signal by more than ε, as the economy would lie in the 'stable region'. For the in-between region, deviation from the midpoint arises as shown above due to the deviation of fundamentals from the tipping point and a consideration of the error term, which operates in both directions.

Aggregate short sales s(φ, I_{x^*}) are decreasing in fundamentals, as r(φ) and, thus, the interest rate differential (r(φ)-r*) (and, hence, the profit of speculators) is decreasing in fundamentals.

In contrast, α(φ), the proportion of speculators whose short-sales are sufficient to induce default at every level of fundamentals is increasing in fundamentals in the ripe-for-attack region, as shown in *Figure 3.3*.

Thus, s(φ, I_{x^*}) and α(φ) cross once at threshold φ* (*Figure 3.4*), where the state of fundamentals is such that equilibrium short sales s(φ, I_{x^*}) are equal to the short sales that are required to induce a default on the government debt a(φ*).[138]

Figure 3.4: The switching point φ for the state of fundamentals at which equilibrium short sales equal the short sales required to induce a default on government debt*

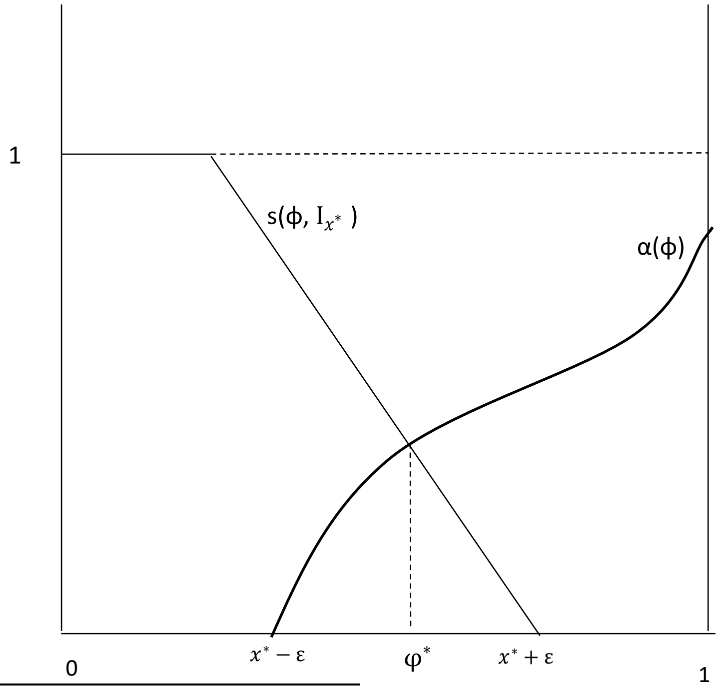


Figure 3.4: The definition of the two cutoff points for the state of fundamentals at which the equilibrium short sales are equal to the short sales required to induce government default.

Source: Morris and Shin (1998a), adapted to this Chapter

[138] Morris and Shin (1998a) prove the above argument analytically.

This point is equal to Jeanne and Masson's H(φ*), the actual default threshold faced by the government, according to the following argument: If φ≤φ*, then s(φ, I_{x^*}) ≥α(φ), i.e. for low levels of fundamentals below some critical threshold, the aggregate short-selling strategy exceeds the percentage of short sales required to induce default, such that the economy is to the left of the tipping point, and the number of short sales increases, ultimately making default self-fulfilling. Therefore, if φ≤φ^*, the government defaults.

In the 'ripe for attack' region, the unique outcome depends on true underlying fundamentals and the threshold emerges at the level of fundamentals at which α(φ) intersects with the strategy profile of speculators s(φ, I_{x^*}). Thus, rather than basing the outcome on multiple expectations-driven switching points using φ^{*e}, which in the Jeanne and Masson (1998a) framework would have depended on the marginal message received x, a unique outcome is determined by the interaction of fundamentals, the observed percentage of speculative attacks based on expectations of default and the strategic complementarity. The unique switching point is, thus, defined in terms of φ^* rather than x*.

In the Jeanne and Masson (2000) framework, this point of intersection would be the point where H(φ^{*e})=H(φ^*). Thus, a more elaborate explanation of the underlying dynamics has shown how, for instance, some 'creative ambiguity' on the macroeconomic situation, is only constructive to the extent that it serves to eliminate the multiplicity of equilibria.[139]

Theorem 2: The role of transaction costs on the maximum sustainable interest rate

Applying Morris and Shin (1998a) to government debt, as noise is reduced, at the limit (i.e. when ε→0), φ* is given by the unique solution to the: r(φ*)=r*+t.

Following Morris and Shin (1998a), the intuition of the above theorem lies on the below argumentation:

The "marginal speculator" will receive a signal equal to the switching point of fundamentals, i.e. x= *φ**. For small ε (*ε→0)*, the speculator believes that true underlying fundamentals tend to the critical

[139] The next section will show how the uniqueness of equilibrium through 'creative ambiguity' is associated with the uniquely 'bad' outcome, upon the emergence of strategic uncertainty and higher order beliefs.

threshold (φ → *φ**). The expected speculator's payoff from short selling the government debt (attack) is (r(φ*)-r*) and the cost is t. For the marginal speculator, the payoff and the cost are equal, such that he is indifferent between attacking and refraining from doing so i.e. (r(φ*)-r*)=t (Morris and Shin, 1998a).[140]

Thus, r(φ*) -*r*=t.* (3.28)

Clearly, a higher level of transaction costs raises the required payoff on government debt at the switching point, implying that only if speculators' payoffs are high enough to meet transactions costs, will they short sell the government debt. This adds to the rationale for imposing capital controls (which add to speculators' transaction costs and, thus, increase *t*) at the peak of sovereign debt crises.

v. Effect of Expectations with Higher Order Beliefs under Uncertainty

A subsequent question, thus, arises in order to judge the desirability of such uncertainty from the point-of-view of welfare: Does the equilibrium switching point under uncertainty (φ*) which lies at the intersection of α(φ) and s(φ, I_{x^*}) shrink the 'ripe for attack' region into a default final outcome or does it tilt the dynamics into a stable repayment outcome?

Uncertainty operates via two components in the higher order-beliefs framework: fundamentals uncertainty (modelled via the noise ε in the signal x received by market speculators) and strategic uncertainty (namely, uncertainty about other speculators' best response to observed signals).

Even if everyone knows that fundamentals are sound, in the words of Morris and Shin (1998a), it may not be the case that "everyone knows that everyone knows this" (Morris and Shin, 1998a). Higher orders of uncertainty about other market participants beliefs become relevant.

The following simple argument applies Morris and Shin (1998a) and may be used to display the operation of higher order beliefs, stemming from uncertainty in the information received about fundamentals:

[140] Morris and Shin (1998a) prove this theorem analytically for the currency crisis framework.

- Under uncertainty, a speculator receiving a noisy signal x< $\overline{\varphi}$-ε, believes that fundamentals lie below the stable region's cutoff point (φ $\leq \overline{\varphi}$).
- Higher order beliefs operate as follows: Since everyone knows that everyone receives a noisy signal of fundamentals x which is separated from the true state of fundamentals by some ε, each speculator knows that other speculators' observed signals cannot differ from his by more than 2 ε (Morris and Shin, 1998a).
- Therefore, if a speculator observes a signal which is located at $\overline{\varphi}$-3 ε , he automatically believes based on the above analysis that the signals of other speculators must also lie below the threshold $\overline{\varphi}$ for the stable region. Therefore, he believes that not only his signal but also the signal received by other speculators implies that fundamentals are in the ripe-for-attack region, such that φ $\leq \overline{\varphi}$. Similarly, "everyone knows that everyone knows … (n times) that everyone knows it" if every speculator has observed a signal lower than or equal to $\overline{\varphi}$-(2n-1) *ε (Morris and Shin, 1998a).
- Common knowledge breaks down due to higher order beliefs as soon as some speculators' belief doubts that fundamentals are in the stable region. At this point, where the breakdown in common knowledge implies that in the ripe-for-attack region, it becomes an optimal strategy for each speculator to attack the government debt in anticipation of higher profits. Since from equation (*3.15*) speculative attack payoffs increase with the percentage of speculators attacking, each speculator will have an incentive to short the government debt in anticipation of higher profits. As more market participants think this way about others' actions and their payoffs, an increased percentage of speculators opt to attack, such that the government is gradually forced into a unique self-fulfilling default outcome.

Therefore, common knowledge for every n signals occurs if and only if there is *nth-order knowledge* for every n that φ $\leq \overline{\varphi}$. However, under uncertainty, common knowledge that φ is in the stable region breaks down, as some iteration of ε and signal x will break down. At this point, uncertainty induces some belief that fundamentals are below the stable region, rendering attack by all the optimal strategy. Even if fundamentals are not in the unstable region, the outcome of the ripe-for-attack region becomes the self-fulfilling default on government debt, sending the economy into explosive debt patterns. Therefore, in the presence of uncertainty, even if the economy's underlying fundamentals are not truly located in the 'unstable region', speculators consider that a potential speculative attack ('ripe for attack' region of multiple equilibria) is bound to send the economy into default. The addition of 'constructive ambiguity' in the context of higher order- beliefs and the failure of common higher order knowledge,[141] explains how government debt default becomes a self-fulfilling prophecy.

3.5 Government Debt Equilibria under 'Radical Uncertainty'-Sunspots

Section 3.3 has provided a simple debt-crisis-based framework for the onset of a sovereign debt crisis arising due to changes in fundamentals and shifts in expectations. However, it does not apply to the analysis of the onset of sovereign debt crises, occurring due to some random pervasive extrinsic shock which may be suddenly and unexpectedly imposed on fundamentals, as occurred in the 2020 COVID-19 crisis.[142] This uncertain random shock is differentiated from the information and strategic uncertainty inherent in financial markets, as portrayed in *Section 3.4*[143]. Thus, the economic impact of COVID-19 on fundamentals serves as an excellent example of a "sunspot variable".

i. Sunspots

Sunspots[144] are "'extrinsic random variables' upon which agents coordinate their decisions" (Shell, 2007). Sunspot equilibria were first introduced by Cass and Shell (Shell, 1977; Cass and Shell, 1982, Cass and Shell, 1983) in "complete rational expectations, general equilibrium models" as an explanation for "excess volatility" (Shell, 2007). Shell (1977) explains that sunspot equilibria may be "mere

[141] The process via which higher-order knowledge breaks down rests on the fact that additional noise in the market, even in the absence of a novel informational event, may suffice to induce uncertainty-driven panic and an inefficient process of aggregation of market beliefs, as opposed to the efficient market hypothesis.
[142] COVID-19 imposed a large negative shock to fundamentals, unrelated to previous period fundamentals, resulting in higher levels of debt and higher risk premia on government debt, indicating a jump to a higher critical threshold of default. Thus, due to this extrinsic uncertainty shock, the economy jumped to an equilibrium where default is more likely. In this section, the simple Jeanne and Masson (2000) model adaptation under common knowledge will be used.
[143] A more elaborate model could show how 'radical uncertainty' interacts with such information-based uncertainty or strategic uncertainty in financial markets to amplify its effects.
[144] The name of such 'sunspot equilibria' has been inspired by Jevons (1878), who noting the random shocks to business cycles, decided to relate business cycle activity to sunspot cycle activity, as observed via telescopes.

randomizations over certainty equilibria", yet "typically they are not" (Shell, 2007).[145] In a game theoretical context, sunspots are "payoff irrelevant signals that coordinate players' expectations" (Morris and Shin, 2003).

According to the so-called 'Cass-Shell Sunspot Immunity Theorem', sunspots matter if and only if there is heterogeneity of beliefs, i.e. agents differ in their beliefs. According to this reading, heterogeneity of beliefs may be one of many sources of sunspots (Shell, 2007).[146] Clearly, sunspot equilibria arise when securities markets are incomplete, and would hence be partially remedied under instruments which increase market completeness as the state-contingent debt proposal discussed in Chapter 5[147].

In pursuit of insight to crisis outcomes due to the prevalence of uncertainty, Shell (2007) distinguishes between sunspot-induced extrinsic random shocks from what he calls 'market uncertainty'. Shell (2007) defines *'market uncertainty'* as uncertainty "created by the economy or adopted from outside the economy as a means of coordinating the plans of individual agents" (Shell, 2007). This definition of uncertainty points to the direction of *"strategic uncertainty"*, which Morris and Shin (1998a) relate to the coordination of market players' beliefs about each other's beliefs regarding fundamentals. Strategic uncertainty emerges due to 'higher order uncertainty' when the assumption of common knowledge is relaxed. Similarly, Morris and Shin (1998a) reference sunspots as a mechanism for the formation of beliefs which are not fully determined by fundamentals yet are logically consistent and coherent. However, the game-theoretic debt crisis literature widely regards 'sunspots' as a random variable on which agents coordinate their beliefs. The outcome of this modelling assumption is the multiplicity of equilibria outcomes. Hence, in such models, sunspot variables resolve strategic uncertainty by introducing fundamentals uncertainty. Under this definition, sunspot-induced radical uncertainty ought to send the economy back to the initial fundamentals-based and expectations-based continuum of

[145] A concise review is provided by Karl Shell (2007), one of the main contributors. Benhabib and Farmer (1994) extensively discuss the sunspots in the context of business-cycle activity.

[146] According to this argument, Morris and Shin (1998a) higher order beliefs could be grouped as one among many sources of sunspot equilibria.

[147] However, Shell (2007) cautions that as argued by Antinolfi and Keister (1998), state-contingent instruments do not immunize the economy against sunspots, as sunspots do not always arise solely due to incomplete markets.

multiple equilibria, as presented in the Jeanne and Masson (2000) context. Morris and Shin (2003) warn against the modelling abuse of sunspot variables as proxies for events such as informational public announcements, as not all such announcements are *fully* payoff-irrelevant, as would have been required by the proper sunspot definition.

ii. Sunspot Equilibria for Government Debt

Sunspot equilibria may be defined as equilibria which result due to the effect of extrinsic uncertainty via a *sunspot*, namely, a variable that affects the coordination of investor expectations (or higher order beliefs) about the state of economic fundamentals. Thus, although jumps across equilibria, corresponding to different levels of default expectations, may arise due to the multiplicity of fundamentals-based equilibria, they may also arise due to extrinsic uncertainty, which is to be distinguished from investors' beliefs about the location of the critical threshold of fundamentals which induces default. In sunspot equilibria, it is the effect of stochastic uncertainty on the coordination of agents' beliefs about such thresholds which gives rise to jumps.

The following characterization of sunspot equilibria is provided by Jeanne and Masson (2000) and may be applied as an extension of our sovereign debt model, as in Bruneau et al. (2012, 2014) and Do Bernardo (2016):

- There are n states s=1,2,…n in the economy, each associated with a different critical level of fundamentals driving the default decision, φ_s^*, below which the government's optimal policy rule is to default (i.e. if $\varphi<\varphi_s^*$) (Bruneau et al., 2012, 2014; Do Bernardo, 2016)
- In time period t, there are as many critical values of fundamentals as there are states to the economy, which may be ranked by increasing order ($\varphi_1^*<\varphi_2^* < \varphi_3^* < \cdots < \varphi_n^*$), so that if default is optimal for the government in state s, it is also optimal for any state higher than s (Bruneau et al., 2012, 2014; Do Bernardo, 2016).

- The economy transitions to future states according to a Markov process and the matrix $\Theta=[\theta(i,j))]_{1\leq i,j\leq n}$, which is independent of fundamentals[148] (Do Bernardo, 2016).

Comparing *sunspot equilibria* to *fundamentals-based equilibria*, Jeanne and Masson (2000) caution that the former also depend on future states of the economy in addition to fundamentals, thus, the distinction between φ_s^* and φ*, which respectively correspond to default decision critical values of fundamentals.

Thus, as in Jeanne and Masson (2000) and Do Bernardo (2016), the probability of default in a sunspot equilibrium (π_t) corresponds to the sum of the next-period probability of default $F(\varphi_t, \Phi_s^*)$, weighted by transition probabilities from state at time t to future states ($\sum_{s=1}^{n} \theta(s_t, s)$):

$$\pi_t = \sum_{s=1}^{n} \theta(s_t, s) F(\varphi_t, \Phi_s^*) \tag{3.29}$$

Following Jeanne and Masson (2000), the Net Benefit of Repayment function (NB) in state s becomes a function of the critical value of fundamentals, in addition to the current state and probability of transition to future states, as follows:

$$\varphi \rightarrow NB(\varphi, \sum_{s=1}^{n} \theta(s, s') F(\varphi, \varphi_s^*)) \tag{3.30}$$

(Do Bernardo, 2016).

As with fundamentals-based equilibria (Section 2.3), the increasing nature of the net benefit function implies that there exists a unique level of fundamentals φ_s^* for which the government is indifferent between repayment and default, such that the net benefit of repayment is zero (Do Bernardo, 2016).

As in *section 2.3*, under rational expectations equilibria, the vector $(\varphi_1^*, \varphi_2^*, \ldots, \varphi_n^*)'$ of critical thresholds should satisfy the below fixed-point equations (Jeanne and Masson, 2000):

$$\text{For every } s \in [1,n],\ \varphi_s^* = H_s(\varphi_1^*, \varphi_2^*, \ldots, \varphi_n^*) \tag{3.31}$$

[148] As noted by Jeanne and Masson(2000), the transition matrix under a fundamentals-based equilibrium is simply the identity matrix, such that the economy does not transition across states but remains in the initial state, thereby indicating that the fundamentals-based equilibrium is a degenerate case of sunspot equilibria (Do Bernardo, 2016).

Jeanne and Masson (2000) distinguish the following: first, the existence of sunspot equilibria is predicated upon the existence of multiple equilibria for sovereign debt (Jeanne and Masson, 2000); second, a comparison to the second-generation crisis models results shows that sunspot equilibria contribute to the understanding of crises by showing that an infinite number of sunspot equilibria may be ‘stacked’ next to each other in a continuum at the limit case, as opposed to the maximum number of three states assumed in second-generation crisis models (Jeanne and Masson, 2000). Differences in the number of states arise due to differences in the setup with respect to the timing of the formation of expectations of default across the two frameworks (Jeanne and Masson, 2000).

Second-generation models assume that the government’s net benefit of repayment depends not on current-period expectations of default but on previous-period expectations of default, such that equation (*3.5*) is replaced by equation (*3.32*) as follows:

$$\pi_t = Prob[NB(\varphi_{t+1}, \pi_t) < 0 \mid \varphi_t] \qquad (3.32)$$

Jeanne and Masson (2000) compare equations (*3.5*) and (*3.32*) to show that the second-generation model expected probability of default is a closed-loop equation whereas the sunspot model in this paper, as in Krugman (1996) is open-loop, thus, yielding more than three equilibria.

In summary of the above, the Jeanne and Masson (2000) adaptation does not provide an answer as to whether the impact of a sunspot variable makes the transition to a “default crisis” equilibrium more likely. Instead, the size of the crisis region seems to depend on expectations, as before, yet sunspots increase ad infinitum the intermediate points, thus, merely enriching the existing framework (Jeanne and Masson, 2000). Plausibly, as sunspots increase the plethora of outcomes, they simply add to the uncertainty about final-outcome predictions. This type of implied uncertainty, however, may not imply any ex-ante increase in the probability of default[149].

[149] A more apt extension of the argument could make use of Chaos Theory.

3.6. Conclusion

The contribution of the above chapter is to elaborate on the process of market belief formation during self-fulfilling debt crises by applying existing frameworks from the currency crisis literature. A coherent framework for the observed multiplicity of outcomes/states in government debt has been provided and an explanation for the process via which the single self-fulfilling default outcome may arise has been offered. Essentially, the applied model proposes an explanation of how any ambiguity or lack of transparency may be related to the emergence of the bad equilibrium over a zone of questionable fundamentals, thus, building a case against 'constructive ambiguity' arguments. Nevertheless, extensions relying on chaos theory and not on stochastic uncertainty could shed new light on the above conclusions.

The application of Jeanne and Masson (2000) and Morris and Shin (1998a) to sovereign debt has elaborated on the role of uncertainty, under various forms, and its effects on the multiplicity of outcomes. Under the Morris and Shin (1998a) definition, uncertainty is portrayed as a noisy error term in the informational signal received by market participants and sets in motion the dynamics that lead to the unique self-fulfilling outcome. In contrast, 'radical uncertainty' which is of non-economic nature, as depicted via a 'sunspot' shock, serves to multiply the multiple equilibria outcomes. The link of sovereign debt crisis to currency crisis models is accomplished through the excess of the interest rate on government debt compared to a maximum sustainable interest rate.

Future research could remedy the following additional limitations: First, a more formal treatment of the fiscal calculus inherent in the government-default decision-making process could be incorporated, using a more detailed analysis of the variables that underlie the costs and benefits in the government default decision-rule. This chapter was limited to an event-driven focus for the onset of debt crisis whereby the short timeframe around some crisis-event is usually not accompanied by a change in official reported fundamentals. Thus, although fundamentals are incorporated in the model, they are accorded only through the higher-level treatment as the focus rests on the behaviour of capital markets. Second, future research could elaborate on the type of government and its preferences. In this chapter, a benevolent rational government is assumed to make the default decision by rationally accounting for the Net Benefit from repayment against default. This assumption is made due to the short timeframe of the onset of debt crisis studied, over which usually no major ideological changes occur, except perhaps under a change in political parties. Future research could elaborate on the effect of different distributions of loss from default by different political parties. Third, as opposed to using discrete timing, future research could involve a continuous-time framework, which is more realistic for modern financial market pricing. However, the higher order beliefs process somewhat compensates against this deficiency. Fourth, one-period debt is implicitly assumed. Future models could incorporate multi-period debt, which would be more useful in a political economy framework depicting time-inconsistent fiscal choices.[150] Fifth, in addition to the interest-rate on government debt, a link could be provided via the other main variables in the basic debt-evolution dynamics equation (level of economic growth, primary surplus). Sixth, a distinction could be made between full or partial default. Seventh, a distinction between private and public signals, and relative weighting among the two, could be incorporated in the belief formation process and noisy signal ε.

[150] Romer's (2012, pp. 632-639) model of multiple equilibria for sovereign debt crises suggests that the beliefs of other market participants become relevant under a multi-period setup.

Appendix A3.1 Summary of Model Variables and Notation

Table A3.1: Summary of Notation

φ	Fundamentals
f(φ)	Function of fundamentals
φ^{*e}	Critical default threshold expected by investors
φ^{*}	Actual default threshold for government, based on its budget constraint and Cost-Benefit-Analysis; corresponds to the unique level at which aggregate short sales equal those required to induce default, i.e. s(φ, I_{x*})=α(φ)
r^{*}	Maximum sustainable interest rate on debt
r	Effective actual interest rate on debt
α(φ)	% of speculators required to attack the public debt to induce default
C(α, φ)	Cost of no default (debt repayment) to the government
$\bar{\varphi}$	The attack/not attack threshold
$\underline{\varphi}$	The repay/default threshold
x	Information signal about fundamentals
ε	Noise in information signal about fundamentals
x*	Unique signal of fundamentals, at which a speculator is indifferent between attacking or not attacking the government debt; corresponds to φ^{*e} (in the Jeanne and Masson(2000) notation)
σ(x)	Short-selling strategy (% of speculators who attack given signal x)

s(φ, σ)	Actual short sales given fundamentals φ and short-selling strategy σ
A(σ)	Event of default; defined based on a comparison of the actual short sales s ( ) and the percentage of speculators required to induce default α( )
h (φ, σ)	Payoff to speculator from attack
U (x, σ)	Conditional payoff to speculator from attack
k	Level of signal of fundamentals x below which all speculators attack the public debt
$I_k x$	Aggregate short-selling strategy; as opposed to conditional short selling strategy σ(x)
U (k, I_k)	Ex ante payoff for aggregate sales given critical signal k; this is equal to zero at the unique x*
s(φ, I_x *)	Aggregate (actual) ex post short sales; compare to s(φ, σ)
Sudden self-fulfilling crisis	Occurs when nth order common knowledge that fundamentals are not in the multiple equilibria region fails, i.e. some investor receives some signal according to which the government will default. Subsequently, increasing percentages speculators attack, as based on their payoff structure they have an incentive to attack if such signal is true. Their attack induces an increasingly insurmountable cost of repayment for the government, thus, precipitating the default. Default crisis expectations become self-fulfilling.

Chapter 4:

Greek Sovereign Spread and Uncertainty:

Fundamentals or Market Sentiment?

4.1. Introduction

This chapter presents a *threshold model* for the Greek sovereign spread. *A market-based metric for uncertainty* is developed through GARCH methods and is subsequently applied as a transition variable to determine two pricing regimes for the Greek sovereign spread: a high-uncertainty pricing regime and a no-uncertainty pricing regime, as in the Morris and Shin (1998a) application suggested in Chapter 3. The implicit assumption is that since 1999, the Greek economy has operated within a zone of multiple equilibria, also evidenced through Time-Varying Coefficient methods. The use of an estimated time-varying measure of uncertainty is well-suited to capture the multiplicity of equilibria within the multiple equilibria zone. Threshold regression further divides the multiple equilibria zone into a 'good equilibrium' zone and a 'bad equilibrium' zone. Component-GARCH estimation shows how time-periods associated with peaks in the Greek debt crisis narrative are driven by short-term market sentiment and liquidity effects.

The model in this chapter is related to the theoretical model in Chapter 3 as follows: *firstly*, since 1999, the Greek sovereign debt is assumed to have resided in the intermediate zone of economic fundamentals in Chapter 3, where both a good and a bad equilibrium are possible and where the bad equilibrium emergences upon the crossing of a threshold of uncertainty (noise greater than ε). In parallel, a critical threshold level of uncertainty is estimated, corresponding to the level of noise beyond which the bad-equilibrium regime operates. Below this critical threshold of uncertainty, the model is in the 'no uncertainty' 'good equilibrium' case of Chapter 3. *Secondly*, in addition to fundamentals, the operation of the uncertainty regime for the Greek sovereign spread is related to market sentiment and liquidity conditions, as theoretically prescribed in Chapter 3. *Thirdly*, CGARCH modelling results relate the effect of the *short-term* component of market sentiment in the Greek sovereign spread to liquidity, as prescribed by the theoretical model. *Fourthly*, the threshold model in this chapter further investigates the Chapter 3 claim that market-sentiment effects are present in the high-uncertainty regime only. *Lastly*, T-GARCH, CGARCH-M and event study methods (see Appendix A4.4) examine the importance of the very short-term impact of news. In the context of Chapter 3, the impact of news serves to increase noise.

The contribution of this chapter is multi-fold: *Firstly*, to the best of our knowledge, this is the first time-series study of the Greek sovereign spread which incorporates GARCH modelling methods as a measure of uncertainty. *Secondly*, to the best of our knowledge, this chapter is the first to develop a threshold model for the pricing of the Greek sovereign spread. *Thirdly*, this study is the first to apply Component-GARCH methods for the distinction between a short-term and a long-term market-sentiment component in the Greek sovereign spread on a time series basis. *Fourthly*, the study provides a model with a very good in-sample forecasting power and fit to actual Greek sovereign spread data. *Fifthly*, the application of time-varying methods provides evidence of the multiplicity of equilibria in the Greek sovereign spread, which to date has not been explicitly shown in a time series context for Greece. *Sixthly*, the analysis accounts for the effect of the European Central Bank's (ECB) extraordinary policy measures in response to the crisis on the Greek sovereign spread in a time series context. *Seventhly*, the chapter accounts for spillover effects of the Eurozone periphery to Greek sovereign spreads through Principal Components Analysis (PCA), which to date has not been applied as such for Greek sovereign risk in a time series context.

This chapter is structured as follows: Section 4.2 provides a brief commentary of how this chapter is positioned with respect to related literature; Section 4.3 introduces the data inputs to the analysis, including separate estimation procedures required for the uncertainty metric (*T-GARCH-based time-varying conditional volatility*) and the Eurozone periphery spillovers measure (*Principal Component Analysis*). Section 4.4. applies rolling regression to the data as evidence of time-variation in the coefficients of the Greek sovereign spread, in further support of the multiple equilibria thesis. Section

4.5 applies threshold regression to the Greek sovereign spread to split the multiple equilibria zone into two regimes ('good' and 'bad equilibria' periods according to an estimated threshold of uncertainty) and provides a dating of uncertainty-regimes for the Greek sovereign spread since January 1999. Section 4.6 performs Component GARCH (C-GARCH) to distinguish the impact of a market-sentiment liquidity-driven component which determines sovereign spread outcomes in periods corresponding to the 'crisis regime'. Section 4.7 provides concluding remarks on the above and suggestions for future research.

In the Appendix, section A4.1 explains the Principal Components Analysis method; section A4.2 provides the outcome of parameter instability tests for the series included in the analysis; section A4.3 presents other pre-estimation and post-estimation tests relevant to the T-GARCH, threshold regression and CGARCH-M models; section A4.4 provides an event study of the Greek sovereign spread for key dates[151] in the narrative of the Greek debt crisis and as a complement to the very short-term nature of market-sentiment effects in the CGARCH-M and T-GARCH models. Section A4.5 presents the exact monthly regime classification into uncertainty/no uncertainty regimes by the threshold regression model.

4.2. Related Literature

Bruneau et al. (2012,2014) use panel threshold methods for the sovereign spreads of six Eurozone countries as an application of the Jeanne and Masson (2000) model of multiple equilibria. They provide the linearization of the probability of default for empirical threshold estimation. Unlike the selected specification in this Chapter (threshold regression), which is best suited to capture the distinction between the uncertainty and no-uncertainty case by the Morris and Shin (1998) extension of higher-order-beliefs, Bruneau et al. (2012, 2014) apply *smooth transition* threshold regression,

[151] Select dates relate to the following events: revelation of the true size of the budget deficit (19/10/2009); the downgrade of Greece into 'selective default' (SD) prior to the PSI (27/02/2012); the election of an anti-austerity leftist party (26/01/2015); the announcement of the Greek referendum (29/06/2015); the imposition of a generalized lockdown in response to COVID-19 (23/03/2020).

whereby the logistic function is used to portray the multiple equilibria in-between two regions separated by a threshold. As uncertainty is not explicitly introduced in the Jeanne and Masson (2000) framework, Bruneau et al. (2012, 2014) examine the model under alternative transition variables. According to Bruneau et al. (2012, 2014), the threshold variable serves as the device that coordinates expectations. Therefore, although threshold regression modelling does not account for the probabilistic Markov chain transitions alluded to in the Jeanne and Masson (2000) model, the sunspot interpretation may not be ruled out, as sunspots are exogenous shocks upon which agents coordinate their expectations.

The choice of the metric for uncertainty to be applied in this Chapter is based on the financial literature. GARCH methods have been applied to sovereign spreads for panel data. Assman and Boysen-Hogrefe (2012) make use of time-varying conditional volatility in the context of state-space methods for sovereign spreads. More relevant to our model are Caceres et al. (2012), Ribeiro et al. (2017) and Sabkha et al. (2018), all of whom, however, use panel data. Unlike these studies, due to the nature of the research question of this thesis, this chapter does not discontinue the analysis upon the estimation of a GARCH-*in-mean* model; instead, T-GARCH estimation is used to extract the time-varying conditional volatility, which is used as an input at a subsequent stage of the main analysis (time-varying coefficients and threshold regression).

The application of Principal Components Analysis (PCA) to sovereign bond yields in the EMU is based on Arghyrou and Kontonikas (2012) and on Afonso et al. (2014). In this line of literature, the second principal component of the yields of EMU core and periphery countries is extracted as a measure of the relative riskiness of the Eurozone periphery. Other studies of sovereign spreads involving Principal Components Analysis include, *inter alia*, Attinasi et al. (2009), Borgy et al. (2011), Manganelli and Wolswijk (2009), and Afonso et al. (2014).

The use of time-varying coefficients for the detection of multiple equilibria is based on Afonso et al. (2018), who apply the Li et al. (2012) Local Linear Dummy Variable method for panel data. Graphical observation of parameter instability and time-varying behavior is interpreted as evidence of multiple equilibria. The choice of variables to be used as determinants of the Greek sovereign spread in this Chapter is partially based on the Afonso et al. (2018) study.

The use of the Engle and Lee (1993, 1999) CGARCH-M model to separate a permanent from a transitory component for volatility is based on a relevant niche literature which relates the existence of components in volatility to trader heterogeneity in financial markets (Muller et al, 1997) and to heterogeneity of information through the arrival of news (Andersen and Bollerslev, 1997b; Zarour and Siriopoulos, 2008). The distinction of a short-run component in volatility is related to speculative short-term traders' position-taking models and market-sentiment effects (Li et al., 2012). A relevant application to EMU sovereign spreads (also covering Greece) has been proposed for panel data by Sosvilla-Rivero and Morales-Zumaquero (2012). Compared to this latter model, this Chapter proposes a time series CGARCH-*M* application to the Greek sovereign spread only and uses a sample that covers the entire debt crisis timeline. Other C-GARCH models have been applied in the literature to test the Uncovered Interest Parity (UIP) (Li et al., 2012) and currency crises (Guimaraes and Karacadag, 2004). According to the literature, the findings of of CGARCH models may be interpreted as a challenge of the Efficient Market Hypothesis, at least in its weak form (Haque et al.,2004; Abraham et al., 2002; Abu Zarour, 2007; Zarour and Siriopoulos, 2008).   The CGARCH model is used as an alternative to the FIGARCH model for long memory in the conditional variance.

A detailed analysis of the determinants of sovereign spreads and methods applied in the literature is offered in Chapter 2.

4.3. Data

This section provides the definition of the data inputs to the analysis, the selection of which is partially based on Afonso et al. (2018). It includes "non-derived" time series entries as well as two separate sub-sections where the estimation of two additional data inputs to the analysis is detailed. Section 4.3.1 presents the dependent and independent variables which did not require derivation. Section 4.3.2 presents the derivation of the proxy of uncertainty used in this chapter through the estimation of a T-GARCH model for the Greek sovereign spread, from which the time-varying conditional volatility is extracted as a data input to further analysis. Section 4.3.3 presents the Principal Components Analysis (PCA) estimation which has been applied to extract the data input corresponding to spillovers among countries in the EMU periphery.

4.3.1. The Dependent Variable and 'Non-Derived' Independent Variables

For the dependent variable, monthly data between January 1999 and December 2020 for the Greek 10-Year Government bond yield spread have been calculated based on monthly data for the Greek 10-Year Government Bond Yield ($Yield_{GR,t}$)and the German 10-Year Bund ($Yield_{GER,t}$) obtained from the FRED Database (2021g, 2021f). The spread has been calculated based on the following equation:

$$spread_t = Yield_{GR,t} - Yield_{GER,t} \quad (4.1)$$

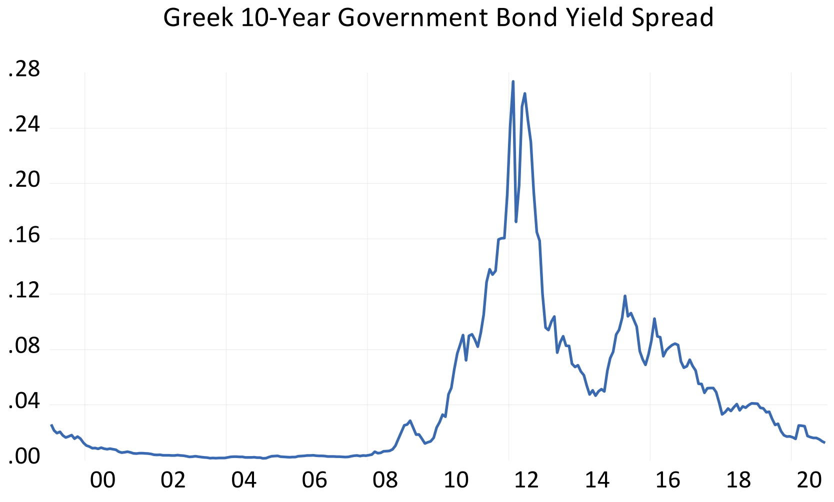


Figure 4.1: Plot of the Greek 10-Year Government Bond Yield Spread

Following the literature,[152] our analysis includes the following variables for monthly data (Jan. 1999-Dec.2020):

- The **VIX Index (VIX)**: the investor 'fear index' i.e. a measure of the volatility of the Chicago Board Options Exchange and a standard proxy of global investor risk aversion. The VIX

[152] The selection of variables has been based on the paper by Afonso et al. (2018), with the addition of the uncertainty proxy (GARCH time-varying conditional volatility term).

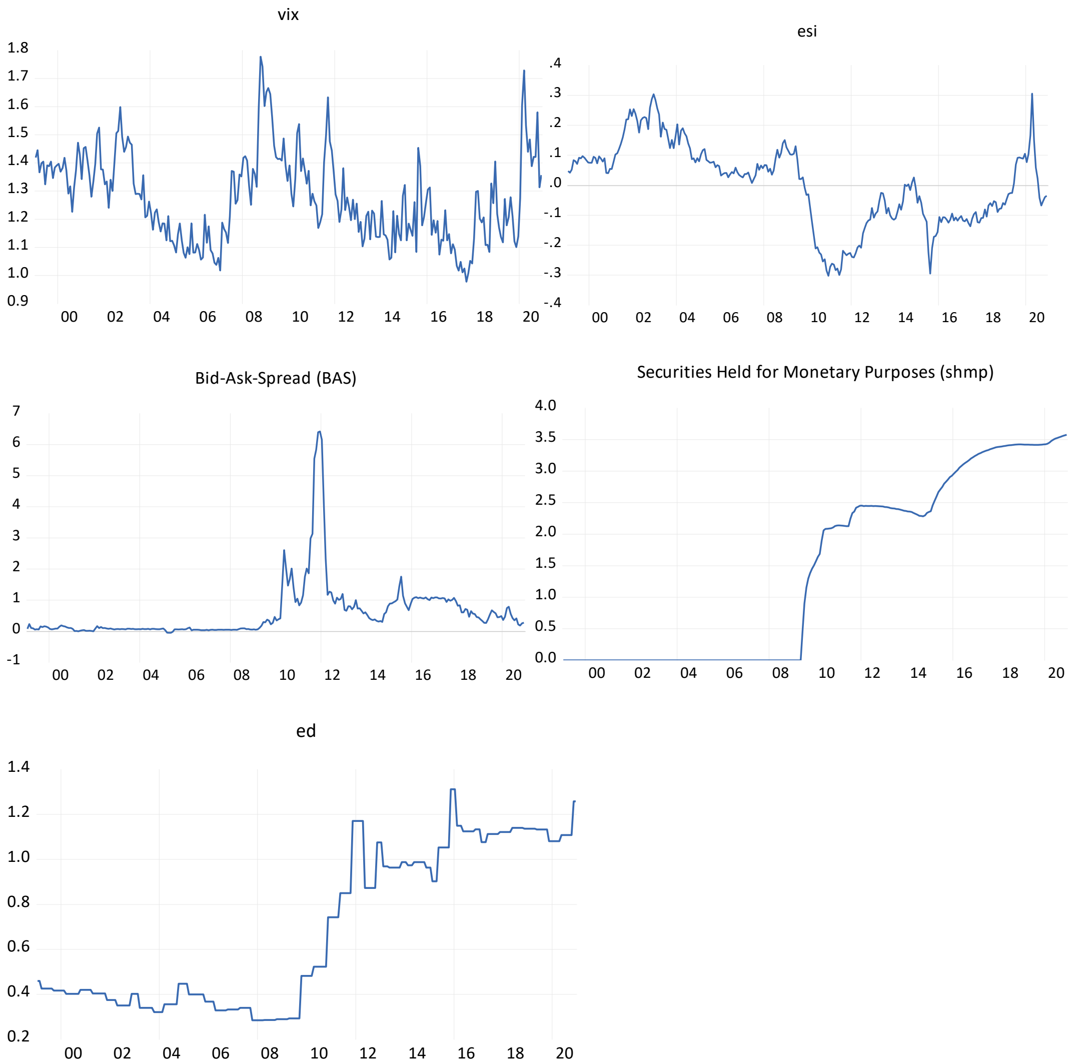
index measures the implied volatility of the S&P 500 index based on a panel of options prices. An increase in global risk aversion has been associated with an increase in sovereign spreads (Beber et al., 2009, Afonso et al., 2015). Low pre-crisis values are shown for this index, followed by substantial increases between 2007 and 2012, and a gradual decline to pre-crisis levels (Afonso et al., 2018). The eruption of the COVID-19 pandemic was accompanied by near-peak levels in the VIX in March 2020. Thereafter, global risk aversion subsided, yet remained far from its pre-COVID-19 low normal. Model estimation includes the logarithm of the vix. Data has been obtained from the FRED Database (2021l).

- The **Bid-Ask spread (BAS)** on 10-year Greek Government Bonds: a measure of liquidity risk. An increase in the bid-ask spread level indicates dvveteriorating liquidity conditions and has, thus, been associated with an increase in sovereign spreads (Favero et al., 2010; Gerlach et al., 2010). The bid-ask spread increased sharply in the beginning of the financial crisis and continued on its upward trend during the Eurozone debt crisis, yet it declined significantly in the aftermath of the ECB's extraordinary reaction to the crisis in 2012. A brief deterioration in liquidity conditions occurred in 2015. Thereafter the bid-ask spread on the Greek 10-year government bond has gradually declined, yet it remains higher than its pre-crisis levels. Data has been obtained from Bloomberg Terminal (2021).
- The **Economic Sentiment Index (ESI)**: a forward-looking measure of economic activity, defined as the difference of the logarithms of the respective ESI indices between Greece and Germany. The ESI is a weighted average of the scores of five survey-based indices reflecting agents' assessments of current economic activity and expectations of future developments. Increased levels of economic activity have been associated with lower credit risk and, thus, with lower levels in sovereign spreads (Monford and Renne, 2013; Dewachter et al., 2015). Data has been obtained from Eurostat (2021).
- The **Expected Debt Differential (ED)**: the difference between the European Commission's forecasts for the general government gross debt-to-GDP ratio of Greece to that of Germany (as a measure of fiscal risk) (European Commission, 2021a). A higher expected debt

differential has been associated with a higher sovereign spread. The *expected* debt differential has been incorporated in lieu of the realized difference in government debt ratios between Greece and Germany to account for the fact that financial markets are forward-looking, and in line with previous studies (Attinasi et al., 2009; Arghyrou and Kontonikas, 2012). As European Commission economic forecasts are available on an approximately quarterly basis[153], in-between monthly values have been kept constant and equal to the previous forecast of the expected debt differential. This introduces an element of discreteness in the data, as in Afonso et al. (2018).

- **"Securities held for monetary purposes by the ECB (SHMP)"**: as a proxy for the unconventional monetary measures adopted by the ECB in response to the crisis, as in Afonso et al. (2018). Data has been obtained from the end-of-month weekly consolidated financial statement of the Eurosystem (item 7.1, asset side), as in Afonso et al. (2018). In the context of the Securities and Markets Program (SMP) in 2010 and since the onset of the Quantitative Easing (QE) programme in 2015, the ECB has significantly increased the size of its balance sheet. Although Greek government bonds were not eligible for the ECB's QE programme until 2020, Greek government bonds may have benefited indirectly through the positive liquidity effects in Eurozone debt capital markets. According to the literature, an increase in asset purchases by the ECB increases liquidity and may, thus, be associated with a decrease in sovereign spreads (Afonso et al., 2018). Unlike Afonso et al. (2018), this Chapter does not consider the change in this variable nor does it apply the metric at a separate second stage of estimation.

[153] European Commission Forecasts are available in February -Winter Economic Forecasts, in May-Spring Economic Forecasts, in July-Summer Economic Forecasts, and in November-Autumn Economic Forecasts.



Figures 4.2-4.6: *Plots of the Determinants of Sovereign Spreads included in the analysis*

4.3.2 Estimating a Measure of Uncertainty-A GARCH Model for the Greek Spread

Evidence of volatility clustering patterns in the plot of the Greek spread (*Figure 4.1*) and heteroskedasticity tests (Appendix A4.3) suggest that a GARCH model could be appropriate for the Greek sovereign spread.

T-GARCH Models

In line with the inclusion of the VIX as a measure of the implied volatility of the S&P 500 in other studies, this study seeks to complement risk aversion metrics with a Greek idiosyncratic measure of uncertainty that is financial-markets-based and which bears the greatest relation to Greek government debt dynamics and debt sustainability:[154] the time-varying conditional volatility of the Greek sovereign spread. Given the presence of heteroscedasticity, a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model for the Greek spread is developed to build a measure of uncertainty.

The GARCH model belongs to the ARCH family of models. ARCH models were introduced by Engle (1982) and GARCH models by Bollerslev (1986) and Taylor (1986) (Eviews User Guide, 2020). Bollerslev, Chou, and Kroner (1992) and Bollerslev, Engle, and Nelson (1994) provide relevant surveys (Eviews User Guide, 2020).

In a GARCH (1, 1) model, the conditional variance evolves according to an ARCH term, represented by lags of the error term ε_t which follows a conditional distribution Ψ_t, and a GARCH term, represented by lags of the variance:

$$y_t = x_t' b + \varepsilon_t$$

$$\varepsilon_t \mid \Psi_t \sim \mathrm{N}(0, \sigma_t^2)$$

$$\sigma_t^2 = \omega + a_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad (4.2)$$

(Greene, 2002).

GARCH models are a popular method for financial time series that exhibit time-varying volatility or volatility clustering, where periods of calm and turbulence are interchanged. Such models are well-suited to study crisis dynamics, whereby brief peaks in volatility alternate with the low-volatility levels exhibited during non-turbulent periods.

Among the options available in the GARCH family, the T-GARCH model is applied, as it includes a threshold leverage term (Black, 1976; Christie, 1982) for the asymmetric impact of bad news against good news. This is complementary to the event study analysis in Appendix A4.4 and fits well with market-sentiment and uncertainty effects described in Chapter 3.

[154] As detailed in Chapter 2, the sovereign spread is a measure of debt sustainability.

Two main versions of the T-GARCH model exist: *The GJR-GARCH* (Glosten, Jagannathan and Runkle (1993)) and the T-GARCH by Zakoian (1994). According to the GJR-GARCH model applied in the analysis, the error term may be modelled as follows:

$$\varepsilon_t = \sigma_t z_t, with\ z_t\ i.i.d. \quad (4.3)$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \varphi\varepsilon_{t-1}^2 I_{t-1} + \beta\sigma_{t-1}^2$$

where I_{t-1}=0 if ε_{t-1}≥0 and I_{t-1}=1 if ε_{t-1}<0 is a dummy variable for the asymmetric effect of news, also known as the 'leverage term' (Black, 1976; Christie, 1982).[155]

Compared to a GARCH(1,1) model, the T-GARCH model contains a dummy variable which takes the value of 1, when residuals are negative and thus corresponds to negative news. The T-GARCH term consists of the interaction of this term with the first lag of the residual. According to the model specification applied to asset returns in the literature, the coefficient on this term should be positive and significant for bad news to bear a stronger asymmetric impact on asset returns. However, in the context of speculative pricing behaviour, financial literature confirms the possibility of a negative sign, such that positive news bear a larger impact than negative news on asset returns (e.g. Koutmos et al., 1993). The impact of news through this T-GARCH term relates to information signals in Chapter 3 and provides a method to empirically validate the prescriptions of the theoretical model. The news impact in T-GARCH methods complements well event-study methods (*see Appendix A4.4*).

Estimation is performed in EVIEWS 12, using the spread as a dependent variable, a constant and the first autoregressive term under a Gaussian error distribution. The GARCH term is the estimated time-varying conditional volatility of the Greek sovereign spread based on a GARCH(1,1) model (Bollerslev, 1986).The first order of ARCH, GARCH, and TARCH effects have been included. The

[155] According to Chistie (1982), the naming of the threshold effect as leverage effect emerges as follows when the threshold GARCH model is applied to price of equity: a reduction in equity value raises the debt-to-equity ratio, thereby increasing the riskiness of the firm, which in turn, raises future volatility.

BFGS Optimization method is applied, with the Marquand step method, maximum iterations 500 and Convergence 0.0001.

T-GARCH Model Results

Dependent Variable: SPREAD

Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)

Date: 03/05/21 Time: 20:54

Sample (adjusted): 1999M02 2020M12

Included observations: 263 after adjustments

Convergence achieved after 41 iterations

Coefficient covariance computed using outer product of gradients

Presample variance: backcast (parameter = 0.7)

GARCH = C(3) + C(4)*RESID(-1)^2 + C(5)*RESID(-1)^2*(RESID(-1)<0) +
C(6)*GARCH(-1)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	1.84E-05	3.81E-05	0.482509	0.6294
SPREAD(-1)	0.982420	0.008506	115.4937	0.0000
Variance Equation				
C	5.02E-09	2.43E-09	2.063061	0.0391
RESID(-1)^2	0.441437	0.065388	6.751085	0.0000
RESID(-1)^2*(RESID(-1)<0)	-0.258428	0.069363	-3.725754	0.0002
GARCH(-1)	0.766920	0.023491	32.64773	0.0000

R-squared	0.958781	Mean dependent var	0.042728
Adjusted R-squared	0.958623	S.D. dependent var	0.053528
S.E. of regression	0.010888	Akaike info criterion	-9.191433
Sum squared resid	0.030943	Schwarz criterion	-9.109939
Log likelihood	1214.673	Hannan-Quinn criter.	-9.158683
Durbin-Watson stat	1.761465		

Table 4.1: T-GARCH Model Results

The estimated T-GARCH model in *Table 4.1* explains 95.9% of the variance according to the Adjusted R-squared. The estimated ARCH (1), GARCH (1) and T-GARCH (1) coefficients are highly significant. The statistical significance of the T-GARCH term confirms the asymmetric impact of good news and bad news. Against the testable hypothesis in T-GARCH models, the coefficient on the T-GARCH term is negative (-0.258), indicative of a stronger impact by positive news than by negative news. This finding may be explained by interpreting the sovereign spread as a risk premium rather than as a return. As such, positive shocks are associated with negative news, which result in an increase in the variance of the risk premium (i.e. in the variance of the Greek sovereign spread). In contrast, negative shocks are associated with good news for the sovereign spread. An alternative explanation evokes the literature on currency crisis models, in which a negative coefficient is indicative of the speculative behavior associated with financial crises.

For stationarity, the sum of the coefficients of the ARCH and GARCH terms should be less than 1. In the estimated model, the sum of the ARCH and GARCH coefficients exceeds 1, indicative of non-stationarity. However, once accounting for the negative coefficient of the TARCH term, the sum is less than 1. Furthermore, according to Tong (2010), Threshold Volatility Models (TVM) are always strictly stationary and ergodic. Under positive shocks (bad "spread-increasing" news), the spread appears to be non-stationary, whereas it remains stationary for negative shocks (good news). This may be interpreted as evidence of speculative behaviour.

The Uncertainty Variable

Based on the outcome of the TGARCH model, the time-varying conditional variance is used as a proxy of radical uncertainty in the Greek sovereign spread market (*Figure 4.7*).[156]

[156] The presence of fat tails and uncertainty in speculative prices, as measured by time-varying second moments was first highlighted by Mandelbrot (1963) and Fama (1965).

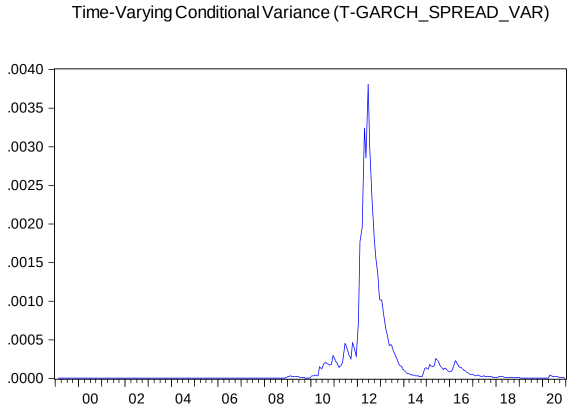


Figure 4.7: Plot of the T-GARCH-based Time-Varying Conditional Variance of the Greek sovereign Spread

Figure 4.7 plots the uncertainty metric (*uncertvar),* namely the time-varying conditional variance of the Greek sovereign spread which will be used in subsequent steps of analysis in this Chapter. The estimated uncertainty metric is close to zero for the pre-crisis period, increases gradually at the onset of the Greek debt crisis and peaks in 2012, at the peak of the Eurozone debt crisis and Greek PSI. Additional small bouts of uncertainty are noted in 2015, when the Second Economic Adjustment Programme ended and the newly elected government undertook a referendum prior to the adoption of the Third Economic Adjustment Programme for Greece. A minor increase in uncertainty is also observed at the end of the sample in 2020, associated with the COVID-19 crisis.

True to the properties of 'higher-order' uncertainty described in Chapter 3, the estimated metric of uncertainty (uncertvar) is not explained by any of the market sentiment or fundamentals determinants of sovereign spreads, nor by the typical measures of uncertainty included in the literature (the VIX index and Economic Policy Uncertainty (epu)). Adjusted R-square is less than 20% and none of the common measures of risk or uncertainty, namely the VIX and Greek EPU, nor the determinants of sovereign spreads explain the estimated measure of uncertainty at the 5% level of statistical significance (see Appendix A4.3, *Table A4.20*). The selected variable is, therefore, a good proxy for radical uncertainty- closer the Knightian sense (Knight, 1921). The behavior of the estimated variable for uncertainty over time (*Figure 4.7)* provides a better fit to Greek data than Greek EPU, which displays peaks during pre-crisis years.

4.3.3 *PC2N:* A Principal-Components-Analysis-Based Measure for EMU Periphery Spillovers

This section estimates a measure of contagion in the Eurozone periphery based on the Principal Components Analysis (PCA) of the 10-year government bond yield spreads of ten Eurozone countries against Germany (in percentage points). Rather than capturing global risk aversion as the VIX index, the estimated variable *PC2N* is a measure of spillover effects between the government bond yield spreads of Eurozone periphery countries, which are perceived to be relatively riskier than core countries[157]. This variable accounts for an additional risk premium for countries in the Eurozone periphery and reflects views about macroeconomic convergence/divergence. According to Arghyrou and Kontonikas (2012) during the early pre-crisis period, investors flocked to periphery bonds in expectation of higher bond yields due to a 'convergence trading hypothesis'; yet, thereafter, 'flight-to-safety' effects were witnessed, as investors distinguished between fiscally sound core countries and the heavily indebted periphery. The measure of Eurozone periphery spillovers (*PC2N*) has been obtained as the negative of the second Principal Component in Principal Components Analysis (PCA) on the government bond yield spreads for ten Eurozone countries (Austria, Belgium, Finland, France, Greece, Ireland, Italy, Netherlands, Portugal, Spain). The methodology and the selection of counties is largely based on Arghyrou and Kontonikas (2012) and relates to the countries classified as "core" and "periphery" for the EMU.

Principal Components Analysis for the Spreads of Select Eurozone governments

Principal Components Analysis (PCA) was applied to generate the components that explain the joint variance in the 10-year government bond yield spreads of the following ten Euro Area countries including Greece: Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal and Spain. Monthly data for 1999m1-2020m12 has been extracted for 10-year government bond yields from the FRED Database (2021a-k). Spreads have been calculated by subtracting the

[157] The application of Principal Components Analysis (PCA) is based on Attinasi et al. (2009), Borgy et al. (2011), Manganelli and Wolswijk (2009), Arghyrou and Kontonikas (2012) and Afonso et al. (2015) inter alia. Contagion has been shown to be relevant for sovereign spreads by Beirne and Fratzscher (2013) and Goldstein (1998).

German Bund yield from the 10-year government bond yields of the ten euro area countries (in percentage points).

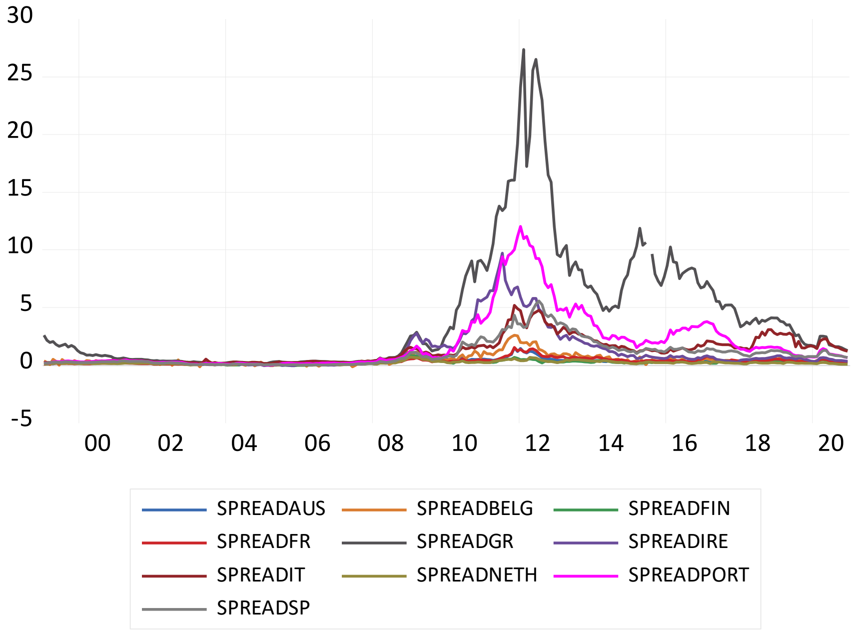


Figure 4.8 Eurozone 10-Year Government Bond Yield Spreads used in PCA (in percentage points)

Principal Components Analysis
Date: 07/18/21 Time: 18:57
Sample: 1999M01 2020M12
Included observations: 263
Balanced sample (listwise missing value deletion)
Computed using: Ordinary correlations
Extracting 10 of 10 possible components

Eigenvalues: (Sum = 10, Average = 1)

Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	8.021254	7.038707	0.8021	8.021254	0.8021
2	0.982547	0.555756	0.0983	9.003801	0.9004
3	0.426791	0.260796	0.0427	9.430591	0.9431
4	0.165995	0.034951	0.0166	9.596586	0.9597
5	0.131043	0.027840	0.0131	9.727630	0.9728
6	0.103204	0.035304	0.0103	9.830833	0.9831
7	0.067900	0.020150	0.0068	9.898733	0.9899
8	0.047750	0.016318	0.0048	9.946483	0.9946
9	0.031431	0.009345	0.0031	9.977914	0.9978
10	0.022086	---	0.0022	10.00000	1.0000

Eigenvectors (loadings):

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
SPREADAUS	0.318828	0.335638	0.153026	-0.267358	-0.398900	-0.179607	0.517439	0.423647	0.005594	0.228402
SPREADBELG	0.331886	0.023036	0.294197	-0.496257	-0.029022	-0.191921	-0.698811	0.120753	0.042799	-0.118629
SPREADFIN	0.264269	0.623934	-0.121484	-0.003062	0.157273	0.661114	-0.121179	-0.082625	-0.205925	0.019418
SPREADFR	0.339088	-0.023925	-0.310659	-0.195812	-0.118718	-0.211032	0.249971	-0.414125	-0.259138	-0.624364
SPREADGR	0.315297	-0.359191	-0.068857	0.231104	-0.522481	0.460067	-0.081362	0.118703	0.413601	-0.192342
SPREADIRE	0.302721	-0.142703	0.692002	0.128446	0.459689	0.123376	0.317719	-0.071177	0.114283	-0.216849
SPREADIT	0.319629	-0.148061	-0.494231	-0.280052	0.493739	-0.027231	0.120250	0.045819	0.481063	0.246416
SPREADNETH	0.306113	0.398686	-0.027516	0.616770	-0.027331	-0.463237	-0.185648	-0.177339	0.285654	0.057741
SPREADPORT	0.330423	-0.304585	0.104439	-0.014926	-0.170818	0.033784	-0.015547	-0.516942	-0.306365	0.628703
SPREADSP	0.327540	-0.271890	-0.198058	0.339017	0.207854	-0.077110	-0.100089	0.554691	-0.545504	-0.014508

Ordinary correlations:

	SPREADAUS	SPREADBELG	SPREADFIN	SPREADFR	SPREADGR	SPREADIRE	SPREADIT	SPREADNETH	SPREADPORT	SPREADSP
SPREADAUS	1.000000									
SPREADBELG	0.879973	1.000000								
SPREADFIN	0.847460	0.693893	1.000000							
SPREADFR	0.855022	0.870951	0.704468	1.000000						
SPREADGR	0.690562	0.802031	0.469672	0.861305	1.000000					
SPREADIRE	0.748946	0.860007	0.532996	0.729825	0.775193	1.000000				
SPREADIT	0.729917	0.801780	0.616677	0.934204	0.834106	0.677329	1.000000			
SPREADNETH	0.885408	0.786974	0.862645	0.814575	0.641312	0.682230	0.706215	1.000000		
SPREADPORT	0.752479	0.882760	0.511493	0.898225	0.943321	0.863019	0.856506	0.690876	1.000000	
SPREADSP	0.718106	0.820997	0.538907	0.902934	0.921931	0.787796	0.911061	0.729363	0.926360	1.000000

Table 4.2. Principal Component Analysis output

The first section of *Table 4.2.* presents the Principal Components ranked by the proportion of variance explained by each. The last column presents the cumulative proportion of variance explained by each component. Based on the estimation output, the first principal component (PC1) accounts for 80.21% of the variance and the second principal component (PC2) accounts for 9.83% of the variance. The first two principal components explain approximately 90.04% of the variance. *Figure 4.9* plots the first two principal components (PC1 and PC2, respectively) obtained from Principal Component Analysis.

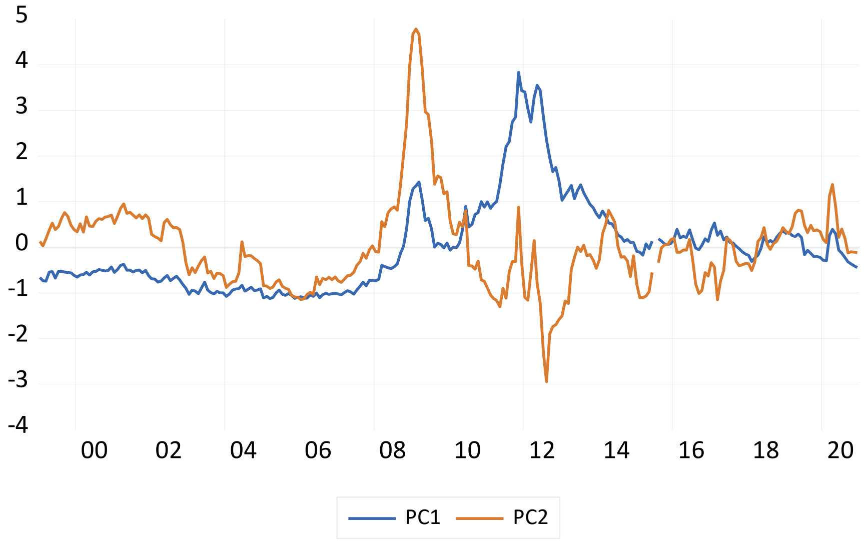


Figure 4.9 The first two principal components of PCA on government bond yield spreads

The location of the elbow in the screeplot is often used as an arbiter of the number of principal components to include in the analysis. Screeplots are a graphical method for selection of the appropriate number of PCs based on the location of the "elbow" of the chart of eigenvalues against the number of PCs. The points in the screeplot depict how much new information is provided by including an additional principal component.

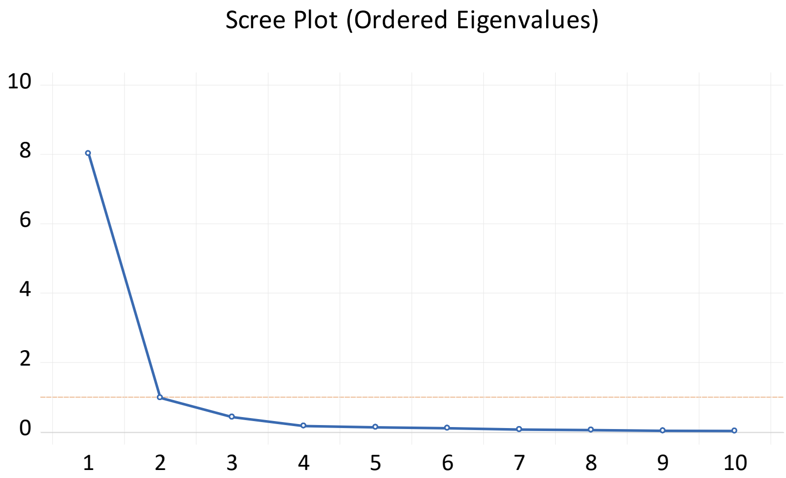


Figure 4.10 Scree Plot

The screeplot in *Figure 4.10* indicates that the first two estimated principal components are sufficient to explain the largest portion of the variance across government bond yield spreads in the euro area.

The second section of *Table 4.2* presents the loadings of each principal component corresponding to the Eurozone yield spreads. In line with the findings in the literature, positive loadings of approximately 30% are shown for PC1. The first principal component in related literature constitutes a measure of contagion or of Eurozone risk aversion. The low loading of Greece indicates that PC1 may not be the most relevant measure to incorporate in Greek sovereign bond yield spreads.

Based on *Table 4.2*, the signs of the loadings with respect to the second principal component for the spreads of Austria, Belgium, Finland and Netherlands is positive, whereas the sign of the loadings of the spreads of Greece, Ireland, Italy, Portugal and Spain is negative. Furthermore, the loading in the second principal component is largest in absolute magnitude for Greece, among the second group of countries, further validating that the second principal component may constitute a measure of the relative riskiness of the periphery. In contrast, Austria, Netherlands and Finland appear to be the safest among core countries. These results are in line with the findings in related literature.

For the second principal component (PC2), the opposite sign in the loadings of government bond yield spreads for core and periphery countries validates the interpretation provided in the literature: whereas the first principal component constitutes contagion, the second principal component is a measure of the relative risk and divergence of core versus periphery EMU government bonds. Orthonormal loadings are plotted in *Figure 4.11*, validating the core versus periphery distinction for the yields of euro area countries.

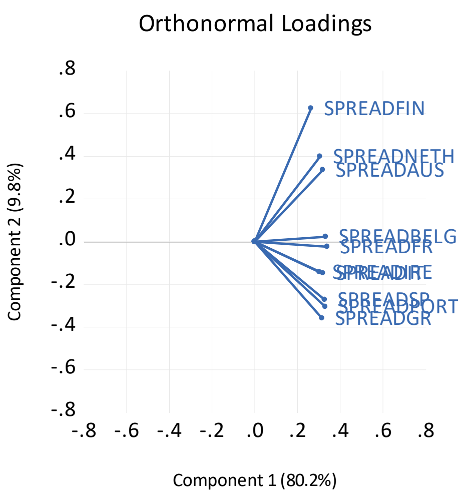


Figure 4.11: Orthonormal Loadings

The Eurozone Periphery Spillovers Measure

We follow Arghyrou and Kontonikas (2012) and normalize the second principal component (PC2 "normalized", PC2N) by taking the negative of the second principal component to ensure that it represents the relative risk of the periphery vis-à-vis core countries (*Figure 4.12*).

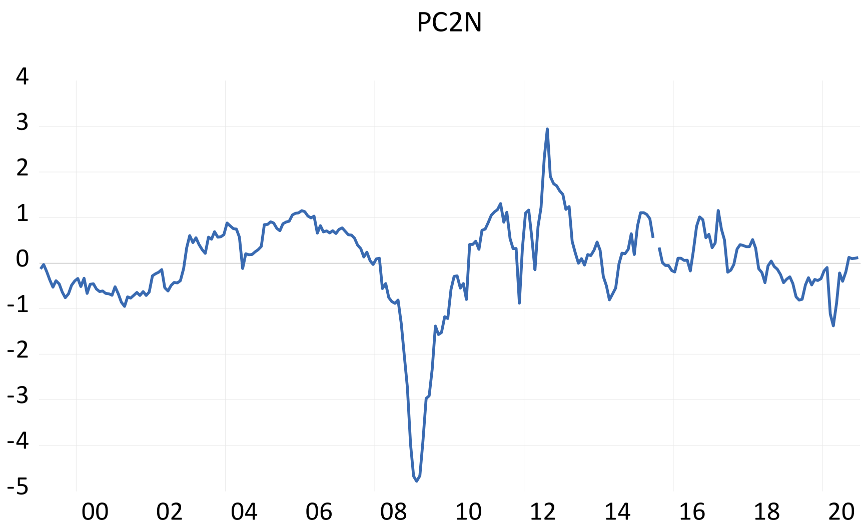


Figure 4.12: A PCA-based measure of Eurozone periphery spillovers

PC2N is used as the proxy of Eurozone periphery spillover effects in subsequent analysis (time-varying coefficients and threshold regression) of the Greek sovereign spread (*Figure 4.12*).

4.4. Time-Varying Coefficients and Multiple Equilibria in the Greek Sovereign Spread

Rolling Regression for the Greek Sovereign Spread

The literature cautions that sovereign spreads are determined by economic fundamentals, market sentiment effects (related to animal spirits and noise trading behavior), as well as by exogenous payoff-irrelevant factors (so-called *'sunspot events'*) (Afonso et al., 2018). *Multiple equilibria* are possible: A 'bad' equilibrium may occur due to the perception of deteriorated fundamentals, due to the increased sensitivity to deteriorating fundamentals (*"wake-up call hypothesis"*), or due to coordination effects among market players without any change in the underlying fundamentals (Afonso et al., 2018). During periods when the perception of sovereign default risk is elevated or when the probability of a eurozone breakup is high, *self-fulfilling crises* are possible as financial markets require increasing risk premia to lend to a heavily indebted government. This adds further pressure to the government budget constraint and precipitates the shift towards a ‘bad equilibrium’, even when underlying fundamentals remain unchanged. Market liquidity and the presence of a Lender of Last Resort (LLR) become critical in coordinating market expectations towards a ‘good’ equilibrium (Afonso et al., 2018). Empirically, the presence of multiple equilibria is examined through the effect of time-varying coefficients or via regime switching models for bond pricing behavior (Afonso et al., 2018).

Ex ante with respect to our analysis, three or four pricing regimes may be discerned for Greek sovereign risk based on the plot of the Greek 10-Year spread (*Figure 4.1*): A period of relative tranquillity since the onset of the EMU and up to the eruption of the US financial crisis in 2007; a turbulent period covering the ripples of the US financial crisis and the Eurozone debt crisis up to Mario Draghi’s famous ‘Whatever It Takes’ speech in 2012. Additional regime switches may be located in 2015, when the political narrative and discussions of Grexit were associated with increased levels of Greek sovereign risk; and in early 2020, when despite the effects of the COVID pandemic, the ECB’s decision to include Greek government bonds in its asset purchases and in the Pandemic Emergency Purchase Programme (PEPP) induced an easing of liquidity conditions and contributed to lower sovereign spread levels.

Rolling OLS regression under a 30-month window is applied for 1999m1-2020m12 in STATA. The regression specification used is:

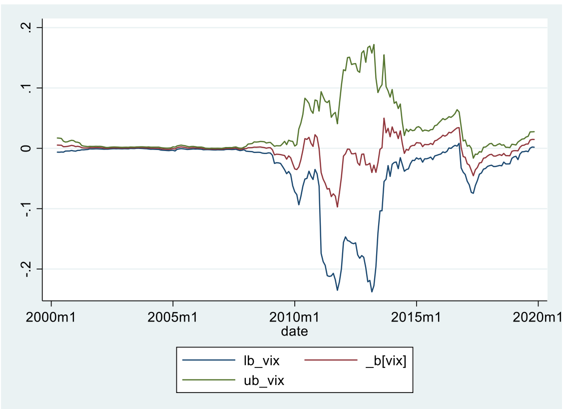
$$spread_t = \alpha * vix_t + \beta * bas_t + \gamma * ed_t + \delta * esi_t + \zeta * pc2n_t + \theta * shmp_t + k * uncertvar_t + c + \varepsilon_t \qquad (4.4)$$

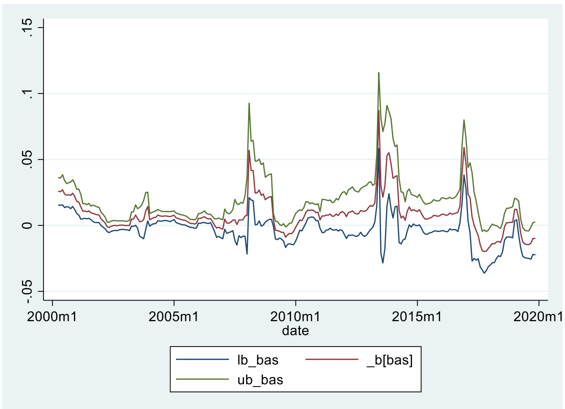
where $uncertvar_t$ is the TGARCH-estimated time-varying conditional variance (section 4.3.2), *pc2n* is the normalized second principal component derived from PCA analysis of 11 EMU countries’ sovereign bond yields (section 4.3.3), c is the constant and the other variables are as defined in data section 4.3.1. For each of the regressions over time, a separate coefficient is estimated.[158]

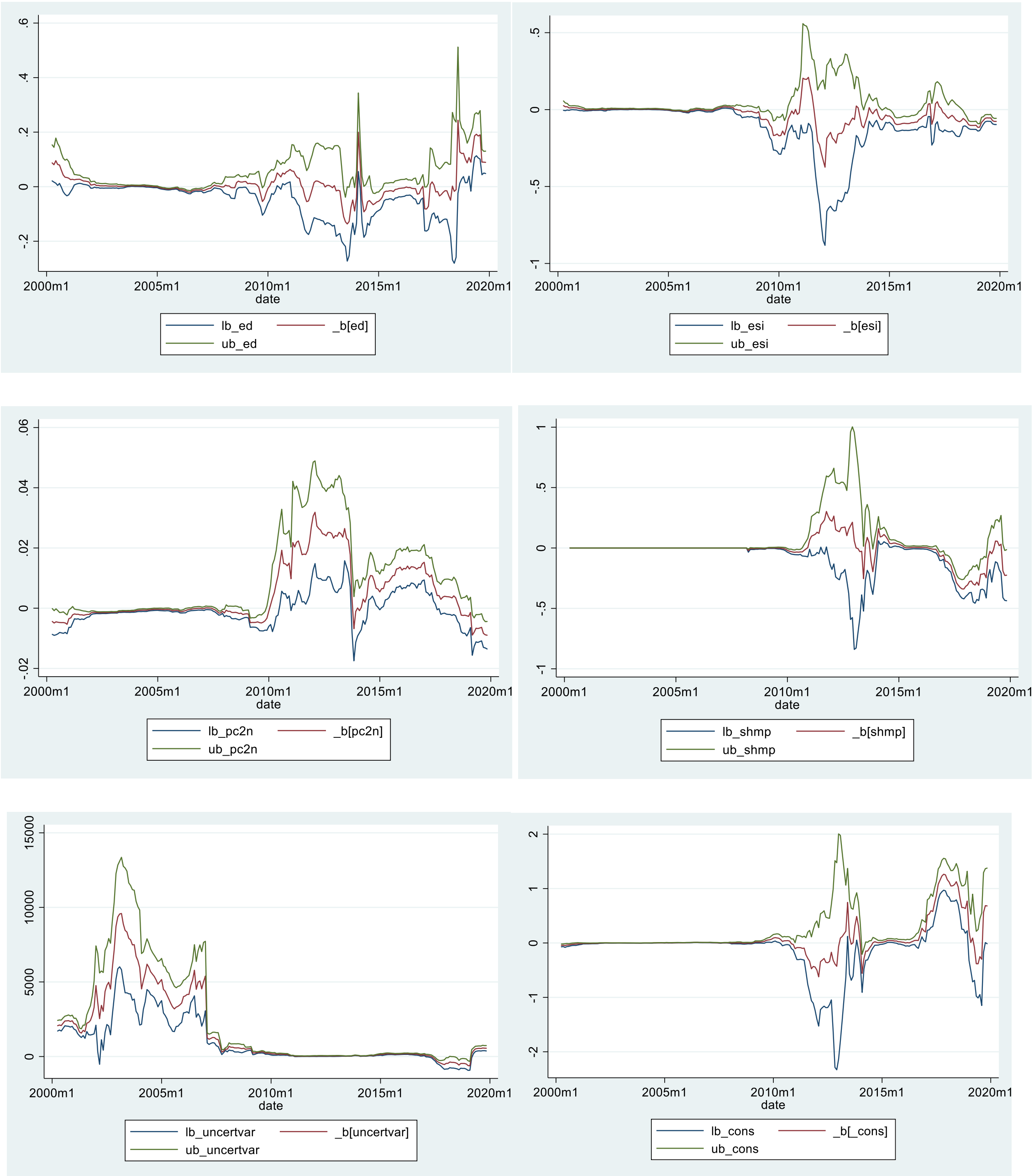
[158] The *rolling* regression equation specification corresponding to *equation 4.4* also incorporates a time subscript for the estimated coefficients, as these are time-varying.

Rolling regression (moving-window) applies regression for at most m periods of the data, where m corresponds to the window size. Starting at t, the window size is kept constant, while the window (starting and ending observations) is shifted for each regression by t+1. Estimation is repeated for the next m periods, starting at t+1 and keeping the window size constant (STATA, time series manual, 2021). Coefficient estimates (and associated standard errors) are stored in STATA as separate time series variables, which are subsequently plotted to display potential time-varying patterns. The larger the size of the window, the lower the time-variation depicted, as for the same sample under examination, fewer regressions are run.

The plots of the estimated coefficients (*Figures 4.13-4.20)*, along with their one-standard-error plots over time, confirm the hypothesis of time-variation in the association of risk factors with the sovereign spread. The confidence intervals have been calculated separately based on the reported standard errors of the coefficients. Multiple structural breaks are shown, whether governed by peaking behaviour in the estimated time-varying coefficients (as in the case of the expected debt differential) or by a regime shift to another level for the coefficient (as clearly in the case of Eurozone periphery spillovers pc2n). This behavior in the time-varying coefficients serves *as evidence of multiple equilibria in the Greek sovereign spread.*







Figures 4.13-4.20: Rolling regression Time-Varying Coefficients plots

Four regimes are evidenced for the association of the *vix* with the Greek sovereign spread: a calm period up the onset of the US financial crisis; a turbulent period between 2009 and 2013; a slight upward trend between 2013-2016; and a final regime between 2016-2020, approximately.

Four regimes are observed in the coefficient of the Greek bid-ask spread, differentiated by sharp peaks corresponding to “key event” dates in-between: the US financial crisis, the peak of the Greek debt crisis in 2012, and a further peak at the end of 2016 associated with Brexit concerns. An additional spike is viewed at the onset of the COVID-19 pandemic in 2020.

For the expected debt differential (*ed*), four regimes are detected: the calm prior to the US financial crisis in 2007; the turbulent period throughout the US financial crisis, the Eurozone and the Greek debt crisis (up to the end of 2014 approximately); the calm period (following a brief peak prior to 2015) between 2014 and 2018 approximately; and a final turbulent regime post-2018.

The same picture of relative calm, turbulence, ease and a final turbulent regime is exhibited for the coefficient of the ESI and for the coefficient of ECB securities held for monetary policy purposes (*shmp*). Eurozone spillovers (*PC2N*) confirm the presence of at least three regimes. Unlike the other coefficients, *PC2N* is flat during the first years of the EMU. Regime-switching behavior is exhibited only after the onset of the Greek debt crisis. Furthermore, changes in regimes for the coefficient of the Eurozone spillover effects (*PC2N)* are not characterized by any in-between calm period.

Similarly, the plot of the coefficient of *shmp* corresponding to the association of the Greek sovereign spread to unconventional ECB reactions to the Eurozone debt crisis is flat prior to the crisis, as the ECB had not engaged in quantitative easing prior to 2012.

Interestingly, two main regimes are depicted for the coefficient of the estimated uncertainty variable. An early turbulent period up to the US financial crisis, a second regime thereafter where parameter stability is displayed. At the end of the sample, turbulence re-emerges, probably due to the COVID-19 pandemic.

4.5. Threshold Regression

Based on the observed four-regime characterization for the coefficients of the rolling regression, threshold regression is applied on the same specification as in *Equation 4.4*. The uncertainty variable (*uncertvar*) of this Chapter (time-varying conditional variance) has been used as the threshold variable to distinguish between *two* regimes: a negligible-uncertainty regime and a high-uncertainty regime. In relation to the model in Chapter 3, the low-uncertainty regime corresponds to the 'good' equilibrium case, where noise is less than some threshold ε, whereas the 'bad' equilibrium case corresponds to the case where noise exceeds this threshold ε. In the parlance of Chapter 3, assuming that the critical threshold is located at the point below which noise is negligible, the two regimes could also be described in more general terms as no-uncertainty/uncertainty regimes.

Threshold regression models are broadly divided into the threshold autoregression model, introduced by Tong (1983), and the self-exciting threshold regression model (SETAR) (Teresvirta, 1994), in which the transition variable is a lag of the dependent variable. Threshold regression models have been used to capture asymmetric behavior, abrupt changes or multiple equilibria in economics. Threshold autoregressions extend linear regression to two regions, each of which is defined based on an indicator function with respect to a threshold (transition) variable. The indicator variable takes the value of 0, for values below or equal to a critical threshold and of 1 for values above it.

A threshold model with two regions, distinguished based on a threshold γ may be formally written as follows:

$$y_t = x_t\beta + z_t\delta_1 + \varepsilon_t \qquad \text{for } -\infty < w_t \leq \gamma \qquad (4.5a)$$

$$y_t = x_t\beta + z_t\delta_2 + \varepsilon_t \qquad \text{for } \gamma < w_t < \infty, \qquad (4.5b)$$

where y_t corresponds to the dependent variable, x_t corresponds to the 1xk vector of covariates, β is a kx1 vector of parameters which do not vary across the two regions, z_t is a vector of exogenous variables whose coefficients vary across regions and δ_1 and δ_2 are the corresponding region-dependent vectors of coefficients (STATA, time series manual, 2020). The threshold variable w_t may also be included in the model variables. γ is a nuisance parameter with a non-standard asymptotic distribution, and is estimated by the model to reflect the value of the threshold for the threshold variable $\mathrm{w_t}$ (STATA, time series manual, 2021).

Equations 4.5a and 4.5b may be combined and written equivalently based on an indicator function as follows for a sequence of T observations:

$$y_t = x_t\beta + z_t\delta_1 I(-\infty < w_t \leq \gamma) + z_t\delta_2 I(\gamma < w_t < \infty) + \varepsilon_t \quad (4.6)$$

(STATA, time series manual, 2021).

Conditional least squares regression is used for the estimation of the parameters in the above threshold regression. The threshold value is calculated based on the location of the minimum among the Sum of Squared Residuals (SSR) of tentative threshold models calculated (STATA, time series manual, 2021).

To estimate the threshold, a trimming percentage of x% implies that T_1observations ($T_1 < T$) lie between the x^{th} percentile and $(100 - x)^{th}$ percentiles of w_t (STATA, time series manual, 2021).

The estimator of the threshold is defined as follows:

$$\hat{\gamma}=\arg\min_{\gamma\in\Gamma} S_{T_1}(\gamma) \quad (4.7)$$

where Γ=(-∞,∞) and

$$S_{T_1}(\gamma)= \sum_{t=1}^{T}\{y_t - x_t\beta - z_t\delta_1 I(-\infty < w_t \leq \gamma) - z_t\delta_2 I(\gamma < w_t < \infty)\}^2 \quad (4.8)$$

(STATA, time series manual, 2021).

Gonzalo and Pittarakis (2002) provide an extension of threshold regression to multiple threshold regions. Hansen (2011) offers a survey of threshold models. Variants include threshold unit root models (Chan et al., 1991; Enders and Granger, 1998; Caner and Hansen, 2003), threshold cointegration (Balke and Fomby, 1997), and Threshold GARCH models (Glosten et al.,1993; Zakoian, 1994; Li, 2009) (Tong, 2010).

For threshold models, parameter instability should be distinguished from unit root behavior (Enders and Granger, 1998; Caner and Hansen, 2003; Bec et al., 2004; Kapetanios et al., 2006). Supremum LM statistics and their asymptotic distributions are derived under the null and the alternative for this purpose.

The Model

Threshold regression is applied to the Greek sovereign spread for two regions, distinguished based on the level of the uncertainty variable as follows:

$$Spread_t = \begin{cases} C_1 + a_1 * spread_{t-1} + \beta_1 * vix_t + \gamma_1 * bas_t + \delta_1 * ed_t + \zeta_1 * esi_t + \theta_1 * pc2n_t + \kappa_1 * shmp_t + \lambda_1 * uncertvar_t + \varepsilon_t, \\ \qquad \text{for} \quad -\infty < uncertvar \leq c \\ C_2 + a_2 * spread_{t-1} + \beta_2 * vix_t + \gamma_2 * bas_t + \delta_2 * ed_t + \zeta_2 * esi_t + \theta_2 * pc2n_t + \kappa_2 * shmp_t + \lambda_2 * uncertvar_t + \varepsilon_t, \\ \qquad for\ uncertvar > c \end{cases} \quad (4.9)$$

where *c* represents the critical threshold value for the uncertainty metric (T-GARCH-based time-varying Conditional Variance), ε_t is zero-mean i.i.d. error term. Region 1 is the region defined by values of the parameters when *uncertvar* lies below or at the critical threshold (no uncertainty regime); and region 2 is the region defined by value of parameters when *uncertvar* is above the critical threshold c for uncertainty (uncertainty regime).

Testable Hypothesis

The testable hypothesis is that below some threshold of uncertainty, the sovereign spread pricing will depend on fundamentals only (no uncertainty regime), whereas above the threshold of uncertainty (uncertainty regime), the sovereign spread will be driven both by fundamentals and market-sentiment variables. In relation to the theoretical model in Chapter 3, the threshold applied in this chapter could relate to the noise term ε, beyond which the uncertainty case is applicable in Chapter 3. In particular, the first autoregressive term of the sovereign spread is assumed to capture the total impact of fundamentals, as high persistence is indicative of high predictability based on fundamentals. Therefore, in the no-uncertainty regime, the coefficient of the first lag of the spread is expected to be statistically significant and close to 1. The coefficients of the other variables are expected not to be statistically significant in this regime, as they contain an element of 'expectations.'

In the uncertainty regime (regime 2), *both fundamentals and market-sentiment* variables are expected to drive sovereign risk pricing. Therefore, the coefficient of variables related to market-sentiment effects is expected to be statistically significant, particularly for liquidity variables (*bas*, *shmp*) and uncertainty (*uncertvar, vix, pc2n*). Variables which relate to expectations about fundamentals (such as the Economic Sentiment Index) and the Expected Debt Differential are expected to also be statistically significant in this regime. In particular:

- In regime 1 (no uncertainty), a_1 is expected to be significant and close to 1. The other coefficients are expected not to be statistically significant in this regime.
- In regime 2 (uncertainty), $\beta_2$is expected to be positive such that increases in global risk aversion are associated with rising risk premia on the Greek government debt; γ_2 is expected to be positive, as increases in the bid-ask-spread correspond to rising illiquidity in the government bond market, which in turn implies higher liquidity risk; δ_2 is expected to be positive, as *ed* represents the expected differential which proxies credit risk; ζ_2 is expected to be negative as improvements in the differential in economic activity of Greece vis-à-vis Germany lower sovereign risk; θ_2 is expected to be positive, indicative of a positive association between Greek spreads and the Eurozone periphery spillover risk; κ_2 is expected to be negative, as increased purchases of sovereign bonds by the ECB improve market liquidity and reduce liquidity risk; λ_2 is expected to be positive, and highly significant, as increases in uncertainty are expected to be associated with increases in sovereign spreads.

Results

Threshold regression

Full sample: 1999m2 - 2020m12	Number of obs = 263
Number of thresholds = 1	AIC = -2576.2353
Threshold variable: uncertvar	BIC = -2511.9366
	HQIC = -2550.3952

Order	Threshold	SSR
1	0.0002	0.0128

spread	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Region1						
spread						
L1.	.917008	.0624319	14.69	0.000	.7946438	1.039372
vix	.0028678	.0044124	0.65	0.516	-.0057803	.011516
bas	.0037639	.0026248	1.43	0.152	-.0013807	.0089084
ed	-.001475	.007186	-0.21	0.837	-.0155592	.0126093
esi	.0005118	.0076519	0.07	0.947	-.0144856	.0155091
pc2n	.0001567	.0007135	0.22	0.826	-.0012417	.001555
shmp	.0000262	.0017166	0.02	0.988	-.0033382	.0033906
uncertvar	48.63448	28.69315	1.69	0.090	-7.603056	104.872
_cons	-.0030143	.0061797	-0.49	0.626	-.0151262	.0090977
Region2						
spread						
L1.	.0943622	.0565022	1.67	0.095	-.0163801	.2051046
vix	-.0210548	.0167538	-1.26	0.209	-.0538917	.011782
bas	.0184181	.0015311	12.03	0.000	.0154171	.0214191
ed	-.0015994	.0125227	-0.13	0.898	-.0261434	.0229446
esi	-.0452094	.0186439	-2.42	0.015	-.0817507	-.0086681
pc2n	.0164821	.0023299	7.07	0.000	.0119156	.0210486
shmp	.0202117	.0082704	2.44	0.015	.0040021	.0364214
uncertvar	42.34667	2.87995	14.70	0.000	36.70207	47.99126
_cons	.0108845	.0300947	0.36	0.718	-.0481	.069869

Table 4.3: Threshold regression estimation output in STATA

**Region 1 corresponds to the no uncertainty regime; Region 2 corresponds to the uncertainty regime.*

The STATA default 10% trimming percentage is applied. 200 regressions are run.

Analysis of results

The estimated threshold for the variance of the Greek sovereign spread is 0.0002, confirming the difference in pricing behavior above and below a threshold of uncertainty (*Table 4.3)*. Below the estimated level of critical uncertainty, the spread is highly persistent (the coefficient of the autoregressive term is 0.917). No other term is statistically significant at the 5% level. Results are in line with the testable hypothesis in this Chapter and with the predictions of the theoretical model in Chapter 3: the level of the spread is primarily driven by fundamentals.

During periods of uncertainty (region 2), the persistence in the Greek sovereign spread declines, as exhibited by the low size of the coefficient of the first lag of the sovereign spread (0.094). The size of the coefficient of the bid-ask spread (0.0184181) is higher than in region 1 and liquidity conditions become statistically significant: in line with Chapter 3, beyond a critical threshold, uncertainty operates through liquidity conditions in the sovereign spread market. However, against the hypothesis, the coefficient of *shmp* is statistically significant but bears the opposite sign to the hypothesis in this section (+0.0202117). This may be interpreted as follows: In line with the testable hypothesis, quantitative easing effects improves liquidity conditions in sovereign debt markets, yet due to non-eligibility of Greek government bonds in ECB purchases, Greek spreads increased relative to the benchmark, as ECB actions lowered the yield of the benchmark. German bonds were direct beneficiaries of the easing effect of the ECB's QE programme, which rendered Greek bonds relatively riskier.

In the uncertainty regime, the two variables incorporated to account for uncertainty, namely Eurozone-periphery spillovers (*pc2n)* and uncertainty *(uncertvar*) become statistically significant and their coefficients increase substantially in size compared to the low-uncertainty region 1 (0.0164821 and 42.34667 for *pc2n* and *uncertvar*, respectively). Interestingly, the effect of the *vix* is in the opposite direction to that prescribed by other studies and it is not statistically significant. This could be interpreted as evidence of the lack of synchronization of the no-uncertainty regime for Greece to that of the US or to the global economic cycle based on which international capital markets become risk-averse. An alternative explanation relates to the concurrent impact of increases in the *vix* on the

Greek yield and the German yield, such that the net effect on the sovereign spread is not significant. Overall, in the uncertainty regime, fundamentals matter to some extent (low persistence), yet uncertainty, liquidity and market sentiment effects also drive the outcome. Results are consistent with the theoretical framework suggested by Chapter 3.

The above conclusions are reinforced by the fact that the fit of the predicted spread (*spread_fitted*) appears to be very good. As at the end of the sample, the residual is -5.6 bps. The fitted spread for December 2020 is 130.5 bps, whereas the actual spread is 124.9 bps.

The good in-sample fit of the model is depicted in *Figure 4.20*, in which the fitted spread is very close to actual data for the Greek sovereign spread- even during periods corresponding to peaks of the Greek sovereign debt crisis. Low in-sample forecast error statistics using *fcstats* in Stata (Baum, 2017) (Baum, 2017) (Root Mean Square Error, Mean Absolute Error and Mean Absolute Percentage Error) displayed in *Table 4.3* point to the same conclusion. The plot of the residual in *Figure 4.22* appears to be mean-reverting (also confirmed via unit-root tests of the residual in Appendix A4.3).

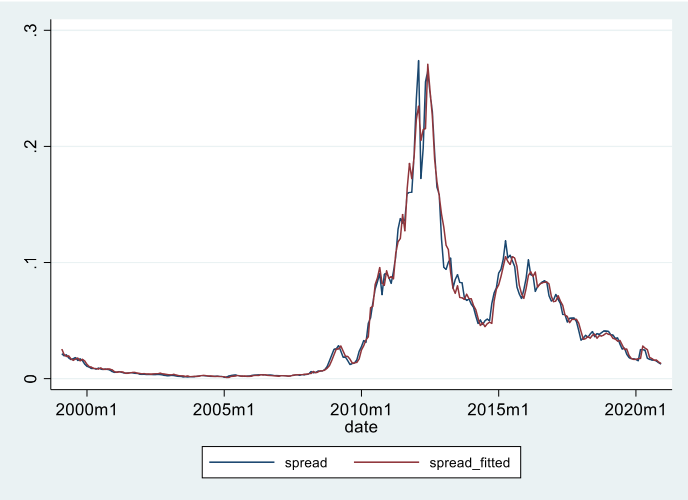


Figure 4.21: Plot of Actual and Predicted Spread (spread vs spread_fitted)

```
Forecast accuracy statistics for spread, N = 263

               spread_fitted
RMSE           .0069694
MAE            .00361698
MAPE           .11533988
Theil's U      1.1356457
```

Table 4.4: Forecast Accuracy statistics

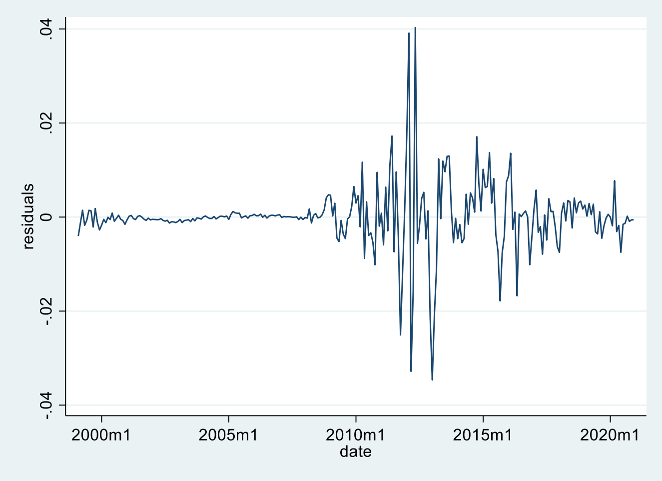


Figure 4.22: Plot of the residuals of the Threshold regression model

Wald tests of the joint equality of coefficients across regimes reject the null hypothesis that the coefficients across regions are equal, validating the regime-switching threshold approach *(Table 4.5).*

```
 ( 1)  [Region1]L.spread - [Region2]L.spread = 0
 ( 2)  [Region1]vix - [Region2]vix = 0
 ( 3)  [Region1]bas - [Region2]bas = 0
 ( 4)  [Region1]ed - [Region2]ed = 0
 ( 5)  [Region1]esi - [Region2]esi = 0
 ( 6)  [Region1]pc2n - [Region2]pc2n = 0
 ( 7)  [Region1]shmp - [Region2]shmp = 0
 ( 8)  [Region1]uncertvar - [Region2]uncertvar = 0

           chi2(  8) =  169.43
         Prob > chi2 =    0.0000
```

Table 4.5: Wald Tests of Equality of Coefficients Across the Two Regions

Based on the outcome of the Wald test, the difference between the coefficients of the 'good equilibrium' and 'bad equilibrium' outcomes is statistically significant.

Regime Dating

Model estimation points to the following binary regime dating classification. *Figure 4.23* is based on a dummy variable (Regime 2), in which a value of 1 corresponds to regime-2 months, whereas a value of 0 corresponds to regime-1 months.

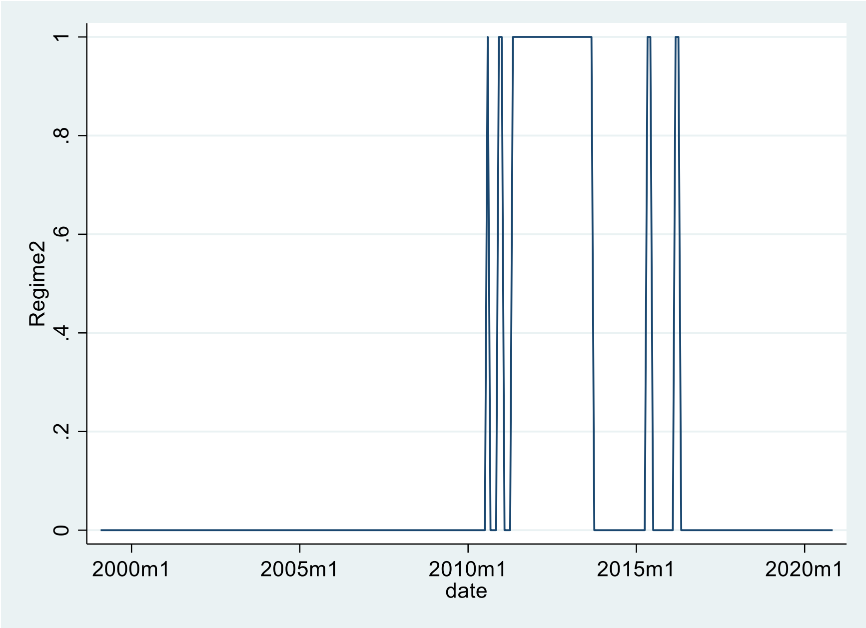


Figure 4.23: Threshold Regression Regime Dating Classification

Based on regime dating classification offered in this Chapter and knowledge of the Greek-crisis timeline, *regime 2* (uncertainty regime) may be attributed to crisis periods, whereas regime 1 (no uncertainty) corresponds to non-crisis months. *Regime 2* occurs at the following quarters: 2010m8; 2010m12-2011m1, 2011m5-2013m9, 2015m5-2015m6, 2016m3-2016m4. *Regime 1* (no uncertainty) occurs at all other periods. The table presenting the associated exact regime-dating output is provided in the Appendix A4.5.

The dating classification of uncertainty versus no-uncertainty periods ('good equilibrium' vs 'bad equilibrium') fits well with knowledge of the Greek debt crisis timeline with respect to crisis vs normal times. Uncertainty-regime periods correspond to bad-equilibria periods:

- *2010m8*: This month comes in the aftermath of the first major pension reform passed in the Greek parliament to comply with the conditionality of the first bailout loan in July 2010. The austerity-inducing impact of conditionality is first-experienced by the Greek public.
- *2010m12-2011m1*: In 2011, Fitch downgraded Greece from BBB- to BB+ and the first austerity budget was approved for 2011 in December 2010.

- *2011m5-2013m9:* This period covers the end of the First Economic Adjustment Programme and the largest portion of the Second Economic Adjustment Programme, also coinciding with the peak of the Eurozone debt crisis. Over the course of this uncertainty regime, markets questioned Greek membership in the EMU. This period was characterized by political instability, riots and resistance to austerity measures. A series of rating downgrades and the largest episode of partial default in history (the Greek PSI) are included.
- *2015m5-2015m6:* This uncertainty regime covers the events that led to the Greek referendum in July 2015 and the expiration of the Second Economic Adjustment Programme. In the absence of an agreed third bailout loan package, markets expected the Greek government to default on its debt servicing obligations after the second half of 2015.
- *2016m3-2016m4:* This period coincides with all-time lows in the Greek stock market, the passing of a new austerity law, and renewed market fears in anticipation of the impact of a Brexit referendum.

In contrast, the model classifies the pre-crisis era as well as the period near the expiration of the Second Economic Adjustment Programme as 'good-equilibrium' regimes, when Greece regained access to international capital markets and the Greek government was credible with respect to its solid progress on fiscal consolidation and structural reforms.

The onset of the Third Economic Adjustment Programme is classified as a 'good-equilibrium' outcome, as market fears of a Greek default and Grexit were eased by agreement with Greece's creditors. The end of the Third Economic Adjustment Programme is classified as a 'good equilibrium' outcome, as substantial prior fiscal consolidation and the May 2018 Eurogroup Agreement on the Medium-Term measures for debt restructuring improved the Greek government debt profile and ensured the credibility of the Greek government with financial markets. The build-up of a cash-buffer also served in this direction. Similarly, the period prior to and immediately after the contracting of the first bailout loan are classified as 'good equilibria' outcomes by financial markets, as international financial assistance and conditionality measures reassured markets that Greek debt-servicing obligations would be met.

4.6. Short-term liquidity-driven market-sentiment effects

A CGARCH-M model, augmented with the BAS in the transitory component of volatility

In this section, the approach of Li et al. (2012) is applied to the Greek sovereign spread to distinguish between a fundamentals and a market-sentiment component in the volatility of the Greek sovereign spread. Following the literature on C-GARCH-M models as applied to the Uncovered Interest Parity (Li et al., 2012) or currency crises (Guimaraes and Karacadag, 2004), the distinction between a permanent (long-term) and a transient (short-term) component relates to the fundamentals-versus-market-sentiment discussion in financial and currency-crisis literature. Pramos and Tamirisa (2006) also relate the transient component in CGARCH models to short-term trader position-taking, which fits well with the analysis in Chapter 3. Since the sovereign spread is a financial-markets-based metric, this section suggests the application of the CGARCH-M model and its interpretation to the Greek sovereign spread. To date, Sosvilla-Rivero and Morales-Zumaquero (2012) have applied a CGARCH model to the sovereign bond yields of a panel of EMU countries to distinguish between a permanent and transitory component in volatility.[159] On a time series basis, for Greece and for the *spread* of government bond yields, the suggested application is novel.

The Component GARCH model was first developed by Engle and Lee (1993,1999) to distinguish between a permanent and a transitory component in the volatility of stock returns. Primary explanations for the existence of components in volatility relate to the heterogeneity of traders in financial markets (Muller et al.1997) and heterogeneity of information, through the arrival of news (Andersen and Bollerslev, 1997a) (Zarour and Siriopoulos, 2008). According to the literature, the findings of CGARCH models may be interpreted as a challenge of the Efficient Market Hypothesis, at least in its strong form (Haque et al.,2004; Abu Zarour, 2007; Zarour and Siriopoulos, 2008). The CGARCH model is used as an alternative to the FIGARCH model for long memory in the conditional variance. Based on an application to oil prices, Kang et al. (2009) have suggested that the out-of-

[159] Sosvilla-Rivero and Morales Zumaquero (2012) develop CGARCH model for daily data of 10-year government bond yields for 11 EMU countries, including Greece, for data between 26 March 2001 and 31 December 2010. In contrast, the model in this section is CGARCH-M with leverage effects (threshold) based on the time-series of the Greek sovereign *spread* only, for monthly data between January 1999-December 2020.

sample fit for FIGARCH and CGARCH models may be superior to that of GARCH and IGARCH models.

The CGARCH model replaces the original GARCH model of the conditional variance as follows:

$$\sigma_t^2 = \omega + \alpha(\varepsilon_{t-1}^2 - \omega) + \beta(\sigma_{t-1}^2 - \omega) \qquad (4.10)$$

with the following equation for the long-run permanent volatility component q_t, which converges to a long-run time-invariant volatility $\widehat{\omega}$, based on the following equation:

$$q_t = \widehat{\omega} + \rho\,(q_{t-1} - \widehat{\omega}) + \varphi(\varepsilon_{t-1}^2 - \sigma_{t-1}^2) \qquad (4.11)$$

Parameter ρ corresponds to the speed with which the permanent component converges to the time-invariant volatility and relates to the long-run persistence of volatility (Sosvilla-Rivero and Morales Zumaquero, 2012). A value of ρ close to 1 indicates the slow approaching of the permanent component of volatility to $\widehat{\omega}$ and a value of ρ close to 0, indicates the fast approaching of $\widehat{\omega}$. The CGARCH model also specifies the short-run dynamics (deviation of time-varying volatility from long-run volatility component σ_t^2-q_t) as follows:

$$\sigma_t^2 - q_t = \gamma\,(\varepsilon_{t-1}^2 - q_{t-1}) + \lambda(\sigma_{t-1}^2 - q_{t-1}) \qquad (4.12)$$

Equation 4.12 corresponds to the transitory component of volatility, which depends on the deviation of the previous-period squared error from the permanent volatility ($\varepsilon_{t-1}^2 - q_{t-1}$) and the previous-period deviation of the volatility from the pervious-period permanent volatility (σ_{t-1}^2-q_{t-1}) (Sosvilla-Rivero and Morales Zumaquero, 2012).

Equations 4.10-4.12 describe the CGARCH model, which shows how past shocks, broken down to a permanent and a temporary component of volatility, influence volatility.

The Model

The following set of equations describes the CGARCH-M model estimated in this chapter, augmented for short-term liquidity effects (bas_t) in the temporary variance equation:

$$spread_t = C + \beta spread_{t-1} + \gamma\sigma_t + \varepsilon_{t-1} \qquad (4.13a)$$

$$q_t = C_4 + C_5\ (q_{t-1} - C_4) + C_6\ (\varepsilon_{t-1}^2 - \sigma_{t-1}^2) \quad (4.13b)$$

$$\sigma_t^2 = q_t + C_7\ (\varepsilon_{t-1}^2 - q_{t-1}) + C_8 D_{t-1}\ (\varepsilon_{t-1}^2 - q_{t-1}) + C_9\ (\sigma_{t-1}^2 - q_{t-1}) + C_{10} bas_t \quad (4.13c)$$

where D_{t-1} is a dummy variable corresponding to the asymmetric effect of shocks, D_{t-1}=1 for ε_{t-1}<0, and D_{t-1}=0 for $\varepsilon_{t-1} \geq 0$; q_t corresponds to the long-run component of the conditional variance indicative of the effect of shocks to economic fundamentals and which converges to the long-run time-invariable volatility level C_4 with a speed of C_5 (Li et al., 2012); C_4 is the long-run volatility component; C_5 is the coefficient of lagged permanent volatility or the coefficient indicative of persistence; C_7 is the coefficient that reflects the initial impact of a shock to the transitory component of volatility; C9 is the "degree of memory in the transitory component" (Li et al., 2012); C_8 is the coefficient of the asymmetric effect once multiplied with the dummy variable. The inclusion of the asymmetric effect term (dummy variable) in the CGARCH-M model follows Li et al. (2012), Guimaraes and Karacadag (2004) and Glosten et al. (1993).

Equation 4.13a is the mean equation, *Equation 4.13b* corresponds to the permanent volatility component and E*quation 4.13c* relates to transitory volatility. Following Li et al. (2012), the transitory component in the variance may be related to market sentiment and short-run speculative pressures.

Testable Hypothesis

The testable hypothesis is the following: i. short-run effects will drive market-sentiment/uncertainty for the Greek sovereign spread; ii. short-run market-sentiment shocks will operate through liquidity conditions, as foreseen in Chapter 3 and as captured by the bid-ask-spread (bas_t) in the model.

Parameters in the *Equations 4.13b* and *4.13c* are expected to be statistically significant, in line with the validity of the model that incorporates both a short-run and a long-run volatility dimension. With respect to market sentiment (the short-run dimension), parameter C_7, which relates to the transitory component of volatility, is expected to be positive, large in magnitude and highly statistically significant. The coefficient of the asymmetric effect of news on volatility C_8 is also expected to be positive and highly statistically significant, so that negative shocks to the sovereign spread (i.e. shocks associated with lower levels of sovereign spreads) will be associated with higher volatility. The hypothesis on coefficient C_8 bears the opposite sign to that in the literature on currency crises and stock prices, as the underlying metric considered is a risk factor, whose increase we expect to be related to higher volatility. C_{10}, the coefficient of the bid-ask spread, is expected to be positive and highly significant, such that the transient component of volatility in the Greek sovereign spread is associated with illiquidity in the Greek government bond market.

Results

Dependent Variable: SPREAD

Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)

Date: 03/11/21   Time: 17:33

Sample (adjusted): 1999M02 2020M12

Included observations: 263 after adjustments

Failure to improve likelihood (non-zero gradients) after 46 iterations

Coefficient covariance computed using outer product of gradients

Presample variance: backcast (parameter = 0.7)

Q = C(4) + C(5)*(Q(-1) - C(4)) + C(6)*(RESID(-1)^2 - GARCH(-1))

GARCH = Q + (C(7) + C(8)*(RESID(-1)<0))*(RESID(-1)^2 - Q(-1)) + C(9)

*(GARCH(-1) - Q(-1)) + C(10)*BAS

Variable	Coefficient	Std. Error	z-Statistic	Prob.
@SQRT(GARCH)	0.981143	0.084113	11.66464	0.0000
C	-9.57E-05	2.16E-05	-4.431439	0.0000
SPREAD(-1)	0.882226	0.001024	861.8090	0.0000
		Variance Equation		
C(4)	-3.34E-07	9.43E-08	-3.543159	0.0004
C(5)	0.554785	0.614446	0.902903	0.3666
C(6)	-0.019568	0.060535	-0.323249	0.7465
C(7)	0.392150	0.080464	4.873585	0.0000
C(8)	-0.302697	0.053158	-5.694271	0.0000
C(9)	0.673732	0.063202	10.66001	0.0000
C(10)	1.58E-06	2.39E-07	6.602047	0.0000

R-squared	0.961166	Mean dependent var	0.042728
Adjusted R-squared	0.960867	S.D. dependent var	0.053528
S.E. of regression	0.010589	Akaike info criterion	-9.062190
Sum squared resid	0.029152	Schwarz criterion	-8.926367
Log likelihood	1201.678	Hannan-Quinn criter.	-9.007606
Durbin-Watson stat	1.713623		

Table 4.6: CGARCH-M Model Results for the Greek sovereign spread

The first portion of *Table 4.6* corresponds to the mean equation and the second portion corresponds to the variance equation. *Figure 4.24* plots the estimated model conditional time-varying volatility and its permanent component. The distance between total conditional time-varying volatility and the permanent component corresponds to the transitory component of volatility. Evidently, over the course of the Greek debt crisis, crisis instances are associated with the short-term component of volatility.

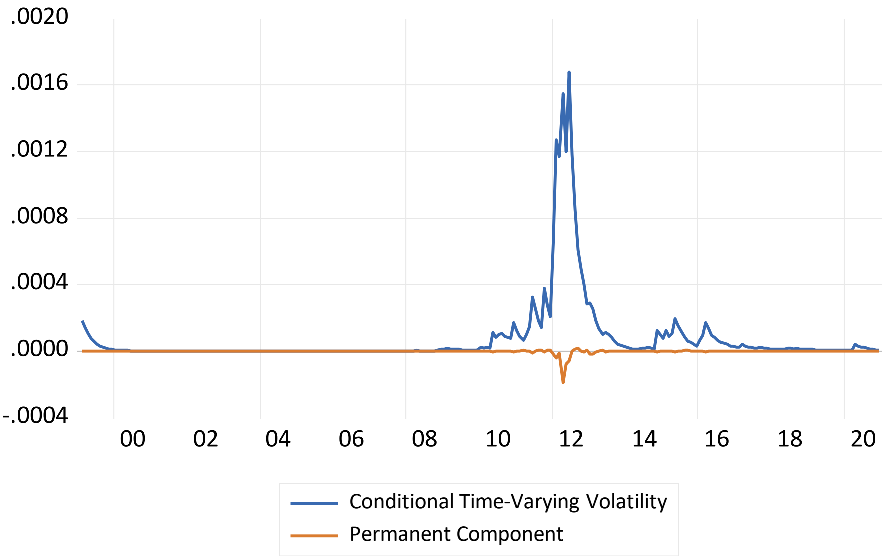


Figure 4.24: Model-based Conditional Time-Varying Volatility and Permanent Component therein

The model's in-sample forecasting fit is strong and there are no remaining ARCH effects based on the ARCH-LM test of the residuals (See Appendix A4.3*)*. Despite the potentially explosive properties of short-run market sentiment, as the estimated model is a threshold volatility model, it is strictly stationary and ergodic.[160] As in December 2020 (end-of sample), the CGARCH-M model predicted value is 134.3 bps whereas its actual value was 124.9 bps.

[160] According to Tong (2010), "a Threshold Volatility Model (TVM) is always strictly stationary and ergodic".

Analysis of Results

According to the estimated coefficients, in the mean equation, the time-varying conditional standard deviation is statistically significant. The constant is very close to zero (-0.0000280) and the coefficient of the autoregressive term is indicative of some persistence in the Greek sovereign spread (0.85).

In the equation for the lagged permanent component in volatility q_t, the size of C_5 (0.529863) suggests some long-run persistence, which nevertheless is not statistically significant. C_4, which represents the time-invariant volatility, is very close to zero. *The absence of statistical significance for C_5 serves as evidence of the dominance of short-term market sentiment effects in the pricing of Greek sovereign spreads.*

Against the testable hypothesis, C_8 (-0.303), the coefficient for the transitory effect of news (multiplied with the dummy variable for negative news) is statistically significant and negative such that negative shocks to the sovereign spread are associated with lower volatility than positive shocks. Our results deviate from the findings of Byrne and Davis (2005) in the literature on currency crises, who apply the Uncovered Interest Parity (UIP) and find that the impact of negative shocks is greater than the impact of positive shocks. In contrast and in line with our findings, Koutmos et al. (1993) find that the impact of positive shocks to volatility is greater than the impact of negative shocks for the Athens stock exchange. This has been interpreted to imply that investors perceive excessive rises in asset prices as evidence of speculative bubble conditions. Therefore, *the sign of this coefficient may be interpreted as evidence of the existence of speculative market pricing effects in the Greek sovereign spread.* Furthermore, also in line with the hypothesis, *short-run market sentiment effects relate to liquidity conditions in the Greek government debt*, as indicated by the positive and highly statistically significant coefficient on the bid-ask spread (C_{10}).

The explanatory power of the model is high (adjusted-R-squared is 96.12%). The coefficient of long-run persistence in volatility is not statistically significant and relatively small in absolute value, thereby indicating that *the impact of short-term market-sentiment effects is large* (C_5=0.529863).[161] The long-run component half-life is thus approximately 1.18 months,[162] using *equation 4.14* for the long-run half-life measure of Sosvilla-Rivero and Morales Zumaquero (2012):

$$LR_{HL}(\hat{\rho}) = \ln\left(\frac{1}{2}\right)/\ln(\hat{\rho}), \qquad (4.14)$$

where $\hat{\rho}$ corresponds to the estimated coefficient C_5.

Some degree of memory is present in the transient component of the volatility, as indicated by the statistical significance of the estimated coefficient C_7. Shock persistence in the transitory component exceeds 1, as captured by the sum of $C_7 + C_9$, indicative of explosive short-run market sentiment behavior.

Based on the graph of the estimated permanent and transitory components (*Figure 4.24), market-sentiment effects were particularly strong during the PSI in 2012, yet thereafter their impact subsided. Additional brief increases in the size of the transient component of volatility are present at end-2014 and in 2016.* These periods correspond to the dating of uncertainty regimes estimated using the threshold regression model in section 4.5. Furthermore, the model works well in showing that crises are associated with short-term market sentiment effects and liquidity. The only instance of partial default in the first half of 2012 is captured by a global peak in the transitory component.

In conclusion, the application of the CGARCH-M model has shown that *the short-run market-sentiment component of volatility dominates market pricing*, as the parameter corresponding to the mean-reversion coefficient was not found to be statistically significant. Therefore, *market expectations and sentiment effects predominantly drive Greek sovereign spread pricing.* The graphical depiction of the evolution of total conditional time-varying volatility and its components over time

[161] In contrast, for daily data in the Greek government bond yield between 2000 and 2010, Sosvilla-Rivero and Morales Zumaquero (2012) estimate this coefficient to be 0.995, indicative of a degree of high persistence in the permanent component of volatility. This section focuses on a portion of the Greek government bond yield only, the spread, and covers the period of the Greek debt crisis. Therefore, the finding of relatively lower persistence appears to be reasonable.

[162] The respective figure for the pre-crisis Greek 10-year bond yield estimated by Sosvilla-Rivero and Morales Zumaquero (2012) was 130 days.

supports the hypothesis that *short-term market-sentiment effects are associated with crisis outcomes and periods.* Furthermore, *this market-sentiment component in the volatility of Greek sovereign spreads operates through liquidity effects.* The impact of news on the transitory component of the Greek sovereign spread is shown to be statistically significant. *The associated sign of the leverage term points to speculative trading effects as drivers of short-term market sentiment*, in line with the model in Chapter 3.

Overall, Greek sovereign risk is shown to be impacted by market sentiment, liquidity conditions and news. The event study in Appendix A4.2, further supports the finding of leverage effects, as *the news (events) associated with key dates significantly impacted Greek sovereign spread.* [163] The results of the CGARCH-M model and of the event study may challenge the Efficient Markets Hypothesis, at least in its strong form.

4.7 Conclusion

In line with related literature on the sovereign spreads in the EMU (e.g. Afonso et al., 2018), time-varying coefficient methods have provided evidence of multiple equilibria and of regime-dependent behavior in the Greek sovereign spread since the onset of the EMU.

Threshold regression has been applied to distinguish between two risk pricing regimes (corresponding to a 'good' and a 'bad' equilibrium) according to the level of uncertainty: At negligible levels of uncertainty (below the critical threshold), financial markets price the Greek sovereign spread based on fundamentals only. Once the level of uncertainty surpasses the critical threshold, both fundamentals and market sentiment drive Greek sovereign risk-pricing behavior. Using Threshold-GARCH methods, an idiosyncratic measure of uncertainty with respect to Greek debt sustainability has been

[163] Event dates include the date of the revelation of the true size of the Greek budget deficit on October 19th, 2009; the downgrade of the Greek debt into 'selective default'(SD) by S&P on February 27th 2012 in anticipation of the PSI; the election of a left-wing government with an anti-austerity fiscal plan on January 26th , 2015; the announcement of the Greek referendum on June 29th , 2015; and the announcement of the COVID-induced generalized lockdown on March 23rd , 2020. (See Appendix A4.4)

estimated for this purpose. The critical threshold level in this metric of uncertainty, beyond which the Greek sovereign spread enters the crisis zone, has been estimated.

By applying a Component-GARCH-M model, a short-term component of uncertainty has been distinguished from the permanent component of uncertainty. During crisis periods for Greece, uncertainty is driven primarily by the transitory component, which has been attributed to short-term market sentiment in the literature. Short-term market sentiment effects are shown to be directly related to liquidity effects in the Greek government bond market.

The threshold regression model has offered a dating classification of the two regimes, which fits well with the narrative of the Greek debt crisis. Bad equilibria, or regimes associated with uncertainty, are shown to occur in the following months for the sample of 1999m1-2020m12: 2010m8, 2010m12-2011m1, 2011m5-2013m9, 2015m5-2015m6, 2016m3-2016m4. The months classified as 'bad equilibria' (uncertainty regimes) match the peaks of the Greek debt crisis. Therefore, the estimated measure of uncertainty-apart from being idiosyncratic to Greek debt sustainability and unrelated to other measures of uncertainty- matches the incidence of crisis for Greece.

Liquidity effects, and other market sentiment variables, are statistically significant in the uncertainty regime *only*. The finding that crisis regimes are driven by speculative liquidity effects and short-term market sentiment may be used to support the *immediate* and *unconditional* access for the Greek government to liquidity lines, such as the Enhanced Conditions Credit Line (ECCL) or the PCCL (Precautionary Conditions Credit Line) of the ESM. Crossing the critical threshold of uncertainty proposed in this Chapter could be used as an arbiter of market-sentiment in relevant argumentation. Last but not least, evidence that the ECB's extraordinary response to the Eurozone debt crisis worked to the detriment of non-eligible Greek bonds during peaks of the Greek debt crisis, may be used as an argument for the preferential access of Greece to programmes such as the Pandemic Emergency Purchase Programme (PEPP) in the future.

Secondary findings in this Chapter relate to the following: Principal Components Analysis has been applied to derive a measure of the relative riskiness of the Eurozone periphery, in line with similar methods in the literature. Furthermore, event study methods in the Appendix have validated the impact of news on key dates for Greek sovereign spreads: the date of the revelation of the true size of the Greek budget deficit on October 19th, 2009; the downgrade of the Greek debt into 'selective default'(SD) by S&P on February 27th 2012 in anticipation of the PSI; the election of a left-wing government with an anti-austerity fiscal plan on January 26th , 2015; the announcement of the Greek referendum on June 29th , 2015; and the announcement of the COVID-induced generalized lockdown on March 23rd , 2020. The latter may serve as a challenge to the Efficient Markets Hypothesis, at least in its strong form, for the Greek sovereign spread.

The methodology and findings in this Chapter are not free of limitations. For the purposes of obtaining a good fit to the data and appropriate signs in the regression coefficients, a limited number of determinants of sovereign spreads is accounted for. In addition, the binary classification of variables as 'expectations variables' or 'fundamentals variables' is not always as clear-cut as desirable.

Future research could delve deeper into the long memory properties of the Greek sovereign spread and associated implications with respect to the Efficient Market Hypothesis. In addition, alternative measures of uncertainty (e.g. EPU) could be used as threshold transition variables. Lastly, more advanced Bayesian Time-Varying Coefficient Methods could be applied.

Appendix A4.1 The Principal Components Analysis (PCA) Method

PCA is a method of reconstructing the original data set with the aim of reducing its dimensionality and of mapping it into a data space where only the most relevant variables are used, in the sense that these variables explain the largest fraction of data variance. PCA is the process via which an original data set (X∈R^m) is transformed into a new lower-dimensional coordinate system (W∈$R^k, where\ k < m$) (Tharwat, 2016). The new axes are orthonormal bases of the new coordinate system and represent the Principal Components (PCs), namely new variables which are linear combinations of the original variables and account for the largest fraction of variance (Tharwat, 2016). Principal Components may, thus, be ranked in terms of significance to the description of the original data set. The first Principal Component represents the axis which may account for the largest percentage of variance in the original data set. The second Principal Component represents the second most important axis for the original data set variance, and so on. Only the first few Principal Components are used in the analysis. These are ranked according to Component Scores. Principal Components, thus, is the basis to construct the PCA space, onto which data is projected and reconstructed. In summary, the orthonormal transformation consists of a rotation of axes and a projection of vectors.

PCA is most useful in data samples with irregular patterns (e.g. clusters) to reveal some internal data structure which explains the variance, while avoiding the danger of overfitting. However, given that judgement is used to select the number of PCs to include in the analysis based on the preferred percentage of variance of the original data set to be described, PCA has been criticized for lacking a formal relevant test.

Two methods may be used for Principal Components Analysis: the Covariance Matrix Method and the Singular Value Decomposition Method (SVD). These methods are used to calculate the eigenvectors and eigenvalues that will be used to construct the transformed Principal Components space.

The Covariance Matrix Method

The Covariance Matrix Method follows two steps: first, the covariance matrix of the original data matrix (X, mxn) is calculated; and subsequently the eigenvalues and eigenvectors of the covariance matrix (Σ, mxm) are calculated as follows.

First, the Data Matrix is Mean-Centered D by subtracting the mean from data (D=X-μ):

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ \vdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \vdots \\ x_{m1} & \cdots & \cdots & x_{mm} \end{bmatrix} - \begin{bmatrix} \mu_1 \\ \vdots \\ \vdots \\ \mu_m \end{bmatrix} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ \vdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \vdots \\ d_{m1} & \cdots & \cdots & d_{mm} \end{bmatrix} \quad \text{(A4.1)}$$

Data Matrix X(mxn) (mx1) Mean-Centered data D(mxn)

where $d_i = x_i - \mu$ (Tharwat, 2016).

Second, the Covariance Matrix Σ(mxm) is calculated as follows:

$$\Sigma = DD^T = \begin{pmatrix} Var(x_1, x_1) & Cov(x_1, x_2) & \cdots & Cov(x_1, x_m) \\ Cov(x_2, x_1) & Var(x_2, x_2) & \cdots & Cov(x_1, x_m) \\ \vdots & \vdots & \ddots & \vdots \\ Cov(x_m, x_1) & Cov(x_m, x_2) & \cdots & Cov(x_m, x_m) \end{pmatrix} \quad \text{(A4.2)}$$

Σ is symmetric (ie. $\Sigma = \Sigma^T$) and positive semi-definite (Tharwat, 2016).[164]

The eigenvectors (V) and eigenvalues (λ) are calculated to solve the covariance matrix:

$$V\,\Sigma = \lambda\, V \quad \text{(A4.3)}$$

The eigenvectors correspond to the orthonormal axes and represent the principal components, while the corresponding eigenvalues represent the scaling factor and their square root corresponds to the percentage of variance in the original data explained by each Principal Component. The eigenvector with the highest eigenvalue is thus the first Principal Component (Tharwat, 2016).

[164] For Σ to be positive semi-definite, for every $v \neq 0$, $v^T \Sigma\, v \geq 0$, such that all eigenvalues of Σ are greater or equal to 0 (Tharwat, 2016).

The Singular Value Decomposition Method

In the Singular Value Decomposition Method (SVD), the original data matrix is diagonalized and decomposed into three data matrices, X=LSR^T, where L(pxp) is a left-singular matrix pxp of vectors, S is a diagonal matrix of singular values, sorted from highest to lowest ($s_1 \geq s_2 \geq \cdots \geq s_q \geq 0$ such that the highest singular value is in the upper-left index position, and R(qxq) is the matrix of right singular matrices, as follows:

$$X=LSR^T=[\, l_1 \ldots . l_p] \begin{bmatrix} s_1 & 0 & 0 & 0 \\ 0 & s_2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & s_q \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} -r_1^T - \\ -r_2^T - \\ \vdots \\ -r_q^T - \end{bmatrix} \quad \text{(A4.4)}$$

L(pxp) S(pxq) R(qxq)

(Tharwat, 2016).

Matrices L and R represent the orthonormal bases.

First, $X\,X^T$ is diagonalized:

$$X\,X^T = (LSR^T)^T(LSR^T) = RS^TL^TLSR^T = RS^2R^T \quad \text{(A4.5)}$$

(Tharwat, 2016).

Second, L is calculated as:

$$L=XRS^{-1} \quad \text{(A4.6)}$$

Such that Xr_i is in the direction of $s_i l_i$ and the columns of R correspond to the eigenevectors or principal components and s_i^2 are the corresponding eigenvalues. The number of eigenvectors in the PCA is q (Tharwat, 2016).

Comparing the two methods, the singular values in the Singular Value Decomposition Method are equal to the square root of the eigenvalues calculated using the covariance matrix. The eigenvectors of

Σ are equal to the columns of R, such that the eigenvalues and eigenvectors calculated under each of the two methods are equal (Tharwat, 2016):

$$DD^T = RS^2R^T = (SVD(D^T))^2, \tag{A4.7}$$

where S^2 corresponds to the eigenvalues of DD^T and the columns of R are the eigenvectors of DD^T.

The PCA Space

Using a linear combination of k of the Principal Components (eigenvectors) found above which will serve to account for the maximum amount of variance in the original data matrix X, the lower-dimensional PCA Space W={$v_{1,} \dots v_1$} is constructed by projecting the demeaned original data onto the PCA space as follows:

$$Y = W^T D = \sum_{i=1}^{N} W^T (x_i - \mu) \tag{A4.8}$$

where Y∈R^k corresponds to the original data set X, projected onto the PCA space W and D is the Matrix of Original Data minus their means, as described in *Equation A4.1* (Tharwat, 2016).

Thus, the original data matrix X can be reconstructed by calculating the reconstructed data set $\hat{X}$ as follows:

$$\hat{X} = WY + \mu = \sum_{i=1}^{N} W\, y_i + \mu \tag{A4.9}$$

(Tharwat, 2016). The reconstruction error is thus calculated as the deviation between the original dataset and the reconstructed data:

$$\text{Error} = X - \hat{X} = \sum_{i=1}^{N} (x_i - \hat{x}_i)^2 \tag{A4.10}$$

The robustness of the PCA space is calculated as the percentage of total variance of the original data explained by the PCA data space (Tharwat, 2016):

$$\text{Robustness of PCA space} = \frac{Total\ Variance\ of\ W}{Total\ Variance} = \frac{\sum_{i=1}^{k} \lambda_i}{\sum_{i=1}^{m} \lambda_i} \tag{A4.11}$$

(Tharwat, 2016). An extended treatment of PCA is provided in Joliffe (2002).

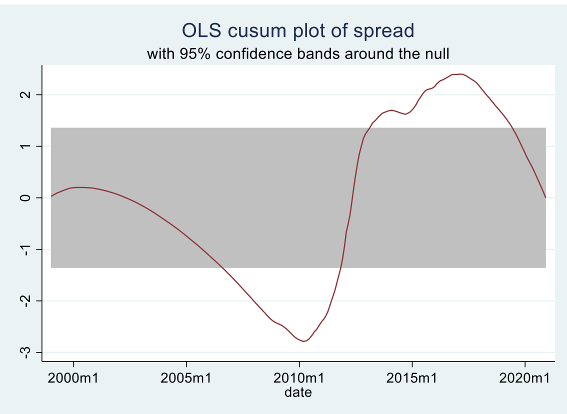
Appendix A4.2. Parameter Instability Tests

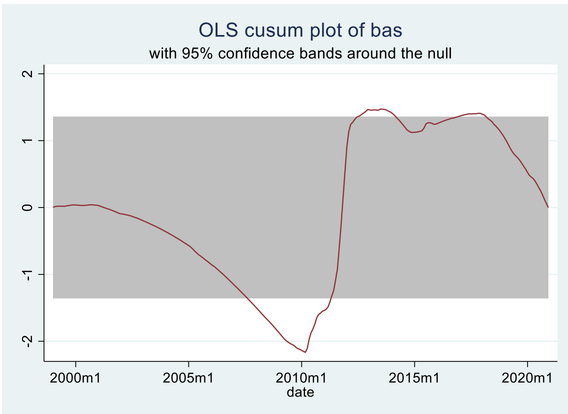
Evidence of parameter instability complements the findings of time-varying coefficients, therefore supporting the thesis of multiple equilibria in the Greek sovereign spread and calling for a Regime-Switching approach. This section performs the CUSUM test and the Chow test for a structural break at an unknown date for each variable.

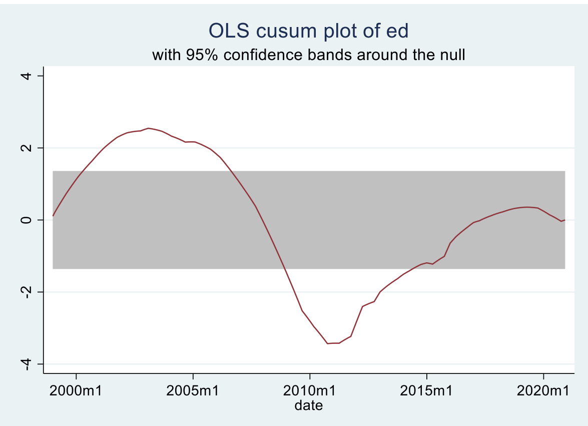
CUSUM Test

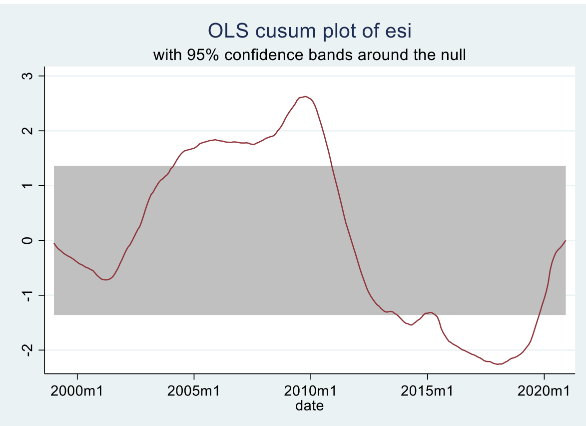
The CUSUM Test (Brown et al., 1975) calculates the weighted cumulative sum of recursive residuals, along with 5% critical lines. Parameter instability occurs when the cumulative sum lies outside the estimated critical bounds.

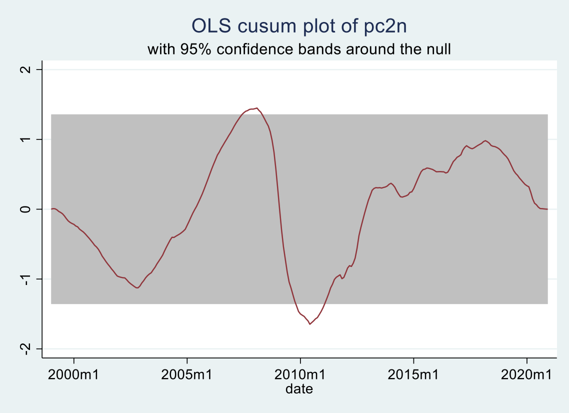
Parameter instability is shown to exist for all variables, when the plot exceeds the 95% confidence bands around the null. (Figures A4.1-A4.7 and tables A4.1-A4.7).

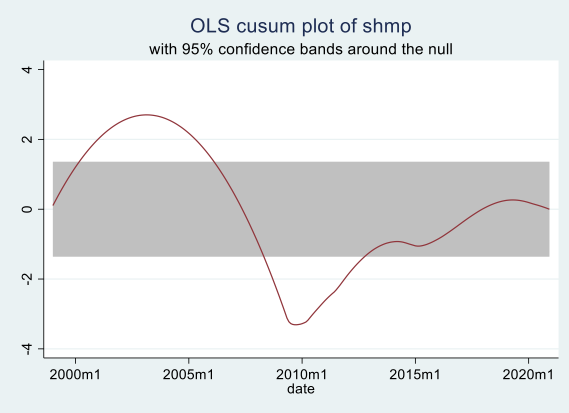


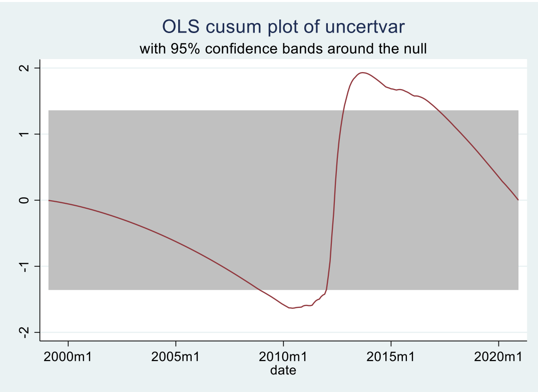












Figures A4.1-A4.7: OLS CUSUM plots of the variables

Based on the estimated test statistic and 5% critical values, the null hypothesis of no structural break is rejected for all variables in the analysis (*Tables A4.1-A4.7*).

Cumulative sum test for parameter stability

Sample: 1999m1 - 2020m12 Number of obs = 264
Ho: No structural break

Statistic	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ols	2.7862	1.6276	1.3581	1.224

Table A4.1: CUSUM Test for spread

Cumulative sum test for parameter stability

Sample: 1999m1 - 2020m12 Number of obs = 264
Ho: No structural break

Statistic	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ols	2.1653	1.6276	1.3581	1.224

Table A4.2: CUSUM Test for bas

Cumulative sum test for parameter stability

Sample: 1999m1 - 2020m12 Number of obs = 264
Ho: No structural break

Statistic	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ols	3.4327	1.6276	1.3581	1.224

Table A4.3: CUSUM Test for ed

Cumulative sum test for parameter stability

Sample: 1999m1 - 2020m12 Number of obs = 264
Ho: No structural break

Statistic	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ols	2.6252	1.6276	1.3581	1.224

Table A4.4: CUSUM Test for esi

Cumulative sum test for parameter stability

Sample: 1999m1 - 2020m12 Number of obs = 264
Ho: No structural break

Statistic	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ols	1.6478	1.6276	1.3581	1.224

Table A4.5: CUSUM Test for PC2N

Cumulative sum test for parameter stability

Sample: 1999m1 - 2020m12 Number of obs = 264
Ho: No structural break

Statistic	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ols	3.3093	1.6276	1.3581	1.224

Table A4.6: CUSUM Test for shmp

Cumulative sum test for parameter stability

Sample: 1999m2 - 2020m12 Number of obs = 263
Ho: No structural break

Statistic	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ols	1.9301	1.6276	1.3581	1.224

Table A4.7: CUSUM Test for uncertvar

Tests for the Date of the Main Structural Break

Table A4.8 summarizes the timing of the main structural breaks for each series. Relevant estimation is performed in STATA using the command for a test for a structural break at an unknown date under the default 15% symmetric trimming. The Null Hypothesis under the relevant STATA command is that there are no structural breaks in the time series.

Variable	**Month**
Spread	*2011m4*
Bas	*2010m4*
Ed	*2010m11*
Pc2n	*2010m7*
Shmp	*2009m7*
Esi	*2010m3*
Uncertvar	*2012m1*

Table A4.8: Summary of main structural breaks

For the *spread* a break is located in 2011m4, a year after the contracting of the first bailout loan, once it became apparent in reviews of the First Economic Adjustment Programme that programme targets would not be met due to the size of the recession (Alcidi et al., 2020). For *bas*, the location of the structural break in 2010m4 coincides with the date when the Greek government issued a request for the first bailout loan. For *ed*, the main structural break is located in 2010m11. This date corresponds to the time reviews of the First Economic Adjustment Programme raise debt sustainability concerns, while reference is also made to debt restructuring through the PSI (Private Sector Involvement) and OSI (Official Sector Involvement) (Alcidi et al., 2020). For the Eurozone periphery spillovers (pc2n), the main structural break occurs in 2010m7, shortly after the first Economic Adjustment Programme. For pc2n, the main structural break occurs in 2010m7, when the Greek debt crisis mutated into a European debt crisis. For the ESI, the main structural break occurs in 2010m3, as the expectations of market participants with respect to economic activity became attuned to the prospect of Greek government default in the absence of a bailout loan. The main break for uncertainty is located in

2012m1, after the last tranche of the first bailout loan was received in December 2011 and prior to the agreement on the Second Economic Adjustment Programme and the Greek PSI in February and March 2012, respectively.

Tables A4.9-A4.15 present STATA output with respect to the above dates.

```
Test for a structural break: Unknown break date

                             Number of obs =        264

Full sample:                  1999m1 - 2020m12
Trimmed sample:               2002m5 -  2017m9
Estimated break date:         2011m4
Ho: No structural break

     Test            Statistic          p-value
-----------------------------------------------
     swald           564.1372           0.0000
-----------------------------------------------
Exogenous variables:           date
Coefficients included in test: date _cons

.
```

Table A4.9: The main structural Break for spread occurs in 2011m4

```
Test for a structural break: Unknown break date

                             Number of obs =        264

Full sample:                  1999m1 - 2020m12
Trimmed sample:               2002m5 -  2017m9
Estimated break date:         2010m4
Ho: No structural break

     Test            Statistic          p-value
-----------------------------------------------
     swald           170.2134           0.0000
-----------------------------------------------
Exogenous variables:           date
Coefficients included in test: date _cons
```

Table A4.10: The main structural break for bas occurs in 2010m4

```
Test for a structural break: Unknown break date

                             Number of obs =        264

Full sample:                  1999m1 - 2020m12
Trimmed sample:               2002m5 -  2017m9
Estimated break date:        2010m11
Ho: No structural break

     Test            Statistic          p-value
───────────────────────────────────────────────
     swald         1025.0219           0.0000
───────────────────────────────────────────────
Exogenous variables:           date
Coefficients included in test: date _cons
```

Table A4.11: The main structural break for ed occurs in 2010m11.

```
Test for a structural break: Unknown break date

                             Number of obs =        264

Full sample:                  1999m1 - 2020m12
Trimmed sample:               2002m5 -  2017m9
Estimated break date:         2010m3
Ho: No structural break

     Test            Statistic          p-value
───────────────────────────────────────────────
     swald          401.3539           0.0000
───────────────────────────────────────────────
Exogenous variables:           date
Coefficients included in test: date _cons
```

Table A4.12: The main structural break for esi occurs in 2010m3

```
Test for a structural break: Unknown break date

                             Number of obs =        264

Full sample:                  1999m1 - 2020m12
Trimmed sample:               2002m5 -  2017m9
Estimated break date:         2010m7
Ho: No structural break

     Test            Statistic          p-value
───────────────────────────────────────────────
     swald           54.8188           0.0000
───────────────────────────────────────────────
Exogenous variables:           date
Coefficients included in test: date _cons
```

Table A4.13: The main structural break for pc2n occurs in 2010m7.

```
Test for a structural break: Unknown break date

                             Number of obs =        264

Full sample:                  1999m1 - 2020m12
Trimmed sample:               2002m5 -  2017m9
Estimated break date:         2009m7
Ho: No structural break

     Test           Statistic          p-value
----------------------------------------------
     swald         2901.9941           0.0000
----------------------------------------------
Exogenous variables:           date
Coefficients included in test: date _cons

.
```

Table A4.14: The main structural break for shmp occurs in 2009m7.

```
Test for a structural break: Unknown break date

                             Number of obs =        263

Full sample:                  1999m2 - 2020m12
Trimmed sample:               2002m6 -  2017m9
Estimated break date:         2012m1
Ho: No structural break

     Test           Statistic          p-value
----------------------------------------------
     swald          175.1876           0.0000
----------------------------------------------
Exogenous variables:           date
Coefficients included in test: date _cons
```

Table A4.15: The main structural break for uncertvar occurs in 2012m1

Appendix A4.3 Pre- and Post-Estimation Tests of Models

T-GARCH Model Pre-Estimation

The output of OLS regression with Newey-West Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors of *Equation A4.12* is depicted in *Table A4.16*.

$$spread_t = \alpha * vix_t + \beta * bas_t + \gamma * esi_t + \delta * ed_t + \zeta * pc2n_t + \theta * shmp_t + c + \varepsilon_t, \qquad (A4.12)$$

Dependent Variable: SPREAD
Method: Least Squares
Date: 04/17/21 Time: 13:18
Sample: 1999M01 2020M12
Included observations: 264
HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 5.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.086645	0.043574	-1.988445	0.0478
VIX	0.063390	0.034549	1.834802	0.0677
BAS	0.018149	0.005391	3.366221	0.0009
ESI	-0.175468	0.037714	-4.652552	0.0000
ED	0.090349	0.027054	3.339603	0.0010
PC2N	0.010293	0.008093	1.271817	0.2046
SHMP	-0.016544	0.006808	-2.430110	0.0158

R-squared	0.720735	Mean dependent var	0.042664
Adjusted R-squared	0.714215	S.D. dependent var	0.053436
S.E. of regression	0.028566	Akaike info criterion	-4.247025
Sum squared resid	0.209720	Schwarz criterion	-4.152208
Log likelihood	567.6072	Hannan-Quinn criter.	-4.208924
F-statistic	110.5455	Durbin-Watson stat	0.234210
Prob(F-statistic)	0.000000	Wald F-statistic	41.18366
Prob(Wald F-statistic)	0.000000		

Table A4.16. OLS Regression

Based on the estimation output of *Table A4.13,* approximately 71.4% of the variance is explained. All variables bear the appropriate signs. However, PC2N and VIX are not statistically significant at the 5% level.

Heteroskedasticity Tests

Heteroskedasticity Test: ARCH

F-statistic	799.9430	Prob. F(1,261)	0.0000
Obs*R-squared	198.3000	Prob. Chi-Square(1)	0.0000

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 04/17/21 Time: 13:23
Sample (adjusted): 1999M02 2020M12
Included observations: 263 after adjustments
HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 5.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000113	5.31E-05	2.137478	0.0335
RESID^2(-1)	0.869129	0.092090	9.437781	0.0000

R-squared	0.753992	Mean dependent var	0.000797
Adjusted R-squared	0.753050	S.D. dependent var	0.002858
S.E. of regression	0.001420	Akaike info criterion	-10.26832
Sum squared resid	0.000527	Schwarz criterion	-10.24115
Log likelihood	1352.284	Hannan-Quinn criter.	-10.25740
F-statistic	799.9430	Durbin-Watson stat	1.463290
Prob(F-statistic)	0.000000		

Table A4.17 ARCH Test for Heteroskedasticity

Heteroskedasticity Test: White
Null hypothesis: Homoskedasticity

F-statistic	6.790403	Prob. F(27,236)	0.0000
Obs*R-squared	115.4240	Prob. Chi-Square(27)	0.0000
Scaled explained SS	702.7438	Prob. Chi-Square(27)	0.0000

Test Equation:

Dependent Variable: RESID^2
Method: Least Squares
Date: 04/17/21 Time: 13:25
Sample: 1999M01 2020M12
Included observations: 264
HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 5.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.27E-05	0.014654	0.003594	0.9971
VIX^2	0.011352	0.006543	1.735171	0.0840
VIX*BAS	-0.002371	0.002507	-0.945662	0.3453
VIX*ESI	-0.025601	0.019612	-1.305357	0.1930
VIX*ED	-0.019595	0.017573	-1.115044	0.2660
VIX*PC2N	0.008151	0.001989	4.097482	0.0001
VIX*SHMP	0.004392	0.003789	1.159107	0.2476
VIX	-0.015553	0.017928	-0.867522	0.3865
BAS^2	-9.98E-06	0.000325	-0.030688	0.9755
BAS*ESI	0.005085	0.007472	0.680601	0.4968
BAS*ED	-0.000406	0.002194	-0.185176	0.8532
BAS*PC2N	-0.000875	0.000335	-2.607418	0.0097
BAS*SHMP	-3.95E-05	0.000898	-0.043979	0.9650
BAS	0.004793	0.004662	1.028087	0.3050
ESI^2	-0.049058	0.021495	-2.282245	0.0234
ESI*ED	-0.091900	0.038482	-2.388144	0.0177
ESI*PC2N	-0.015397	0.006919	-2.225419	0.0270
ESI*SHMP	0.012369	0.005657	2.186473	0.0298
ESI	0.079186	0.039322	2.013805	0.0452
ED^2	0.020815	0.009922	2.097899	0.0370
ED*PC2N	-0.008669	0.004249	-2.040458	0.0424
ED*SHMP	-0.018476	0.006392	-2.890425	0.0042
ED	0.018810	0.025496	0.737760	0.4614
PC2N^2	0.000879	0.000164	5.355292	0.0000
PC2N*SHMP	0.001525	0.000727	2.097830	0.0370
PC2N	-0.004810	0.002527	-1.903269	0.0582
SHMP^2	0.002718	0.000912	2.980660	0.0032
SHMP	0.000484	0.004965	0.097568	0.9224

R-squared	0.437212	Mean dependent var	0.000794
Adjusted R-squared	0.372825	S.D. dependent var	0.002853
S.E. of regression	0.002259	Akaike info criterion	-9.247444
Sum squared resid	0.001205	Schwarz criterion	-8.868177
Log likelihood	1248.663	Hannan-Quinn criter.	-9.095043
F-statistic	6.790403	Durbin-Watson stat	0.725709
Prob(F-statistic)	0.000000		

Table A4.18 White Test for Heteroskedasticity

Heteroskedasticity Test: Breusch-Pagan-Godfrey
Null hypothesis: Homoskedasticity

F-statistic	5.977235	Prob. F(6,257)	0.0000
Obs*R-squared	32.32886	Prob. Chi-Square(6)	0.0000
Scaled explained SS	196.8300	Prob. Chi-Square(6)	0.0000

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 04/17/21 Time: 13:28
Sample: 1999M01 2020M12
Included observations: 264
HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 5.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.006400	0.003623	-1.766788	0.0785
VIX	0.005525	0.003279	1.684831	0.0932
BAS	-0.000246	0.000326	-0.753500	0.4518
ESI	-0.005126	0.004040	-1.269024	0.2056
ED	0.000479	0.001953	0.245130	0.8066
PC2N	0.000810	0.000758	1.067783	0.2866
SHMP	-1.30E-05	0.000465	-0.027891	0.9778

R-squared	0.122458	Mean dependent var	0.000794
Adjusted R-squared	0.101970	S.D. dependent var	0.002853
S.E. of regression	0.002704	Akaike info criterion	-8.962313
Sum squared resid	0.001879	Schwarz criterion	-8.867496
Log likelihood	1190.025	Hannan-Quinn criter.	-8.924213
F-statistic	5.977235	Durbin-Watson stat	0.316816
Prob(F-statistic)	0.000007		

Table A4.19. Breusch Godfrey Test for Heteroskedasticity

The residuals of the basic OLS regression on the sovereign spread against the independent variable inputs shown (*vix, bid-ask spread, expected debt differential, esi, pc2n, shmp*) with Newey-West Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors in this chapter exhibit heteroskedasticity, according to the ARCH test (*Table A4.17*), the White test (*Table 4.18*) and the Breusch Godfrey test (*Table 4.19*). The estimated test statistics across all tests reject the null hypothesis of homoskedasticity. These findings validate the use of the GARCH approach.

T-GARCH-Model Post-Estimation Tests

Unit Root Tests for the residual and squared residual of the T-GARCH model for the spread

Based on the test statistics of the unit root tests of the residual (*Table 4.20*) and squared residual (*Table 4.21*) of the T-GARCH model for the Greek sovereign spread, the null hypothesis of a unit root may be rejected at the 5% level. The residual and squared residual of the T-GARCH model is stationary.

Null Hypothesis: RESID_TGARCH has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=15)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-13.13783	0.0000
Test critical values:	1% level	-3.455289	
	5% level	-2.872413	
	10% level	-2.572638	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(RESID_TGARCH)
Method: Least Squares
Date: 03/19/21 Time: 12:01
Sample (adjusted): 1999M04 2020M12
Included observations: 261 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RESID_TGARCH(-1)	-1.064891	0.081055	-13.13783	0.0000
D(RESID_TGARCH(1))	0.203683	0.060932	3.342802	0.0010
C	0.000761	0.000660	1.153326	0.2498

R-squared	0.465534	Mean dependent var	2.25E-06
Adjusted R-squared	0.461391	S.D. dependent var	0.014476
S.E. of regression	0.010624	Akaike info criterion	-6.239931
Sum squared resid	0.029122	Schwarz criterion	-6.198959
Log likelihood	817.3109	Hannan-Quinn criter.	-6.223461
F-statistic	112.3626	Durbin-Watson stat	1.962293
Prob(F-statistic)	0.000000		

Table A4.20: Augmented Dickey Fuller Unit Root Test for the Residuals of the T-GARCH Model of the Greek Sovereign Spread

Null Hypothesis: RESID2_TGARCH has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=15)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.583136	0.0000
Test critical values:	1% level	-3.455289	
	5% level	-2.872413	
	10% level	-2.572638	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(RESID2_TGARCH)
Method: Least Squares
Date: 03/19/21 Time: 12:03
Sample (adjusted): 1999M04 2020M12
Included observations: 261 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RESID2_TGARCH(-1)	-0.363454	0.065099	-5.583136	0.0000
D(RESID2_TGARCH(1))	-0.504034	0.053771	-9.373633	0.0000
C	4.30E-05	3.52E-05	1.223811	0.2221

R-squared	0.527376	Mean dependent var	-5.53E-09
Adjusted R-squared	0.523712	S.D. dependent var	0.000803
S.E. of regression	0.000554	Akaike info criterion	-12.14650
Sum squared resid	7.93E-05	Schwarz criterion	-12.10553
Log likelihood	1588.118	Hannan-Quinn criter.	-12.13003
F-statistic	143.9443	Durbin-Watson stat	1.964677
Prob(F-statistic)	0.000000		

Table A4.21: Augmented Dickey Fuller Unit Root Test for the Squared Residual of the T-GARCH Model of the Greek Sovereign Spread

Test for Remaining ARCH effects

The ARCH-LM test outcomes reject the null hypothesis of remaining ARCH effects (*Table A4.22*).

Heteroskedasticity Test: ARCH

F-statistic	0.133770	Prob. F(1,260)	0.7149
Obs*R-squared	0.134730	Prob. Chi-Square(1)	0.7136

Test Equation:
Dependent Variable: WGT_RESID^2
Method: Least Squares
Date: 03/06/21 Time: 13:18
Sample (adjusted): 1999M03 2020M12
Included observations: 262 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.017076	0.171768	5.921207	0.0000
WGT_RESID^2(-1)	-0.022668	0.061978	-0.365746	0.7149

R-squared	0.000514	Mean dependent var	0.994333
Adjusted R-squared	-0.003330	S.D. dependent var	2.587438
S.E. of regression	2.591743	Akaike info criterion	4.750142
Sum squared resid	1746.454	Schwarz criterion	4.777382
Log likelihood	-620.2686	Hannan-Quinn criter.	4.761090
F-statistic	0.133770	Durbin-Watson stat	1.998926
Prob(F-statistic)	0.714852		

Table A4.22: ARCH LM Test

OLS Regression of the Estimated Measure of Uncertainty Against other Uncertainty Variables and Determinants of Sovereign Spreads

The association of this metric with the standard determinants of sovereign risk is examined in *Table 4.23*. OLS regression with Newey-West standard errors is applied with the time-varying conditional variance as the dependent variable (*uncertvar*) against the previously defined variables (*vix, ed, bas, shmp, pc2n*). The difference of the Real Effective Exchange Rate (REER) of Greece to that of Germany and the Hardouvelis et al. (2018) Economic Policy Uncertainty (EPU) index for Greece are also included in logarithms.

The regression specification used is:

$$uncertvar_t = \alpha * vix_t + \beta * bas_t + \gamma * esi_t + \delta * ed_t + \zeta * shmp_t + \theta * reer_t + k * epu_t + c + \varepsilon_t \qquad (A4.13)$$

Dependent Variable: uncertvar
Method: Least Squares
Date: 04/17/21 Time: 14:03
Sample (adjusted): 1999M02 2020M11
Included observations: 262 after adjustments
HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 5.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.007543	0.004245	-1.777016	0.0768
VIX	0.000208	0.000209	0.995894	0.3202
BAS	-4.09E-06	6.26E-05	-0.065413	0.9479
ESI	-0.001440	0.000856	-1.681347	0.0939
ED	0.000959	0.000590	1.624530	0.1055
SHMP	-0.000266	0.000150	-1.771673	0.0776
REER	0.003248	0.001915	1.696269	0.0911
EPU	0.000372	0.000248	1.502944	0.1341

R-squared	0.218941	Mean dependent var	0.000157
Adjusted R-squared	0.197416	S.D. dependent var	0.000490
S.E. of regression	0.000439	Akaike info criterion	-12.59430
Sum squared resid	4.89E-05	Schwarz criterion	-12.48535
Log likelihood	1657.854	Hannan-Quinn criter.	-12.55051
F-statistic	10.17139	Durbin-Watson stat	0.169446
Prob(F-statistic)	0.000000	Wald F-statistic	2.074345
Prob(Wald F-statistic)	0.046771		

Table A4.23: OLS regression of the Uncertainty Metric (Time-Varying Conditional Variance) against Fundamentals and Market-Sentiment Variables

Threshold Regression Model Post-Estimation

Unit-root tests of the residual of the threshold regression indicate that the residual is stationary (see Tables A4.24, A4.25).

Augmented Dickey-Fuller test for unit root — Number of obs = 261

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-11.388	-3.459	-2.880	-2.570

MacKinnon approximate p-value for Z(t) = 0.0000

D. residthresh	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
residthresh						
L1.	-.9118462	.0800695	-11.39	0.000	-1.069519	-.7541732
LD.	.092612	.0619627	1.49	0.136	-.029405	.2146291
_cons	.000016	.0004267	0.04	0.970	-.0008242	.0008563

Table A4.24: Augmented Dickey Fuller Test for a Unit Root in the Residual of the Threshold Regression

Phillips-Perron test for unit root — Number of obs = 262, Newey-West lags = 4

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-207.262	-20.310	-14.000	-11.200
Z(t)	-13.557	-3.459	-2.880	-2.570

MacKinnon approximate p-value for Z(t) = 0.0000

Table A4.25: Phillips Perron Test for a Unit Root in the Residual of the Threshold Regression

CGARCH Model of the Greek Sovereign Spread Post-Estimation

Heteroskedasticity Tests

Heteroskedasticity Test: ARCH

F-statistic	0.133770	Prob. F(1,260)	0.7149
Obs*R-squared	0.134730	Prob. Chi-Square(1)	0.7136

Test Equation:

Dependent Variable: WGT_RESID^2

Method: Least Squares

Date: 03/11/21 Time: 17:52

Sample (adjusted): 1999M03 2020M12

Included observations: 262 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.017076	0.171768	5.921207	0.0000
WGT_RESID^2(-1)	-0.022668	0.061978	-0.365746	0.7149

R-squared	0.000514	Mean dependent var	0.994333
Adjusted R-squared	-0.003330	S.D. dependent var	2.587438
S.E. of regression	2.591743	Akaike info criterion	4.750142
Sum squared resid	1746.454	Schwarz criterion	4.777382
Log likelihood	-620.2686	Hannan-Quinn criter.	4.761090
F-statistic	0.133770	Durbin-Watson stat	1.998926
Prob(F-statistic)	0.714852		

Table A4.26: ARCH-LM test of Residuals of CGARCH-M model

Based on *Table A4.26*, the null hypothesis of no ARCH effects in the residuals of the CGARCH-M model may not be rejected.

The Engle-Ng Sign-Bias Test is applied to detect any remaining leverage effects in the residuals. The sign-bias test of Engle and Ng (1993) regresses squared residuals against dummy variables and depends on the sign of the previous residuals. For the model to be correctly specified, the sign of the previous residuals should not impact current squared residuals i.e. under the null hypothesis, all parameters should be zero. Based on *Table A4.27*, the null hypothesis of no leverage effects in the standardized residuals cannot be rejected.

Engle-Ng Sign-Bias Test
Null Hypothesis: No leverage effects in standardized residuals

	t-Statistic	Prob.
Sign-Bias	-0.149200	0.8815
Negative-Bias	0.760691	0.4475
Positive-Bias	0.014778	0.9882
Joint-Bias	0.740336	0.8636

Test Equation
Dependent Variable: RESID^2
Method: Least Squares
Date: 03/11/21 Time: 17:54
Sample (adjusted): 1999M03 2020M12
Included observations: 262 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.052755	0.251202	4.190869	0.0000
SMINUS(-1)	-0.053371	0.357717	-0.149200	0.8815
SMINUS(-1)*RESID(-1)	17.12274	22.50945	0.760691	0.4475
SPLUS(-1)*RESID(-1)	0.354805	24.00829	0.014778	0.9882

R-squared	0.002861	Mean dependent var	0.994333
Adjusted R-squared	-0.008733	S.D. dependent var	2.587438
S.E. of regression	2.598712	Akaike info criterion	4.763058
Sum squared resid	1742.353	Schwarz criterion	4.817537
Log likelihood	-619.9607	Hannan-Quinn criter.	4.784955
F-statistic	0.246779	Durbin-Watson stat	2.042129
Prob(F-statistic)	0.863590		

Table A4.27: Engle-Ng Sign-Bias Test

Appendix A4.4: Event Study of the Greek Sovereign Spread for Select Dates

This event study is a very-short-term complement to the question of the news-impact on sovereign spreads, validating market-sentiment effects even under unchanged fundamentals. It offers a direct link to the Chapter 3 process, based on which uncertainty about fundamentals or economic policy leads to strategic uncertainty setting in motion self-fulfilling dynamics through shifts in investor beliefs towards the bad equilibrium- even when quarterly or monthly fundamentals have not changed.

In line with recent literature on the effect of uncertainty on sovereign spreads, standard event-study methods are applied to Greek sovereign risk. Daily data on Greek 10-Year Government Bond Yields and 10-Year German Bund Yields are extracted between January 2, 2002 and October 15, 2020 (market close values, in percent format). The Greek sovereign spread is calculated in levels (as percentage points) using trading-day data, and after correcting for trading-day differences across the two countries.

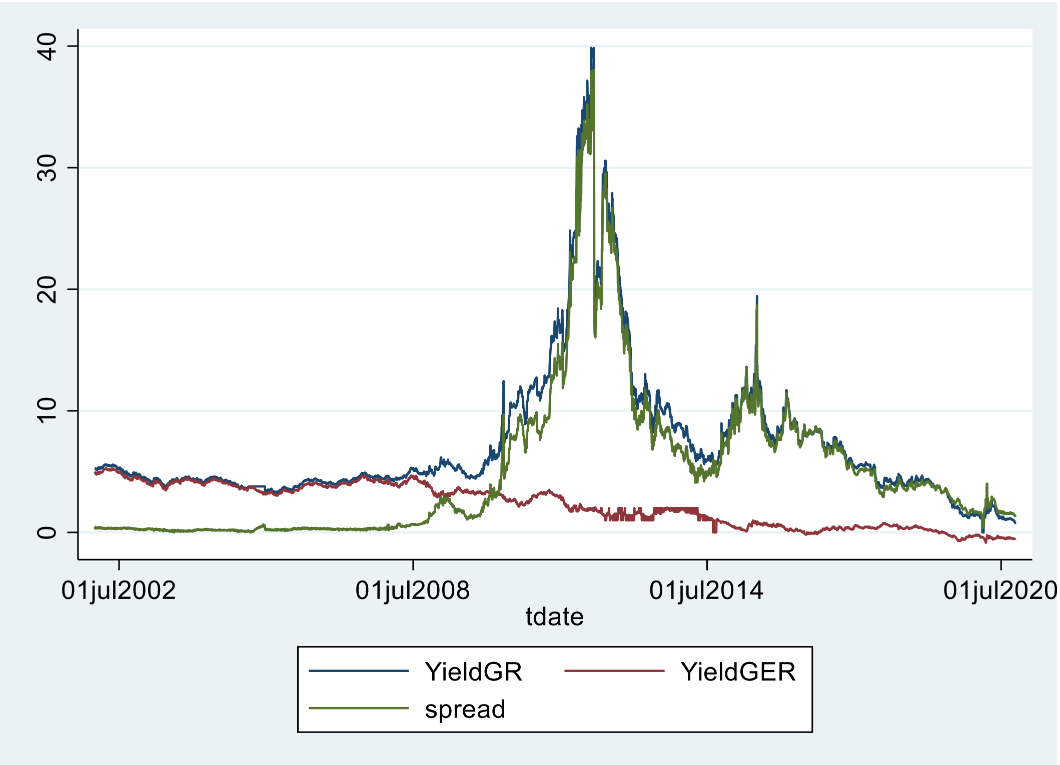


Figure A4.8: The Evolution of Daily Greek and German 10-year Government Bond Yields and of the Spread therein (percentage points)

The following key dates are selected for an event study of abnormal returns for investors on Greek bonds (based on the cumulative abnormal *yield* and *spread* of the Greek 10-year government bond)[165] for dates when Greek debt sustainability concerns were stronger:

[165] The yield of the Greek 10-year government bonds is used in the second part of the event study analysis (rather than the spread), as the German Yield is included as the benchmark based on which the cumulative average abnormal return is calculated.

- the time of the revelation of the Greek deficit by the newly elected government, also deemed to be the official start of the Greek and Euro area debt crisis: October 19, 2009[166]
- the S&P downgrade of the Greek debt into 'selective default'(SD) in anticipation of restructuring: February 27, 2012[167]
- the election of a left-wing government with an anti-austerity fiscal plan: January 26, 2015
- the announcement of the Greek referendum to be held on July 6, 2015, also considered as the tipping point for the potential of a government policy choice for Grexit: June 29, 2015[168]
- the government reaction to COVID-19 by imposing a generalized lockdown: March 23, 2020

For the definition of the event window, a topic of debate in relevant studies, this chapter follows Godl and Kleinert (2016) in selecting 4 days prior and 4 days after the event (s=4) "to hedge against the possibility of assigning the wrong date to an event" (Godl and Kleinert, 2016). As a "robustness check", a 10-day event window was also selected (s=10).

The event-study setup requires the selection of an appropriate benchmark to compute abnormal returns, as equity-market event studies make use of a benchmark market portfolio (MacKinlay, 1997). For the Greek yield, this benchmark safe rate was the equivalent-maturity German Bund (10Year), as the computation of a euro-area average yield would be problematic in terms of economic significance (Godl and Kleinert, 2016). This choice reflects basic asset pricing theory, according to which the yield on the Greek bond should be equal to the risk-free interest rate plus a risk premium. Assuming that the German Bund yield is approximately a risk-free rate and assuming that risk-aversion does not vary, if there is no information-relevant event, the yield on the Greek government bond should remain stable unless there is a change in market "expectations about the future solvency of the issuer" (Godl and Kleinert, 2016), i.e. a change in debt sustainability (see Chapter 2 Literature Review).

[166] https://www.kathimerini.gr/politics/765432/to-elleimma-toy-2009-i-megali-ekplixi/
[167] https://www.bloomberg.com/news/articles/2012-02-27/greece-cut-to-selective-default-by-s-p
[168] https://www.in.gr/2018/06/27/politics/tria-xronia-apo-tin-anakoinosi-tou-dimopsifismatos/

According to the null hypothesis, the trading date considered for each case does not constitute an event for Greek sovereign yields.

Using the Historical Mean of the Greek 10-Yr Government Bond Yield as Benchmark

Cumulative Average abnormal returns (CAARs) are computed for the 10Yr-Government Bond Yield compared to its historical mean value, estimated via the *estudy* command in *STATA.*

```
Event date: 19oct2009, with 2 event windows specified, under the Normality assumption
SECURITYCAAR[-4,4]       CAAR[-10,-10]
spread  769.32%***        83.84%
          (0.0000)         (0.1393)
---------------------------------------------------
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.28: Event Study CAAR for Greek Sovereign Bond Yields, Oct 19, 2009

The date corresponding to the announcement of the size of the true Greek budget deficit is statistically significant only when a 4-day event window is used.

```
Event date: 27feb2012, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  26552.37%***     2791.05%***
           (0.0000)         (0.0000)
----------------------------------------------------
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.29: Event Study CAAR for Greek Sovereign Bond Yields, Feb 27, 2012

Under both event-window specifications, the date of the downgrade by the S&P of the Greek government into Selective Default status, a number of days prior to the PSI, is statistically significant as an event.

```
Event date: 26jan2015, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  1250.87%          66.50%
           (0.5420)         (0.9224)
----------------------------------------------------
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.30: Event Study CAAR for Greek Sovereign Bond Yields, Jan 26, 2015

The election of a new left-wing party in government, although associated with a very high CAAR on a 4-day window, it does not appear to be a statistically significant event for Greek sovereign yields based on this method.

```
Event date: 29jun2015, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  4356.61%**       467.27%
           (0.0309)         (0.4870)
----------------------------------------------------
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.31: Event Study CAAR for Greek Sovereign Bond Yields, Jun 29, 2015

The announcement of a referendum is associated with the highest CAAR calculated among all 4-day event windows and is statistically significant at the 5% level. However, the event may not be significant for a 10-day window.

```
Event date: 23mar2020, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  -4650.93%**      -579.99%
           (0.0102)         (0.3364)
----------------------------------------------------
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.32: Event Study CAAR for Greek Sovereign Bond Yields, Mar 23, 2020

Under a 4-day event window, the announcement of a general lockdown due to COVID-19 proved to be an informational event for Greek yields at a 4-day event window. However, statistical significance is not confirmed under a 10-day window.

Therefore, under the normality assumption and using historical mean yields as a benchmark, only the announcement of the PSI is statistically significant under both event windows.

Using the Market Index (German Bund) as Benchmark

```
Event date: 19oct2009, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  -528.16%***      -82.02%*
          (0.0000)          (0.0529)
────────────────────────────────────────────────────
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.33: Event Study CAAR for Greek Sovereign Bond Yields, Oct 19, 2009

Under this specification, whereby CAAR for the Greek yield are compared to those of a market benchmark (the Bund yield), the announcement of the Greek deficit is associated with an opposite sign, potentially indicating the European dimension of the debt crisis. When a 10-day event window is applied, results are not statistically significant at the 5% level.

```
Event date: 27feb2012, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  6613.45%***      572.07%
          (0.0000)          (0.2254)
────────────────────────────────────────────────────
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.34: Event Study CAAR for Greek Sovereign Bond Yields, Feb 27, 2012

Surprisingly, the announcement of the Greek downgrade is not statistically significant with a 10-day event window. Yet, it remains highly significant under a 4-day event window.

```
Event date: 26jan2015, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  2036.56%***      157.92%
           (0.0000)         (0.1632)
─────────────────────────────────────────────────────
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses

.
```

Table A4.35: Event Study CAAR for Greek Sovereign Bond Yields, Jan 26, 2015

The January 2015 election is highly statistically significant and is associated with a very large CAAR for Greek sovereign spreads under a 4-day event window.

```
Event date: 29jun2015, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  4579.25%***      477.65%***
           (0.0000)         (0.0003)
─────────────────────────────────────────────────────
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.36: Event Study CAAR for Greek Sovereign Bond Yields, Jun 29, 2015

In contrast, the announcement of the Greek referendum constitutes a statistically significant event under both event windows.

```
Event date: 23mar2020, with 2 event windows specified, under the Normality assumption
SECURITY CAAR[-4,4]       CAAR[-10,-10]
YieldGR  568.36%***       125.52%*
           (0.0047)         (0.0607)
─────────────────────────────────────────────────────
*** p-value < .01, ** p-value <.05, * p-value <.1
p-values in parentheses
```

Table A4.37: Event Study CAAR for Greek Sovereign Bond Yields, Mar 23, 2020

As under the alternative method, the announcement of a general lockdown in response to COVID-18 in March 2020 constituted a statistically significant event only with a 4-day event window at the 5% level of significance.

Combining the results of *Tables A4.28-A4.37*, although all event dates may be statistically significant under a 4-day event window, the announcement of the Greek downgrade into Selective Default by S&P prior to the PSI has a more robust effect on Greek yields, compared to historical means. Similarly, when the benchmark is the cumulative return on the German Bund, the announcement of the Greek referendum is the most robust event, although 4-day CAAR is still higher in the days prior to the Greek PSI.

Event Date	**Method 1**	**Method 2**
10Oct2009	Significant at 4-day window	Significant at 4-day window, but negative CAAR
27Feb2012	Significant at 4-day and 10-day window	Significant at 4-day window
26Jan2015	Not significant	Significant at 4-day window
29Jun2015	Significant at 4-day window	Significant at 4-day and 10-day window
23Mar2020	Significant at 4-day window	Significant at 4-day window

Table A4. 38: Summary of Statistically Significant CAAR Event Study Dates, at the 5% Significance Level.

Appendix A4.5. Regime Dating Classification

Table A4.39 provides a detailed classification of months into the uncertainty and no-uncertainty regimes discussed in section 4.6 and corresponds to *Figure 4.22.* A value of 1 corresponds to months when the threshold regression crosses the uncertainty threshold and the Greek sovereign spread is in the uncertainty regime (regime 2). A value of 0 corresponds to the no-uncertainty regime.

Table A4.39. Threshold Regression Regime Dating Classification

date	Regime2
1999m2	0
1999m3	0
1999m4	0
1999m5	0
1999m6	0
1999m7	0
1999m8	0
1999m9	0
1999m10	0
1999m11	0
1999m12	0
2000m1	0
2000m2	0
2000m3	0
2000m4	0
2000m5	0
2000m6	0
2000m7	0
2000m8	0
2000m9	0
2000m10	0
2000m11	0
2000m12	0
2001m1	0
2001m2	0
2001m3	0
2001m4	0
2001m5	0
2001m6	0
2001m7	0
2001m8	0
2001m9	0
2001m10	0
2001m11	0
2001m12	0
2002m1	0
2002m2	0
2002m3	0
2002m4	0
2002m5	0
2002m6	0
2002m7	0
2002m8	0
2002m9	0
2002m10	0
2002m11	0
2002m12	0
2003m1	0
2003m2	0
2003m3	0
2003m4	0
2003m5	0
2003m6	0
2003m7	0
2003m8	0
2003m9	0
2003m10	0
2003m11	0
2003m12	0
2004m1	0
2004m2	0
2004m3	0
2004m4	0
2004m5	0
2004m6	0
2004m7	0
2004m8	0
2004m9	0
2004m10	0
2004m11	0
2004m12	0
2005m1	0
2005m2	0
2005m3	0
2005m4	0
2005m5	0
2005m6	0
2005m7	0
2005m8	0
2005m9	0
2005m10	0
2005m11	0
2005m12	0

2006m1	0
2006m2	0
2006m3	0
2006m4	0
2006m5	0
2006m6	0
2006m7	0
2006m8	0
2006m9	0
2006m10	0
2006m11	0
2006m12	0
2007m1	0
2007m2	0
2007m3	0
2007m4	0
2007m5	0
2007m6	0
2007m7	0
2007m8	0
2007m9	0
2007m10	0
2007m11	0
2007m12	0
2008m1	0
2008m2	0
2008m3	0
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Chapter 5

GDP-linked Bonds: Simulations of the Greek Government Debt and a Historical Counterfactual

5.1. Introduction

In line with the state-contingencies of changes in uncertain market sentiment conditions and in fundamentals, the previous chapters have shown that sovereign debt repayment capacity is state-contingent. The potential for self-fulfilling market-sentiment dynamics in the feedback loop between market interest risk premia and government debt has pointed to the need for an immediate liquidity solution to shield the sovereign from short-run uncertainties that affect the sovereign's debt servicing capacity. Combining the above finding and the insights from the fiscal fatigue literature, in addition to proposals for automatic liquidity crisis assistance, a state-contingent solution that contractually protects the sovereign from adverse economic growth outcomes becomes necessary. As the availability of fiscal space is associated both with current fiscal fatigue but also with potential output and intertemporal debt sustainability, the relevance of policy circles' discussions regarding the introduction of sovereign GDP-linked bonds becomes apparent.

This chapter takes note of the acknowledged failure of the IMF and European Institutions to accurately forecast the growth path in relevant debt sustainability analyses prior to the prescription of conditionality measures that accompanied the Greek bailout loans. Therefore, a state-contingent solution that not only shields against uncertain future worst-case scenarios for the rate of economic growth, but also applies a probabilistic 'fan chart'-based method that explicitly accounts for forecasting and measurement uncertainties and errors, is examined.

This chapter contributes to the literature on sovereign debt by being the *first to our knowledge to provide a historical counterfactual of the evolution of the Greek public debt/GDP ratio with and* *without GDP-linked bonds, both from an ex-ante forecasting baseline perspective as in 2010 (prior to the contracting of the first bailout loan) and from an ex-post perspective.* This Chapter applies the Blanchard et al. (2016a, 2016b) methodology, albeit in a historical counterfactual context, and for the case of Greece. In addition, partial indexation and sensitivities with respect to the percentage of debt-to-GDP being GDP-indexed and with respect to the risk premium charged are added to the procedure developed by Blanchard et al. (2016a,2016b). The main question raised is whether the evolution of the public debt-to-GDP ratio would have been more favorable with GDP-linked bonds than without.

Using the forecasting input macroeconomic scenario of the IMF prior to the contracting of the first bailout loan in 2010, the evolution of the Greek public debt-to-GDP ratio is examined as a forecasting exercise of regular non-indexed bonds ('plain vanilla') against the path of the public debt-to-GDP ratio under the assumption that a fraction (or all) of the debt were indexed to GDP-linked bonds to provide an *ex ante evaluation*. Sensitivities with respect to the percentage of government debt outstanding being indexed are provided, as well as sensitivities of the risk premium charged on this product. The exercise is repeated based on actual historical data input in lieu of the forecasting macroeconomic scenario for an *ex post evaluation*. A link to regime-switches in sovereign risk is provided, as a threshold of overindebtedness, beyond which a higher risk premium is charged by financial markets, is incorporated endogenously in the dynamic evolution of the public debt. A novelty premium is charged on GDP-linked bonds and analysis of results comments on relevant sensitivities for the evaluation of the state-contingent solution.

Chapter 5 is structured as follows: Section 5.1 provides a brief overview of GDP-linked bonds, and of the advantages and disadvantages of their introduction according to the literature; Section 5.2 presents the method applied for the simulations of the Greek debt; Section 5.3 presents data inputs; Section 5.4 analyzes the model-based results; Section 5.5 concludes. Results are provided in Appendices 5.3 and 5.4. A complementary brief history of state-contingent measures is offered in Appendix 5.1. A detailed version of the methodology is provided in Appendix 5.2.

5.2. Advantages and Disadvantages of GDP-linked Bonds

GDP-linked bonds are state-contingent sovereign debt instruments which feature a continuous adjustment of debt servicing obligations. According to proposed contractual designs in the literature, principal payments may be directly indexed to nominal GDP, and coupon payments may, thus, also be indirectly indexed to nominal GDP by percentage of principal. Indexation to real GDP is a feasible alternative, yet nominal state variables are preferred as they are both associated with the borrower's repayment capacity while also offering investors an implicit protection against inflation.[169] By tying interest and principal payments to the sovereign's repayment capacity, GDP-linked bonds act as a countercyclical insurance mechanism, contributing to the stabilization of the sovereign's Debt-to-GDP ratio and improving the sovereign's borrowing capacity (IMF,2017).[170]

The literature on GDP-linked bonds has emerged in response to policy circles' quest for alternative financing solutions to sovereign overindebtedness, both in the 1980s[171] and in the 2010s, in the aftermath of the Latin American debt crisis and the Eurozone and Greek sovereign debt crises. Thus, the vast majority is 'policy-oriented' rather than focused on academic or theoretical developments. Across time, models have emphasized and sought to overcome the empirical difficulty of providing a "theoretical price" for GDP-linked bonds and its concomitant effect on the debt-to-GDP ratio in the absence of any relevant bond issuance. Analytical pricing complexity has been suggested as a primary challenge against the introduction of GDP-linked bonds by investor surveys (Chamon and Mauro,

[169] Such inflation protection is associated with the GDP deflator rather than the CPI, as customary with inflation-linked securities.

[170] In contrast to GDP-linked warrants, GDP-linked bonds may offer (symmetric) repayment profiles allowing for differential payments on the upside and downside scenarios for economic growth (Kopf, 2017). Bowman and Naylor (2016) highlight the difficulties involved in pricing GDP-linked bonds in the absence of relevant precedent by indicating that warrant pricing, due to non-exposure to downside scenaria related to economic growth, does not provide an appropriate compass.

[171] In response to the debt crises of the 1980s, Krugman (1988) and Froot et al. (1989) were the first to suggest linking debt repayment to macroeconomic variables to increase risk-sharing and reduce the probability and cost of sovereign default (Borensztein and Mauro, 2002).

2005). The majority of studies focus on reduced-form models, as these have been deemed to be preferable for modelling the dynamics of sovereign debt (Duffie,2002).[172]

In reflection of continued turmoil with emerging markets sovereign debt, during the 1990s and early 2000s, a number of indexation schemes were proposed at a time when the first GDP-warrants were issued during the Brady Plan restructurings of Bulgaria, Bosnia and Costa Rica (IMF, 2017). Shiller (1993,2003) recommended the introduction of "Trills", "perpetual claims on one-trillionth of a country's GDP" for the purposes of increasing risk diversification (Barr et al., 2014). Barro (1995) suggested that the government's optimal debt management strategy would entail linking sovereign debt to government expenditure for tax smoothing purposes. Moral hazard concerns with regard to the potential for direct manipulation of government expenditure shifted the discussion to indexing debt repayments to GDP.

During the 2000s, on behalf of the IMF, Borensztein and Mauro (2002), "revived the Case for GDP-Indexed Bonds" by reflecting upon the advantages of GDP-linked bonds for sovereigns and pricing considerations for international investors, while also hinting at potential challenges and relevant solutions. Borensztein and Mauro (2002) developed the first simple quantitative model of GDP-linked bond simulations, comparing debt profiles with and without indexed debt and forming basic calculations of the risk premium for the sovereign debt of Emerging Markets, Advanced Economies and Developed Countries

The nascent literature on GDP-linked bonds is focused around one or more of the following topics: i. policy papers discussing design characteristics, advantages and disadvantages of those instruments and relevant clauses; ii. the pricing of GDP-linked bonds and particularly the appropriate risk-premium charged; iii. the debt-stabilizing effect of GDP-linked bonds. In addition, the literature distinguishes between the theoretical advantages that would arise by the issuance of GDP-linked bonds during normal times to the advantages arising due to the issuance during debt restructurings.

[172] Duffie (2002) compares corporate and sovereign debt and builds a case in favour of reduced-form models for the latter, as it involves the possibility of strategic default, often lacks seniority structure, liquidity considerations differ and due to difficulties involved in assessing the repayment capacity of the sovereign.

As this chapter develops simulations for Greece, the results of Fratzscher et al. (2014) are noted, which, however, do not represent a historical counterfactual as at the time of writing in 2014 but are relevant in the sense that a portion of the Greek public debt is being simulated. Fratzscher et al. (2014) convert official sector loans, and particularly the Greek Loan Facility (GLF) portion, into GDP-linked bonds. They estimate that in the worst percentile, under the path of macroeconomic forecasts as in 2014, debt stabilization would be impossible without the introduction of GDP-linked bonds.

The following section summarizes the basic arguments in favor and against the introduction of GDP-linked bonds.

5.2.1. Advantages Associated with GDP-Linked Bonds

The advantages and disadvantages of GDP-linked bonds are summarized by a number of papers, including, *inter alia*, Borensztein and Mauro (2002), Chamon and Mauro (2005), Brooke et al. (2013), Benford et al. (2016), IMF (2017), and Fournier and Lehr (2018). Advantages are viewed both from the perspective of the issuing sovereign and from that of the investor community and international financial architecture.

i. Countercyclical Fiscal Space

The primary advantage associated with the issuance of GDP-linked bonds relates to optimal debt management and tax-smoothing considerations over the business cycle, as proposed by Bohn (1990) and Barro (1995). According to Barro (1995), optimal debt management should link debt servicing obligations to debt repayment capacity, thereby offering a “natural hedge” against shocks to the government balance. Tax revenues, the tax base or government expenditure were originally suggested as indexation variables. However, given the ability of the government to directly manipulate the above, moral hazard concerns have required the consideration of GDP or economic growth as proxies for debt-repayment capacity and next-best alternatives for the purposes of tax-smoothing and debt stabilization (Chamon and Mauro, 2005).

By linking the level of principal and associated coupon payments to the level of economic activity, GDP-linked bonds operate as automatic stabilizers. They provide additional fiscal space during times of distress, when tax revenues are lower and the need for countercyclical government expenditures is highest, thereby enhancing the potential for repayment and minimizing the probability of default, while also contributing to the prospects of economic recovery. Therefore, GDP-linked bonds alleviate both the self-fulfilling effects and any long run fiscal insolvency dynamics. The above properties are critical during times of debt overhang (Krugman,1988). By symmetry, during good economic times, they restrain the procyclicality of fiscal policy and allow sovereign debt investors to reap higher yields, while enjoying an 'equity stake' on economic activity, in the conceptual framework by Kamstra and Shiller (2009). Papers which include a fiscal reaction function to changes in the growth rate and endogenous effects on the interest rate on GDP-linked bonds (such as Borensztein and Mauro, 2002) provide evidence in support of such countercyclical properties of GDP-indexed debt.

The benefits of the introduction of GDP-linked bonds have been associated with the level of public debt-to-GDP. GDP growth-indexed bonds are deemed to be "most useful when the debt ratio is 'high but not catastrophically high,'" (Blanchard et al., 2016a) as the decrease in the upper tail of the distribution of possible government debt ratios at each point in time is irrelevant on two occasions: when the level of debt is very low and when it is already extremely high (Blanchard et al., 2016a). During times of economic stress, the fiscal space generated by GDP-linked bonds serves to reduce the probability of default by leading to lower credit premia being demanded by investors and, hence, less explosive debt paths. This beneficial effect is more pronounced for lower-rated sovereigns, whose credit spread is larger (Benford et al., 2016). Chamon and Mauro (2005) are the first to develop a Monte Carlo GDP-linked bond pricing framework for the purposes of estimating the reduction in the probability of sovereign default due to the introduction of GDP-indexed bonds. For their average Emerging Markets case considered for simulations, they find that full indexation reduces the probability of default from 28% to 19% (Chamon and Mauro, 2005). Similarly, GDP-linked bonds may reduce the size of official sector loans required in future sovereign debt crises (Barr et al., 2014) and contribute to the restoration of debt sustainability in sovereign debt restructuring.

As such, under a portfolio of GDP-linked debt, the so-called maximum sustainable debt threshold for the sovereign, namely the level beyond which the public debt becomes explosive, or the maximum level of debt-to-GDP that can be sustainably serviced by the sovereign, is pushed to higher levels as a percentage of GDP (Barr et al., 2014; Benford et al., 2016).[173] Barr et al. (2014) develop a simple model for sovereign debt simulations under investor risk aversion, whereby the debt limit under GDP-linked bonds may almost double under certain circumstances compared to the debt limit under conventional debt. The effect on the maximum sustainable debt threshold depends on the implicit risk premium demanded by investors, and particularly on the relative effects of a decrease in the probability of default due to a larger fiscal space against costs of an additional GDP risk premium charged by investors. Manna (2017) probes into the theoretical effects of GDP-linked bonds on the maximum sustainable debt by suggesting that the latter is not constant as presumed in the majority of papers in the 'maximum sustainable debt level' literature; rather, it is a time-varying function of the growth rate, the interest rate and the shock on the public debt, derived by assuming that the primary surplus reacts to keep the debt-to-GDP ratio constant (Manna, 2017).

ii. Debt Stabilization

The second critical advantage of the issuance of GDP-linked bonds concerns debt stabilization, namely the decrease in the variance of the path of the debt-to-GDP ratio. Clearly, a less variable debt-to-GDP ratio enables enhanced fiscal planning while reducing the need for sharp fiscal consolidations and the frequency of default. A less variable debt-to-GDP ratio also bears a positive effect on investor expectations with regard to the default premium charged on debt issuances (Benford et al., 2016; Blanchard et al., 2016a).

Naturally, the stabilization properties of GDP-linked bonds are greater the more variable GDP is. A simple decomposition of the variance of the Debt/GDP ratio shows that variability in the Debt/GDP ratio comes from the variability of the primary balance, the variability of the interest-growth

[173] This argument is in line with the Reinhart et al. (2003) "debt intolerance" argument for Emerging Markets, whereby once debt-to-GDP surpasses a critical value, default is triggered.

differential and the covariance between the primary balance and the growth-interest differential (Benford et al., 2016; Blanchard et al., 2016a).

Below is the basic equation for the evolution of the dynamics of sovereign debt in the local currency:

$$\Delta d_t=\frac{i_t-g_t}{1+g_t}d_{t-1}\text{-}pb_t+sfa_t \qquad (5.1)$$

where Δd_t represents the change in the debt-to-GDP ratio, $i_t$represents nominal interest rates, g_t represents nominal economic growth, d_{t-1} stands for the debt-to-GDP ratio in the previous period, pb_t represents the primary balance and sfa_t corresponds to the so-called "stock flow adjustment" term, a residual capturing, inter alia, market valuation effects and contingent liabilities[174] (Benford et al., 2016; Blanchard et al., 2016a).

A number of shocks may govern the alternative plausible paths for debt-to-GDP, as follows:

$$\Delta d_t=\frac{(i_t+\varepsilon_{i,t})-(g_t+\varepsilon_{g,t})}{1+(g_t+\varepsilon_{g,t})}d_{t-1}\text{-}(pb_t+\varepsilon_{PB,t})+sfa_t, \qquad (5.2)$$

where $\varepsilon_{i,t}$, $\varepsilon_{g,t}$ and $\varepsilon_{PB,t}$ can be assumed to be drawn from a joint normal distribution (Benford et al., 2016; Blanchard et al., 2016a). Other models use a single error term capturing the accumulation of all the above. Economic literature suggests that this error term plays a significant effect on the debt evolution dynamics (Campos et al., 2006; and Abbas et al., 2011).

Therefore, taking the variance of each side of Equation 5.1 and omitting the stock-flow-adjustment term for simplicity:

$$\text{Var}(\Delta d_t)=\text{Var}(pb_t)+d_{t-1}^2\text{Var}(i_t-g_t)\text{-}2d_{t-1}cov(pb_t,i_t-g_t) \qquad (5.3)$$

(Carnot and Sumner, 2017).

Based on estimations for G7 countries, where the dynamics of GDP are inherently more stable, Benford et al. (2016) find that approximately one half of the variance of the public debt-to-GDP ratio is attributed to 'growth shocks' and to the covariance of growth and the cyclical primary balance. The

[174] The stock flow adjustment term is explicitly monitored and detailed for EMU countries in the context of EDP (Excessive Deficit Procedure).

covariance term between the primary balance ratio and the interest-growth differential is generally found to be negative or slightly positive due to the “negative cyclical impact of growth on the primary balance” due to lower tax revenues (Carnot and Sumner, 2017).

Assuming that GDP-linked bonds pay a return of:

$$i_t^{GDP} = g_t + \text{k}\ , \tag{5.4}$$

namely the return on GDP bonds is equal to the level of nominal growth, plus a constant GDP-risk premium k (Carnot and Sumner, 2017) and given that k is a constant, such that Var(k)=0, and the fact that from (*5.4*),

$$i_t^{GDP} - g_t = \text{k}, \tag{5.5}$$

the variance of the interest-growth differential for GDP-linked bonds is stabilized:

$$\text{Var}(i_t^{GDP} - g_t) = Var(\text{k}) = 0, \tag{5.6}$$

(Carnot and Sumner, 2017).

This, in turn, implies that under GDP-linked debt, equation 5.3 for normal debt corresponds to equation 5.7:

$$\text{Var}(\Delta d_t) = \text{Var}(pb_t) - 2d_{t-1}cov(pb_t, i_t - g_t).\text{[175]} \tag{5.7}$$

(Carnot and Sumner, 2017).

Based on the above, GDP-linked bonds decrease the overall variance for the evolution of the public debt-to-GDP ratio (Blanchard et al., 2016a; Benford et al., 2016; Carnot and Sumner, 2017). Also, the combination of any imposed primary balance targets[176] and GDP-linked bonds may result in substantial debt-stabilization.

[175] The correlation between the primary balance and ‘i-g’ is negative for most countries (Blanchard et al., 2016a).

[176] In addition to debt repayment considerations, the imposition of primary balance targets on the Greek government could also be viewed as a debt-stabilizing metric, assuming that the Greek government does reach such targets. However, it should be noted that over the course of the European Semester and the submission of budgetary plans by Euro Area governments, coordinated pressure is applied for targets to be reached and

Barr et al. (2014) distinguish a number of determining factors for the extent to which a sovereign may benefit from GDP-linked bonds. Sovereigns with higher levels of debt, more volatile interest-growth differentials and with constraints on the effectiveness of their monetary policy stand to benefit the most (Barr et al., 2014). For countries where monetary policy is constrained or central bank independence has been abandoned due to membership in a currency union, GDP-linked bonds may prove to be even more desirable due to their partial stabilization of the variability in the interest-growth differential (Benford et al., 2016). In contrast, low-debt countries or Emerging Market economies with flexible-exchange-rates will reap less of the benefit associated with GDP-linked bonds (Barr et al., 2014).

However, the simplicity of models underlying the above calculations and benefits requires caution prior to reaching conclusions with respect to the benefits of GDP-linked bonds. For instance, Barr et al. (2014) admit the presence of large uncertainty in their calculations, noting that the benefits of GDP-linked bonds will be lower in the presence of a positive correlation between economic growth and interest rates.

Furthermore, the stabilization properties of GDP-linked bonds are further compromised by: i. a negative correlation between the primary balance and the growth-interest differential;[177] ii. the presence of contingent fiscal liabilities; iii. the incidence of exchange-rate shocks; iv. an endogenous change in the borrower's behavior due to the introduction of GDP-linked bonds (Blanchard et al, 2016a).

The latter alludes to the political economy of sovereign debt as applicable to GDP-linked bonds, as a sovereign's borrowing behaviour may be altered following the introduction of GDP-linked bonds.

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variance in the primary balance to be minimized. To the extent that fiscal targets placed by official loan agreements are stricter, there is marginal value in the debt stabilizing benefits of primary balance targets for Greece.

[177] As GDP-linked bonds reduce the variance of the r-g term, the more variable this term is, the greater the stabilization benefits from the use of such state-contingent bonds. However, such stabilization properties are somewhat reduced if the covariance between interest rates and economic growth is positive, as higher interest rates are offset by higher economic growth, implying that there is less of a need for GDP-linked bonds.

Therefore, it is possible that models of strategic default a la Eaton and Gersovitz (1981) be developed for state-contingent debt (Barr et al, 2014).

iii. Insurance against Transitions into a 'Bad Equilibrium'

Based on their stabilization properties, GDP-linked bonds may offer *ex ante* insurance against bad states of the world, limiting the occasions on which the sovereign moves from a "good equilibrium" to a "bad equilibrium". GDP-linked bonds may, thus, avert a liquidity crisis and its transformation into a solvency crisis and associated deadweight losses. This is particularly true when issued during a sovereign debt restructuring (Benford et al, 2016). In the domain close to the maximum sustainable debt threshold, if credit risk premia on conventional non-contingent debt are higher than the GDP-risk premium on GDP-linked bonds, a net decrease in the level of spreads is achieved by indexing sovereign debt to GDP, thereby contributing to more stable equilibrium dynamics. Chamon and Mauro (2005) find that GDP-indexation reduces the probability of default by one third or one-fourth of its initial level for emerging market bonds. Although GDP-linked bonds have been suggested primarily as a solution against *solvency* rather than *liquidity* concerns (IMF, 2017), the reduction of debt servicing obligations during bad states of the world may be particularly important for liquidity-constrained Emerging Market economies, which often respond to low levels of growth via increases in their primary balance to maintain credibility and access in financial markets (Borensztein and Mauro, 2002).

iv. Strengthening the International Financial Architecture

In addition to the above advantages, GDP-linked bonds serve to enhance the resilience of the international architecture. Under the status quo, risk-sharing between the sovereign and investors under conventional debt is suboptimal due to the large deadweight losses associated with default. De Paoli et al. (2009) find that the mean output loss from default is 15% due to the concurrent effect of banking and currency crises. Benjamin and Wright (2009) find that sovereigns regain market access with debt ratios that are more elevated compared to pre-default ratios, even after having imposed losses on investors. Moreover, the mere anticipation of default may induce large output losses, as evidenced by Levy-Yeyati and Panizza (2011) who suggest that the contraction in output occurs prior to sovereign default. By limiting the frequency and severity of contagious sovereign debt crises, GDP-linked bonds could improve the international financial and fiscal architecture.

In general, GDP-linked bonds serve to strengthen the international monetary and financial system by reducing the probability of solvency crises and associated costs of default or restructuring processes (Benford et al., 2016; IMF, 2017). From a theoretical standpoint, GDP-linked bonds offer improved risk-sharing opportunities, which in the context of the Arrow-Debreu framework, serve to increase the number of states spanned by securities, thereby enhancing market completeness. The increase in risk-sharing and reduction in default risk reduces the need for international bailouts, thereby also mitigating creditor moral hazard (Benford et al.,2016). In addition, GDP-linked bonds replace the burden of a deterioration in economic growth from the shoulders of the domestic taxpayer to those of investors in GDP-linked bonds, which are also more likely to be less risk-averse and more diversified in their financial portfolio (Benford et al., 2016; Kamstra and Shiller, 2009; Fournier and Lehr, 2018).

Furthermore, the issuance of GDP-linked bonds will invite financial markets to conduct further macro research on the appropriate pricing of sovereign risk. This will reduce informational asymmetries currently present in the market of sovereign risk and, thus, also limit abrupt herding behaviour that occurs with sudden shifts in expectations, potentially also reducing the incidence of sudden stops and capital flight, which exacerbate the vicious dynamics of sovereign default. Bikchandani et al. (1992) show that herding behaviour is more prevalent in markets where information is thin. In the context of the discussion on EMU deepening, Blanchard et al (2016a) suggest that the cross-border holdings of GDP-linked bonds could be a partial alternative to a fiscal transfer union. Also, by increasing fiscal space during times of recession or lower growth, GDP-linked bonds may contribute to a reduction in negative spillovers from one country to another, as these occur predominantly at times of concurrent consolidation efforts and low growth (Benford et al.,2016; Auerbach and Gorodnichenko, 2013).

v. Investor Risk Diversification

From the investors' perspective, current sovereign debt instruments appear to be suboptimal as markets remain largely incomplete, or equivalently, in the Arrow-Debreu framework, there exist states of nature which are not spanned by securities, thus, leading to suboptimal risk-sharing and hedging. This suggests a role for additional risk-sharing opportunities, such as those offered by GDP-linked bonds. Under plain-vanilla bonds, in bad states of the world, losses are "passed on to investors", leading to suboptimal levels of risk-sharing, as these are usually confined to 'tail events', which in turn implies that there is scope for additional risk sharing (Barr et al, 2014). Instead, GDP-linked bonds may also benefit the investor community and global risk-sharing by providing opportunities to invest directly into GDP risk across countries. Economic literature presents evidence of large unrealized gains for international risk sharing with respect to GDP, given the low correlation between GDP per capita across countries, as evidenced by Athanasoulis and van Wincoop (2000) and Athanasoulis et al. (1999). The Capital Asset Pricing Model (CAPM) contends that expected returns should only reflect systematic risk as idiosyncratic risk is diversified away. However, in the context of GDP risk, the systematic portion of risk is relatively small compared to idiosyncratic risk (Borenszein and Mauro, 2002), which in turn implies that if such risk is not diversified, any financial instrument offering direct exposure to it will benefit from international risk diversification. From a risk management perspective, indexation to GDP is also more advantageous for investors in countries where stock markets are not well diversified and stock markets fluctuations exhibit low levels of correlation with a country's growth rate (Borensztein and Mauro, 2002). These benefits are lower for advanced economies and whose GDP moves in parallel and higher for international portfolios investing in emerging market growth risks, as Capital Asset Pricing Model (CAPM) betas or estimates of emerging-market co-movement with an international "market portfolio" are very low (Borensztein and Mauro, 2002). The above risk-diversification benefits may also serve as an allure to increase the investor base on sovereign debt and hence the liquidity of public debt securities. Investor gains from risk diversification are also evidenced by Cabrillac et al. (2016,2018), who note that the inclusion of GDP-linked bonds in lieu of a stock market index reduces the variance of the portfolio due to GDP-growth being less volatile than most stock markets and due to a lower correlation of nominal GDP growth with relevant 'market portfolios'. Thus, GDP-linked bonds maximize Sharpe ratios (Sharpe, 1994) across 75 percent of simulations performed by Cabrillac et al. (2016, 2018).

Cabrillac et al. (2016, 2018) contend that GDP-linked bonds present an additional advantage, "automatic partial long-run currency risk hedging", as bidirectional feedback loops exist between the nominal exchange rate and nominal GDP growth, even though the exact sign of the relationship is plagued by uncertainty.

The advantages of GDP-linked bonds have also been considered in the context of issuance during sovereign debt restructurings, whereby they serve to 'bridge' the negotiating gap between investors and the sovereign, while also reducing GDP growth-uncertainty (Brooke et al., 2013; Fratzscher, et al., 2014; Goodhart, 2015; Honohan, 2011). Easterly (2002) finds that a one percentage point decrease in average annual GDP growth lead to 1.5 more debt reschedulings over the following 15 years (Borensztein and Mauro, 2004). Benford et al. (2016) distinguish three primary benefits of GDP-linked bonds during debt restructurings: i. they backload the debt repayment schedule to ensure it is in line with repayment capacity; ii. they act as 'deal sweeteners' thereby reducing the costs of delay and associated deal uncertainties; iii. they reduce the need for additional future debt restructurings due to their insurance and debt-stabilizing properties, which is particularly useful in the face of historical evidence of recurrent debt restructurings and of 'serially defaulting' countries (Benford et al, 2016). [178]

5.2.2. Disadvantages Associated with GDP-linked Bonds

i. Moral Hazard

A series of complications govern the issuance of GDP-linked bonds, raising impediments to their wide adoption by the investor community. First and foremost is the topic of *moral hazard* (Arrow, 1968). In insurance terminology, *moral hazard* is defined to occur in the "case when people engage in

[178] Since the 1980s, two thirds of restructurings with private creditors have proven inadequate to restore debt sustainability, thereby leading to repeat restructurings (Benford et al., 2016; IMF, 2014).

riskier behavior with insurance than they would if they did not have insurance" (Openstax, Chapter 16, 2020) [179] , which in turn increases the probability that insurance is activated and augments expected costs for the insurer. Moral hazard has stood at the heart of public policy debates on sovereign debt restructuring and has given rise to an extensive literature on creditor and debtor moral hazard and institutional solutions that serve to reveal hidden interests or align incentives (Kahan and Leshem, 2017; Ghosal and Miller, 2003). In the context of GDP-linked bonds, given the potential of making lower debt repayments in times of lower economic growth, the sovereign may be partially incentivized to steer away from growth-enhancing reforms and policies (Fournier and Lehr, 2018; IMF, 2017; Bowman and Naylor, 2016; Chamon and Mauro, 2005; Schroder et al.,2004).[180] As the complete elimination of moral hazard is impossible, a number of contractual design characteristics of the GDP-linked bond term sheet may contribute to its minimization. For example, the selection of a state variable which is not directly under the sovereign's influence, as opposed to tax revenues, and a preference towards a variable such as GDP, or if applicable, some commodity price, is noted as a cautionary measure against moral hazard in the literature (IMF, 2017). However, a trade off emerges between moral hazard and the degree to which the state variable is associated with the government's repayment capacity for GDP-linked bonds to operate as an effective countercyclical mechanism (IMF, 2017). As a compromise to the above tradeoff, the maintenance of conventional debt may serve to align incentives of creditors and debtor policy. The IMF (2017) suggests two potential 'mitigating factors': i. the maintenance of sufficient 'skin in the game', namely the non-total replacement of conventional bonds, may serve to align creditor and debtor incentives; ii. political incentives to prevent 'bad states of the world' from occurring (IMF, 2017). Furthermore, the contractual inclusion of caps and floors[181] on the indexation formula applied could also mitigate the degree of moral hazard, as these serve to minimize the extent of debt relief granted (IMF, 2017).[182]

[179] https://opentextbc.ca/principlesofeconomics/chapter/16-2-insurance-and-imperfect-information/
[180] This is also true for sovereign-CoCos, where the sovereign may reduce the level of precautions taken against the incidence of the event that the trigger protects the sovereign against.
[181] Schinckus (2013) develops a short paper on the pricing of GDP-linked collar bonds applying max-min formulas to the indexation scheme.
[182] The Bank of England has proposed an indicative term sheet for GDP-linked bonds, the so-called "London Term Sheet".

ii. Adverse Selection

State-contingent debt, and GDP-linked bonds in particular, are plagued by the problem of adverse selection, which arises in the presence of information asymmetries (IMF, 2017). Given that the sovereign benefits from enhanced information on the sustainability of its debt in view of forthcoming policy choices compared to what may be known in the investor community, investors will assume that sovereigns tapping the GDP-linked bond market are those with the worst macro and growth outlook. The quality of data, enhanced transparency of official statistics, and the presence of an international institution validating official statistics, such as Eurostat in the case of the European Union, may serve to minimize this issue. Adverse selection may also be minimized by the coordinated issuances across sovereigns (Brooke et al., 2013; Bowman and Naylor, 2016), for instance, in the context of the European Semester.[183]

iii. Data Concerns

Furthermore, GDP statistics may be plagued with problems of data availability, integrity and timeliness (IMF, 2017; Cecchetti and Schoenholtz, 2017). In countries with less transparent and credible official data, GDP-linked bonds may generate incentives for GDP data manipulation. However, in an attempt to dispel relevant investor fears about potential losses associated with revisions of GDP statistics, Chamon and Mauro (2005) show that a decline in expected growth by one percentage point is associated with minimal investor losses. The linking of repayment to GDP, particularly in the presence of a payment floor may incentivize the indebted sovereign to report lower levels of GDP (Ceccheti and Schoenholz, 2017). As such, some form of sanction may be applied, potentially via a put option embedded in the design of the bond, such that any delay in official

[183] The European Semester refers to the framework of economic coordination among member states of the EMU:
https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester_el

statistics grants the investors the option to buy back the bond at a predetermined price. Put events may also be associated with the fulfilment of policy conditionality (IMF, 2017).

However, basing the index on lagged values involves an additional tradeoff between the countercyclical properties of GDP-linked bonds against solutions to prevent moral hazard. As in the case of inflation-linked bonds,[184] given the frequent revisions of official statistics, proposals suggest indexation to the previous quarter or earlier data reported, which, however, may not be reflective of the prevailing macroeconomic situation. In the event of a sharp reversal to economic growth between two quarters would, thus, result in higher debt repayments, thereby exacerbating procyclical effects on the budget. As such, policy circles are examining indexation to a moving average of the state variable over the business cycle to reduce such cliff effects.

iv. Adverse Effects on Conventional Debt

Furthermore, the issuance of GDP-linked bonds may result in the "cannibalization" of the market for conventional non-contingent debt instruments (IMF, 2017). Depending on the level of investor risk aversion and the specific macroeconomic characteristics and terms of the GDP-linked term sheet, investors may display a sustained preference for GDP-linked bonds, resulting in the selloff of conventional debt, which in turn could increase the credit spread on conventional debt. The yields on conventional bonds may be driven to unsustainable levels, such that GDP-linked bonds would have induced the liquidity crisis they were meant to avert. Seniority and cross-default clauses are central to this issue, as is the appropriate management of the percentage of debt indexed to GDP in the total sovereign debt portfolio (IMF, 2017). Thus, a further tradeoff emerges between the level of GDP-linked bonds uptake by the investor community against the credit risk premium on conventional debt (Bowman and Naylor, 2016; Chamon and Mauro, 2005; Manna, 2017).

[184] ICMA suggested that timings should be made to be close to those of inflation-linked bonds for quarterly GDP data with six-month lags being used instead of the three-month lags used for inflation data (Kopf, 2017).

v. Transfer of Risk to the Private Sector

If GDP-linked bonds are held by financial institutions, they may lead to the migration of sovereign risk back to the sovereign as the sovereign-bank nexus may be reinforced (IMF, 2017). The additional risk premium on GDP-linked bonds may have an adverse balance sheet effect on financial institutions, raising the probability for the need of state aid and for recapitalizations. Therefore, the stabilization potential offered by state-contingent debt may be limited due to a potential associated increase in the size and risk of contingent liabilities for the government.

The above are indicative of the general market failures due to which financial innovation might fail to emerge, thus, suggesting a role of government intervention, as highlighted by Allen and Gale (1994).[185]

vi. The Cost of a GDP-linked Bonds Risk Premium

The above challenges affect pricing via the introduction of additional risk premia compared to conventional debt. Apart from the standard credit risk premium, which depending on the terms and percentage of debt indexed may be substantially lower for GDP-linked bonds than plain-vanilla bonds, additional risk premia, such as a *default/credit risk premium*, a *GDP-risk premium,* a *novelty premium,* and a *liquidity premium* may work in the opposite direction and may lead to a combined premium that is higher than the premium on plain vanilla bonds. The above distinction between the different premia is maintained by many papers (Carnot and Summer, 2017; IMF, 2017; Blanchard et al, 2016a; Fournier and Lehr, 2018; Cabrillac et al., 2016, 2018; Bowman and Naylor, 2016), while others focus on calculating the total risk premium, or *insurance premium,* associated with GDP-linked bonds.[186] The total risk premium corresponds to the addition of the above-mentioned risk-premia, as these are considered to be additive according to Treynor (1961).

[185] Borensztein and Mauro (2002) connect the Allen and Gale (1994) framework for financial innovation to GDP-linked bonds by focusing on parallels with respect to product uncertainty, externalities and coordination problems, as well as the highly competitive structure of financial markets.
[186] Barr et al. (2014), Blanchard et al. (2016a) and Fournier and Lehr (2018) distinguish between a credit default risk premium and a GDP risk premium only.

GDP-linked bonds have been associated with reduced *credit risk* for the sovereign due to two main properties inherent in their counter-cyclical nature: first, debt increases caused by GDP contractions are limited, thus, stabilizing debt shocks due to the containment of the "growth shock" component of the evolution of public debt-to-GDP and the reduction in the Debt-to-GDP variance (Brooke et al,2013); second, as the maximum sustainable debt for a sovereign increases, more fiscal space is provided for governments to use counter-cyclical pro-growth fiscal policy during crises (Brooke et al,2013). Therefore, as far as the *credit risk premium* is concerned, *ceteris paribus* and assuming no effects on conventional debt or full indexation, in bad economic times, the increase in fiscal space provided by the smoothening of the repayment profile of the sovereign clearly indicates that the probability of default is lower with GDP-indexed debt than conventional debt (Brooke et al,2013). Based on standard bond-pricing, a lower probability of default is associated with a lower credit risk premium. Bowman and Naylor (2016) suggest that the size of the credit risk premium depends on the size of the premiums on existing debt and on how GDP-linked bonds are perceived to affect sovereign debt sustainability. Carbillac et al. (2016) highlight that GDP-linked bonds are usually associated with decreases in default risk, thereby improving long-term solvency.[187]

The *novelty premium* is attached to all new financial market instruments and is considered to subside over time, as a "critical mass" of market volume is attained. From the perspective of public finance economics, the novelty premium alludes to standard market failures (Costa et al., 2008). Externalities and coordination failures arise as investors face high pricing computation costs and do not internalize the social benefit they provide for other investors. A first-mover disadvantage arises for the first sovereign to issue GDP-linked bonds due to the high costs entailed for the first-mover and low imitation costs for market participants based on low barriers to entry, thereby resulting in a socially suboptimal outcome and deadweight losses (IMF, 2017; Chamon and Mauro, 2005). Such collective action problems call for market-making assistance by International Financial Institutions and suggest

[187] However, sovereign CoCos involving an automatic deferral of payments would have been more effective (Cabrillac et al., 2016, 2018).

that coordinated issuances by advanced countries could eliminate first-mover disadvantages (Borensztein and Mauro, 2002; Allen and Gale,1994).

The *liquidity premium* refers to the low depth of the market and small volume of transactions that may prevail for GDP-linked bonds. In response, Brooke et al. (2013) call for international cooperation for the achievement of a critical mass in liquidity of GDP-linked debt, for the establishment of valuation practices and common standards, as well as the build-up of a specialized trading platform (Brooke et al, 2013). As with the novelty premium,[188] the liquidity premium is expected to be high initially, yet to gradually decrease over time, as the GDP-linked bonds market is developed (Bowman and Naylor, 2016).

The *GDP risk premium* arises due to the variability of GDP, which according to the indexation rule applicable in the term sheet, implies that investors will demand a higher premium in compensation against lower debt repayments during good economic times. Considerable uncertainty surrounds the size of the GDP risk premium to be demanded by investors, as there is substantial variability in economic growth and uncertainty about macro forecasts. Across international studies, estimates of the GDP risk premium range between 20 bps and 350 bps. Barr et al. (2014) suggest that the benefits of issuing GDP-linked bonds exceed the costs when the GDP-risk premium is at levels below 200-350pbs. Miyajima (2006) and Kamstra and Shiller (2009) locate the risk premium at lower levels of approximately 150bps. Blanchard et al (2016a, 2016b) use a premium of 100 bps for Advanced Economies and comment that substantial uptake of GDP-linked bonds by internationally diversified investors would serve to gradually reduce this GDP risk premium.

Fournier and Lehr (2018) define a 'critical risk premium' to be the risk premium that would equate the debt-to-GDP ratio with and without GDP-linked bonds.[189] Fournier and Lehr (2018) find the critical risk premium to range between 0 (for Belgium and Netherlands) and 3.32% (for Ireland).

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[188] Costa et al. (2008) find that the novelty premium associated with Argentina's GDP-linked warrants is reduced by approximately 600 basis points during the eighteen months after issuance (Bowman & Naylor, 2016).

[189] They first estimate the growth process via a simplistic bivariate VAR model of the interest-growth differential and the primary balance for select euro area countries.

Interestingly, the risk premium for Greece is 2.96%. [190] Such high levels of risk premia required by GDP-linked bonds explain why GDP-linked bonds may only be appropriate for counties whose debt levels are "high, but not catastrophically high" as cautioned by Blanchard et al (2016a). Across all methods applied[191], Fournier and Lehr (2018) find that the risk premia associated with GDP-linked bonds are lower than CDS default premia, such that, on average, they correspond to a 40% reduction in the perceived probability of default (Fournier and Lehr, 2018). Similarly, Barr et al. (2014), explain that when the sovereign "approaches the debt limit," the default premium on conventional bonds may be lower than the GDP-risk premium on GDP-linked bonds, such that the probability of default is reduced. This is modelled to occur when the implied required GDP risk premium drops below 3.7% (Barr et al., 2014).

The specific design of the GDP-linked bond may bear an effect on the risk premium. Greater complexity in design will entail a greater cost for the pricing of risk and greater uncertainty with respect to the risk-reward profile of the bond, thereby increasing both the novelty and liquidity premia. Similarly, while call options have been used with state-contingent debt in the past, their embedding in the contract may entail a tradeoff between stabilization for the indebted sovereign against investor risk (IMF, 2017). In good states of the world, the sovereign may weigh the cost of making GDP-linked repayments on debt against the cost of buying back the GDP-linked bond and issuing a conventional, non-indexed bond with lower repayment obligations for times of high economic growth. Naturally, the specific design of the option may limit investors' profits in upside scenarios, inducing a *call option premium*, as also typical with inflation-linked bonds (IMF, 2017). For example, in Bulgaria, investors swapped contingent debt for non-indexed debt as the trigger

[190] Fournier and Lehr (2018) caution that the 90th percentile which has been used for the calculation of the 'critical risk premium' is not associated with sovereign debt crises for most advanced economies.
[191] Fournier and Lehr (2018) also estimate ARMA (p,q) models for the GDP growth rate, as well as a VAR with the OECD Composite Leading Indicator (CLI) and extract the persistence factor for growth shocks, as they consider that a persistence highlights the risk of protracted recession and hence investors in GDP-linked bonds would require to be compensated via higher risk premiums. According to Fournier and Lehr(2018), although the novelty and liquidity premia may be substantial, they are by nature temporary and would not concern medium-to-long-term investors, who instead would be focused on the risk premium associated with GDP volatility.

appeared more likely (Borensztein and Mauro, 2002). Clearly, investor concerns with the call option are stronger the earlier the potential to exercise the option.

5.3. Methodology

5.3.1. Simulation of the Debt-to-GDP ratio

This chapter follows the methodology for debt-to-GDP simulations, as used by Blanchard et al (2016a, 2016b), Benford et al. (2016) and Cabrillac et al. (2016, 2018), albeit with differences: partially indexed debt-to-GDP ratios are foreseen in addition to plain-vanilla (non-indexed) and fully-indexed debt; and debt is indexed to real GDP growth, as in Blanchard et al (2016a, 2016b). Furthermore, it goes beyond the above in that sensitivity analysis on levels of the risk premium charged on indexed debt and on the percentage of debt-to-GDP being indexed is provided.

Simulations are performed using Matlab[192] and are based on the following standard equation for the evolution of public debt dynamics:

$$\Delta d_t = \frac{i_t - g_t}{1 + g_t} d_{t-1} - pb_t + sfa_t \tag{5.6a}$$

where Δd_t represents the change in the debt-to-GDP ratio for country i, $i_t$represents the level of the nominal interest rate for country i, g_t represents the level of nominal economic growth d_{t-1} stands for the debt-to-GDP ratio in the previous period for country i, $pb_{i,t}$ represents the primary balance ratio for country i and $sfa_{i,t}$ corresponds to the so-called "stock flow adjustment" term for country i, a residual capturing, *inter alia*, market valuation effects and contingent liabilities.[193] In this chapter, the code has dropped the stock-flow adjustment term due to data limitations for the early EMU period.

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[192] The Blanchard et al. (2016b) relevant code has been altered to consider the above differences for the application to this thesis.

[193] The stock flow adjustment term is explicitly monitored and detailed for EMU countries in the context of EDP (Excessive Deficit Procedure).

As historical counterfactuals do not envisage the PSI, the bias of this omission in the counterfactual should be limited[194]. Thus, the following equation is used for simulation purposes:

$$d_t=\frac{1+r_t}{1+g_t}d_{t-1}\text{-}pb_t \qquad (5.6b)$$

where r_t and g_t are the effective interest rate on government debt and the rate of economic growth in real terms, respectively.

A number of shocks may govern the alternative plausible paths for debt-to-GDP, as follows:

$$\Delta d_t=\frac{(i_t+\varepsilon_t)-(g_t+\varepsilon_{g,t})}{1+(g_t+\varepsilon_{g,t})}d_{t-1}\text{-}(pb_t+\varepsilon_{PB,t})+sfa_t, \qquad (5.7)$$

where $\varepsilon_{i,t}$, $\varepsilon_{g,t}$ and $\varepsilon_{PB,t}$ can be assumed to be drawn from a joint normal distribution. Other models use a single error term capturing the accumulation of all the above shocks at the end of the equation. Economic literature suggests that this error term plays a significant effect on the debt evolution dynamics (Campos et al. (2006) and Abbas et al. (2011)). Naturally, the error terms for each of the three variables may either reinforce each other or partially offset the effect of one another on the evolution of debt dynamics, as opposed to the functioning of a single error term.

Equation (5.6b) for the evolution of public debt is simulated based on 10,000 paths, a standard number of paths in the relevant literature, with the exception of Chamon and Mauro (2005), who apply 50,000 paths. An algorithm is used for the purpose of generating a forecast distribution across macroeconomic scenaria and over time for debt-to-GDP ratios of i. conventional debt (non-indexed); ii. fully indexed debt; and iii. partially indexed debt. Simulations draw on IMF macroeconomic forecast inputs, simulate macroeconomic data inputs in the equation for the evolution of the public debt ratio, endogenously calculate resulting per-period risk-premia based on the level of sovereign indebtedness, exogenously apply a novelty premium for GDP-growth indexation and exogenously account for some percentage of sovereign debt being indexed.

[194] The IMF WEO does not report the Stock-flow-adjustment term (sfa), while AMECO reports of the sfa only provide data for 2010-2016. Clearly, this is an inherent limitation in the results of the present study.

Historical Counterfactual

The below steps are followed in two cases, which are distinguished according to the baseline macroeconomic scenario input in simulations: *case a*, which uses IMF 2010 forecast data (IMF, May 2010), and *case b,* which uses the actual historical macroeconomic data as inputs into the baseline. Case a represents a forecast as would have been performed at the time in 2010; case b uses actual historical annual data for 2010-2018 as reported by the IMF, to produce the forecasts which would have been produced by an omniscient analyst as in 2010.

Year-end macroeconomic inputs for real GDP growth, the primary balance ratio and the effective real interest-rate on Greek government debt (up to the end of 2009) are calculated based on reported associated nominal data (see data section 5.4).

Calculated year-end data for the three macroeconomic variables (for years 2000-2009) are used to compute a variance-covariance matrix of the three variables.

For *case a*, the baseline macroeconomic forecast path of the input variables (as reported by the IMF in 2010) is used to simulate a range of forecast macroeconomic scenaria from the standpoint of 2010. Simulations, therefore, are performed according to the IMF baseline (for 2010-2019) as in the macroeconomic scenario of the IMF Staff Report upon the request of the first bailout programme for Greece in 2010 (IMF, May 2010) and draw shocks from the variance-covariance matrix of historical data up to 2009.

For *case b*, actual macroeconomic outcomes (known ex post) are included as the baseline macroeconomic forecast path, such that baseline simulations are as if perfect foresight were in place.[195]

[195] Naturally, the ex-post claim of perfect foresight is limited due to the endogenous effect of the ex post bailout loans and conditionality first-order and second-order macroeconomic effects incorporated in historical data over 2010-2018.

In each case, semi-parametric Monte Carlo simulations using10,000 macroeconomic paths using shocks drawn from the variance-covariance matrix are performed to derive the paths of each of the three macroeconomic variables (r, g, pb).[196]

For indexed (GDP-linked) debt simulations, an additional GDP (novelty) risk premium k is added to simulated paths for the interest rate, as well as the difference between the simulated real growth rate minus the baseline IMF forecast growth rate for each period, according to the following *indexation rule*:

$$r_{indexed,t} = r_t + \omega * (g_t - g_{Base\ t}) + k \ , \tag{5.8}$$

where the coupon rate is equal to the (simulated) baseline non-indexed real effective interest rate plus a premium based on the extent to which (simulated) real growth exceeds the baseline forecast for real GDP growth, plus a novelty risk premium (k), which is exogenous to the model and lies in the range of 1% to 3.5%, in line with the relevant literature. This novelty premium captures the combined effect of the novelty premium as well as risk attitudes related to the quality of reported GDP statistics. Alternative values of *k* are input to the model to check for the sensitivity of the resulting debt-to-GDP distribution. A more elaborate setup could have linked the value of k to the degree of transparency and accuracy of GDP statistics.

The selected indexation formula follows Schroder et al. (2004), who first moved beyond "GDP-linked" schemes into "growth-linked rules." More recent literature has also adopted this selection (eg. Blanchard et al., 2016a).

For *case b*, the worse-than-expected-in-2010 actual growth benchmark baseline is expected to increase the distance between simulated growth rates and the baseline. *The hypothesis is that*

[196] Monte Carlo simulations are performed for the three variables via matrices which involve multivariate random number generation, with the historical standard errors superimposed so as for country-specific historical patterns to be preserved, as in Berti (2013) and as in the European Commission (2019). Thus, while random numbers are generated for historical forecasts, the evolution of the variables is not purely stochastic; rather, it is constrained by individual-country historical dynamics via the addition of the country-specific standard error term for each variable. This has been incorporated to compensate for the theoretical simplicity of the macroeconomic dynamics included and to ensure that forecasts are more representative of the public debt dynamics of Greece. For each point in time and for each of the 10,000 paths, the value of GDP growth, of the interest rate and of the primary balance ratio is simulated around the baseline.

simulations for indexed debt ratios in the historical counterfactual b will be higher than those in a, and that b will result in stronger rejections of the GDP-linked bonds case. This outcome is expected by the design of GDP-linked bonds and the method of indexation proposed. In particular, we expect the overindebtedness risk premium to dominate any fiscal space generated by the indexation scheme due to lower growth due to the fact that the Greek government is heavily indebted. Therefore, ex ante, it is clear that conclusions are highly contingent on the contractual form of indexation, and as with all derivative financial products, the devil lies in the detail. In turn, this implies an additional layer of uncertainty: the government's main focus on any relevant contracts should be based on the indexation scheme suggested against some set of future path ratios which is highly uncertain, *ex ante*. Different macroeconomic scenaria would be best served by different indexation contracts.

In *equation 5.8*, the parameter ω represents the degree of indexation, i.e. the percentage of the public debt ratio that is indexed (ω ∊ (0, 25%, 50%, 75%, 100%)). Full indexation corresponds to ω=100% and no indexation (i.e. 'plain-vanilla' debt) corresponds to ω=0%.

The above indexation shields the sovereign against 'unexpected' deviations from the forecast path of GDP growth.

In contrast, the interest rate on conventional non-indexed debt is modelled based on simulated interest rates:

$$r_{non-indexed,t} = r_t \tag{5.9}$$

where r_t corresponds to the simulated interest rate from the above step.

A major difference in the source of variability between the two cases (indexed and non-indexed) emerges: For indexed debt, the variability of the effective interest rate arises due to the variability of the deviation of the simulated growth rate from the baseline forecast and the degree of indexation plus some novelty premium k. In contrast, for non-indexed debt, variability is based on simulated interest rates, which in turn are partially affected by the history of the variability of the joint distribution of the three macroeconomic variables, and partially random.

Taking 2009 as the last historical known annual data point, 10,000 simulations of the evolution of the public debt ratio according to Equation *5.6b* are taken for years 2010-2018, using the above-mentioned inputs for simulated growth rates and interest rates as inputs. To use the above notation, simulations follow the below equations for the evolution of the public debt ratio:

For non-indexed debt, the following formula is applied:

$$d_{non-indexed,t}=\frac{1+r_{non-indexed,t}}{1+g_t}d_{t-1}-pb_t \quad (5.10)$$

For fully indexed debt, the following formula is applied:

$$d_{indexed\ t}=\frac{1+r_{indexed,t}}{1+g_t}d_{t-1}-pb_t \quad (5.11)$$

For partially indexed debt, the following formula is applied:

$$d_t=(1-\omega)\left(\frac{1+r_{non-indexed,t}}{1+g_t}d_{non-indexed,t-1}\right)+\omega*(\frac{1+r_{indexed,t}}{1+g_t}d_{indexed,t-1})-pb_t \quad (5.12)$$

According to the outcome of simulations for each period, an additional *credit risk premium* (RP_t) is calculated. The level of the estimated risk premium depends on whether the simulated public debt ratio exceeds a threshold of overindebtedness. This risk premium is subsequently added to the debt-to-GDP simulations of *equation 5.6b* as follows:

$$d_t=\frac{1+r_t+RP_t}{1+g_t}d_{t-1}-pb_t \quad (5.13)$$

This premium is related to the level of debt-to-GDP in the previous period (as observed by financial markets when forming expectations) and its deviation from the IMF forecast,[197] according to the following non-linear rule:

[197] The above equation is suggested in the methodology employed by Blanchard et al. (2016). Alternatively, in line with standard interest-rate feedback rules used in Debt Sustainability Analysis (DSA) models, a linear function of the risk premium against the debt-to-GDP ratio could have been used as follows:

$$RP_t=0.04*(d_{\_,t-1}-60\%)$$

where the risk-premium increases by 4 percentage points for each deviation of the debt-to-GDP ratio above the 60% debt-to-GDP threshold (also the Maastricht limit), following Laubach (2009), Ardagna, Casseli, Lane (2006) and Engen and Hubbard (2005).

$$RP_t = \beta * (d_{t-1} - d\_IMF_{t-1}), \qquad (5.14)$$

where β=0.03 if d_t>140% and β=0.02 if d_t≤140%.

The non-linearity introduced by the value of the parameter β captures the higher sensitivity of government bond yields for very highly indebted countries. 140%[198] was used as an arbitrary *debt threshold of 'overindebtedness'*, as in Blanchard et al (2016a, 2016b).

Therefore, a two-stage procedure of simulations is applied for the calculation of default risk premia on government debt.

For all years in the forecast horizon under each case, the distribution of debt-to-GDP ratios, and its percentiles (1st, 5th, 35th, 50th, 65th, 95th and 99th percentiles) correspond to simulated values generated by the 10,000 simulations in each case (non-indexed, partially indexed, fully indexed debt). The 1st percentile (0.01) corresponds to the lowest 1% of simulated debt-to-GDP ratios for each year. Similarly, the 99th (0.99) percentile corresponds to the highest 1% of simulated debt-to-GDP ratios for each year. In the fan charts, the upper path corresponds to the 99th percentile whereas the lowest path corresponds to the 1st percentile of the forecast GDP-linked and conventional debt-to-GDP ratio distribution for each country.

Naturally, forecast uncertainty increases with the forecast horizon, thus, explaining the resulting shape in fan-charts for public debt-to-GDP ratios, as standard in debt sustainability models. The 'opening' of the fan-chart portrays an increase in the range of debt-to-GDP ratios provided between the 1st and 99th percentiles of the simulated debt-to-GDP ratios for each year. By construction and via the setup of the indexation rule, GDP-linked debt ratios shall, in most cases, lie above those for conventional debt due to the additional premium (k) added to the debt dynamics under indexed debt. However, the following opposite effects are in place compared to conventional debt: when GDP growth is high (compared to the forecast baseline), debt repayment obligations under GDP-linked bonds are higher even though debt dynamics are more favourable as the interest-growth differential (r-g) is likely to

[198] 140% has been selected based on Blanchard et al. (2016b). This threshold is also validated by our analysis of a threshold model of the Greek sovereign spread with debt-to-GDP as the threshold transition variable.

shrink, which in turn decreases the multiplier on public debt. The opposite is true when GDP growth is relatively low (compared to forecasts). The novelty premium counteracts some of the increase in the fiscal space granted when worse-than-expected GDP-growth outcomes emerge under indexed debt.

Under the applied *symmetric rule of indexation* (which need not be the case in reality), GDP-linked bonds provide insurance during times of lower-than-expected economic growth yet compensate for this via higher debt repayments during 'good economic times'. Due to the additional novelty premium, *it is expected that only under the worst macroeconomic scenario will debt-to-GDP ratios under GDP-linked debt be lower to the case of conventional debt.*

The above methodology was selected due to the lack of precedence of any GDP-linked bond issuance, which would have potentially enabled the use of more standard methods such as the Synthetic Control Method (SCM).[199]

5.3.2. Implicit Model Assumptions and Limitations

The following assumptions are implicit to the model and responsible for certain limitations in results. Firstly, as cautioned by Benford et al. (2016), due to the use of a joint normal distribution, the model implicitly assumes a simple, linear dependence structure between variables, thus, underestimating the probability of tail events (fat tails), which have been deemed to be critical for macroeconomic variables (Fagiolo et al., 2008). In the presence of fatter tails, the benefits of GDP-linked bonds should be probably even more pronounced (Benford et al., 2016).[200]

Secondly, as detailed above, the effective interest rate is used instead of the actual modelling of interest rates on new debt. Naturally, forecasts will diverge from real-time results; however, due to severe data constraints in constructing an extended debt-sustainability analysis model, which in turn,

[199] The Synthetic Control Method (SCM) has recently been applied in the context of the historical evaluation of Greek debt sustainability by Alcidi and Gros (2020), albeit with respect to GDP-per capita. GDP-linked bonds are not the focus of this paper.
[200] Bootstrapping techniques could be applied to the residuals of a VAR on public debt to capture a more realistic distribution for the standard errors used to generate the simulated variables.

would contain additional assumptions about the type of bonds issued in each period, the effective interest method is a standard compromise in similar macroeconomic models. It implicitly assumes that public debt is composed of similar type, currency and maturity bonds, which is a simplification compared to reality. On this note, it is worth mentioning that unlike previous models in the literature (except for Blanchard et al (2016a, 2016b)), the default risk premium on debt is an endogenous function of the level of debt-to-GDP. Nevertheless, no additional risk premium is modelled on conventional bonds due to the introduction of GDP-linked bonds in the case of a 'mixed debt' portfolio, i.e. we do not consider cross-interactions between the interest rate charged on indexed and non-indexed debt, when both are present in the government debt structure.

Thirdly, all public debt is assumed to be in the domestic currency, such that external debt and exchange-rate effects are not explicitly considered in the model. Clearly, this represents a drawback with respect to insights, yet the vast majority of advanced countries' debt, and in particular EMU public debt is denominated in the domestic currency (the euro).

Fourthly, shocks are assumed to be constrained to one standard error of identical and independent distributions over time, such that shocks in period t do not affect shocks in period t+1.

Furthermore, simulations of the debt-to-GDP ratio under indexed and non-indexed debt implicitly assume that the same dynamics govern the joint distribution of growth and the primary balance in the case of indexed and when conventional debt is used. This may not be realistic, as the change in fiscal space generated in the presence of GDP-indexed debt could affect growth levels (Benford et al, 2016).

A zero stock-flow adjustment is assumed in the equation applied to government debt ratio simulations.

In addition, the model assumes no fiscal reaction function, such that the primary balance is determined solely by the historical joint distribution of growth and effective interest rates since 1999, as in Benford et al. (2016) and Blanchard et al. (2016a).

Unlike the majority of papers on GDP-linked bonds, this chapter has extracted nominal data, yet indexation is based on the real effective interest rate on government debt outstanding rather than on the nominal interest rate. This choice follows Blanchard et al (2016a) to be line with the Blanchard et al. (2016b) proposed method followed in the simulations.

Last but not least, the proposed methodology emphasizes the stock of public-debt-to-GDP ('stock perspective') without accounting for Gross Financing Needs. The latter requires detailed data on bond maturity dates, *inter alia*, and constitutes a complimentary approach ('*flow perspective*').[201]

5.3.3. Summary of Code

Summarizing the above, the following steps are taken by the code applied:

- *Set number of simulations to 10,000.*
- *In case a set the baseline equal to the IMF macro baseline as in 2010; for case b set the baseline equal to actual reported data for 2010-2018. Force long-term baseline forecasts (beyond t+5) to be constant and equal to their t+5 value for the real interest rate, the real GDP growth rate and the primary balance-to-GDP ratio.*
- *Based on historical data (2000-2009), calculate the variance-covariance matrix.*
- *Perform semi-parametric Monte Carlo simulations for the real interest rate, the real GDP growth rate and the primary-balance-to-GDP ratio.*
- *Calculate the simulated indexed bonds interest rate according to Equation 5.8.*
- *Based on simulated macroeconomic variables, simulate the evolution of debt: i. if all debt is conventional; ii. if all debt is indexed to GDP growth; iii. if debt is partially indexed to GDP growth.*
- *Calculate an appropriate risk premium based on the ensuing debt-to-GDP ratio under each model according to an overindebtedness threshold*
- *Find the simulated distribution of Debt-to-GDP of all paths*

[201] Alcidi and Gros (2018) offer an overview of Debt Sustainability Analysis, as currently applicable by policymakers. For the flow perspective and an application to Greece (also in relation to the Greek sovereign spread), see Gabriele et al. (2017). For an evaluation of the Debt Sustainability Analysis applied on the Greek government debt over the course of three Economic Adjustment Programmes, see Alcidi and Gros (2020). For an examination of the Greek government debt sustainability as in 2018, see Eichengreen et al. (2018).

A more elaborate version of the exact steps taken is presented in Appendix A5.2.

5.3.4 Testable Hypothesis

From the perspective of Chapter 3, in a world plagued with sunspots and regions of multiple equilibria, the reduction in the range of possible public debt ratios and the shielding from growth-shock effects could prove to be beneficial-particularly for the worst 1 percent of simulated debt paths. Namely, extending the static setup of Chapter 3 into the forecast horizon, GDP-linked bonds are expected to shrink the size of the intermediate region of fundamentals. Therefore, *we expect the indexation of debt to GDP growth to result in a lower variance and smaller range of simulated debt ratios for indexed debt, as opposed to non-indexed debt.*

In line with panel-based findings, we expect the worst percentile of simulations (at least for some low risk premium) to benefit from the introduction of GDP-linked bonds. Cabrillac et al. (2016, 2018) find that GDP-link bonds also provide some stabilization for the 95th and 99th percentiles of paths of simulated debt ratios across time. Therefore, *we expect lower government debt ratios for the 99th percentile of simulated indexed debt-to-GDP than for the equivalent percentile for non-indexed simulated debt-to-GDP ratios.*

As the actual macroeconomic baseline scenario for the historical counterfactual was far worse to that of the baseline forecast by the IMF in 2010, *we expect debt ratios under case b to be much higher on average compared to case a.*

Overall, following the literature on GDP-linked bonds and the caution against examples of "catastrophically" heavily indebted countries by Blanchard et al (2016a), *we expect the overall outcome of sensitivity analysis not to present a strong case in favor of GDP-linked bonds for Greece.* Furthermore, *for median paths of debt, the highly indebted status of Greece should not suggest that indexation to GDP-linked bonds would make sense.*

5.4. Data

Post-1999 annual data for Greece on nominal GDP at market prices, the GDP Deflator, Public Debt, Interest Payable on Debt and the Primary Balance has been obtained from the IMF World Economic Outlook (WEO) database. Historical counterfactual simulations use 2009 as the starting point (t=0), drawing on IMF Review annual data for 2009, such that the value of 2010 (which is affected by the interim 2010 bailout loans) is the first forecast value.

For case a, the IMF WEO forecasts for each macroeconomic variable for years up to t+5 have been incorporated in simulations, namely forecasts for years 2010-2015. For years t to t+5, these IMF WEO forecasts have been included as the baseline scenario, as in the IMF Staff Report on Request for a Stand-By Agreement by Greece in May 2010 (IMF, May 2010). Thereafter, forecasts are kept constant to the last reported figure. For case b, actual reported data were incorporated as the macroeconomic baseline, as extracted from the IMF World Economic Outlook (WEO) database.

The following calculations are applied under both cases (a and b):

Real GDP at time period t has been calculated based on GDP at market prices and the GDP Deflator according to the following formula:

$$GDP_{real,t} = \frac{GDP_{nominal,t}}{GDP\ Deflator_t} * 100 \tag{5.15}$$

Real GDP growth has been calculated as the percentage change in real GDP as follows:

$$Real\ GDP\ growth_t = 100 * (\frac{GDP\ real\ _t}{GDP\ real\ _{t-1}} - 1) \tag{5.16}$$

Inflation has been calculated as the percentage change in the GDP Deflator as follows:

$$GDP\ Deflator_t = 100 * (\frac{GDP\ Deflator\ _t}{GDP\ Deflator\ _{t-1}} - 1) \tag{5.17}$$

Debt-to-GDP and the primary balance as a percentage of GDP have been calculated as simple ratios of respective data obtained from the WEO.

The Nominal Implicit Rate on public debt has been calculated as the ratio of the interest payable on public debt in period t over the previous period's public debt:

$$Nominal\ implicit\ rate_t = \frac{Interest\ Payable_t}{Debt_{t-1}} * 100 \qquad (5.18)$$

The real implicit rate for country i in period t has been calculated based on the Fisher Equation as follows:

$$\text{Real implicit rate}_t = \frac{1+Nominal\ implicit\ rate_t}{1+inflation_t} - 1 \qquad (5.19)$$

Due to the various categories and maturities of public debt, the implicit interest rate has been used as the effective interest rate on total public debt for the purpose of simulations.

The two baselines for the three main variables feeding into the simulations, namely the primary balance surplus (as a percentage of GDP), the real effective interest rate on the Greek government debt and the Greek public debt-to-GDP ratio are depicted in *Figures 5.1* and *5.2*.

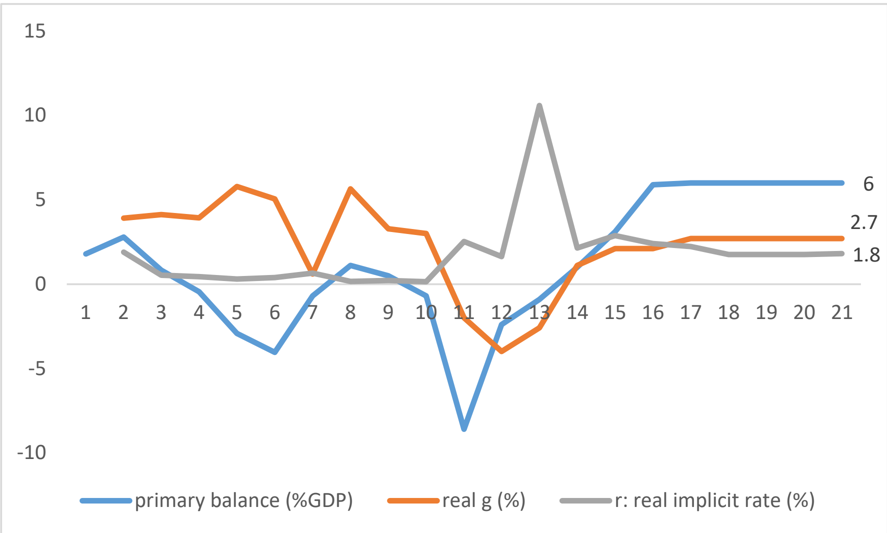

Figure 5.1. IMF 2010 Basaline

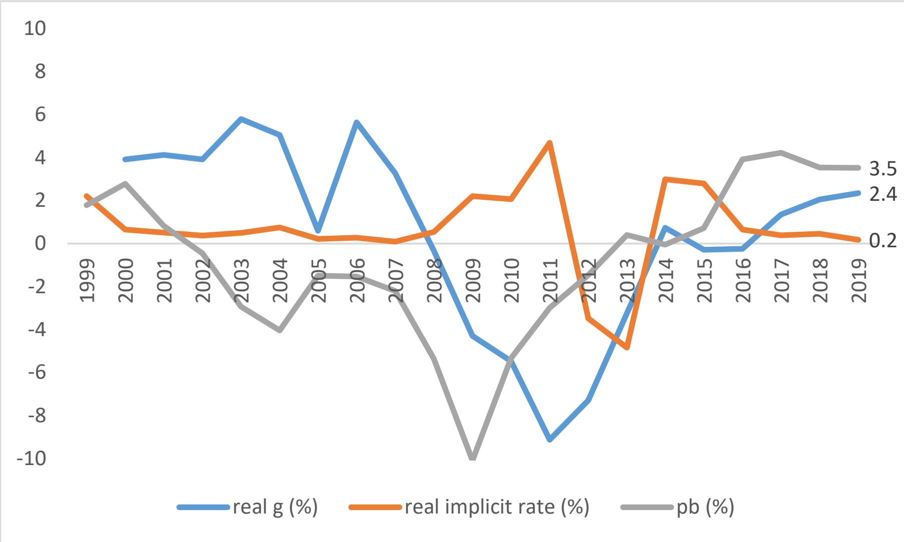

Figure 5.2. Actual Historical Data Baseline

5.5. Analysis of Results

The results of simulations and sensitivities with respect to the degree of indexation (ω) and novelty risk premium (k) are presented in the Appendices 5.3 and 5.4. As the only model outcome is the year-end public debt stock, evaluation in the analysis is restricted to this criterion, which is clearly limiting for the analysis of results compared to the multifaceted scope of debt sustainability. Nevertheless, the broad consideration of uncertainty, serves to compensate for the otherwise limited number of model variables.

5.5.1. Historical Counterfactual (ex ante Baseline Macroeconomic Scenario)- Case a

Results for case a are presented in Appendix 5.3.

First, the actual path of the historical Greek government debt ratio is mapped onto the distribution of simulated non-indexed government debt ratios as follows: Across all years, actual data were worse than the 99th percentile of the simulated distribution, except for 2012, when actual data correspond to the region between the 65th and 95th percentiles. Therefore:

- *The actual historical path of the Greek government debt ratio turned out to correspond to the worst 1 percent of possible forecasts as in 2010.*

- *Actual data in 2012 were slightly better than the worst of worlds simulated for other years, due to the short-lived and insufficient effect of the PSI.*[202]

Second, simulations of non-indexed debt ratios show that in the best 1 percent of future paths envisaged in 2010, the Greek government debt could have been on a declining path. The median path points to a peak of the Greek government debt in 2012 at approximately 140 % GDP and subsequent decline in debt ratios. The 99th percentile of simulated non-indexed public debt ratios points to a peak in the Greek non-indexed government debt ratio at approximately 178% GDP in 2014, and subsequent decline in public debt ratios.

Third, it is worth asking whether a policymaker with the baseline macroeconomic scenario of the IMF prior to the programme would have had any reason to opt for GDP-linked bonds, and if so, under which circumstances. Simulations based on the ex-ante IMF baseline show that *for a policymaker in 2010, it would be worthwhile to recommend GDP-linked bonds to the Greek government if and only if the novelty premium on such bonds were less than or equal to 200 bps ($k \leq 200$bps) and if and only if, the policymaker were certain that the worst one percent of possible future government debt paths would materialize* [203]. For the worst percentile, small improvements are obtained if novelty premia remain under 200bps. These conclusions are based on a comparison of equivalent indexed and non-indexed percentiles for each novelty premium.

Fourth, with respect to the shape of the backtested public debt ratio path and debt stabilization, the following are noted: actual data pointed to a multipeaked path in time and some degree of stabilization to levels close to 175%-180% GDP by the end of the third programme for Greece; constantly increasing public debt ratios and, thus, explosive debt dynamics are noted solely in the following cases: for a risk premium k=250bps under the 99th percentile path with 100%-indexed debt (ω=100%); for k=250bps under the 95th and 99th percentile for ω=100%; for k=250bps under the 99th percentile for ω=100%; for k=350bps for the 50th-99th percentiles with ω=100%; for k=350bps for the

[202] The short-lived positive impact of the PSI on Greek debt sustainability, countenanced by adverse growth dynamics thereafter is also shown in Alcidi and Gros (2020).
[203] The policymaker would also marginally recommend GDP-linked bonds based on the 95th percentile under a novelty premium of k=100bps.

99th percentile with ω=50%; for k=350bps for the 95th and 99th percentiles with ω=75%. *Therefore, only at low levels of indexation does GDP-linked debt stabilize the public debt ratio (ω=25%).*

Fifth, considerable losses in terms of higher percentage points of GDP for the public debt ratio emerge under optimistic paths of the Greek government debt ratio.

Sixth, *in the absence of a guarantee of 200bps as a cap to the novelty premium associated with GDP-linked bonds, a policymaker in 2010 with the baseline forecast of the IMF at the time would not have taken the initiative to recommend a risky novel financial product, even if he believed in the worst of worlds for the future path of the Greek government debt.* This cutoff point is selected to avoid the emergence of explosive paths.

Seventh, the range of the public debt ratios between the 1st and 99th percentiles is lower the higher the degree of indexation. Narrower fan charts are depicted under GDP-linked bonds, yet the median of associated distributions is higher to that under non-indexed debt.

Eighth, non-indexed debt ratios never exceed 200%GDP. In contrast, the 99th percentile under ω=100% and for k ≥350 bps exceeds 200% GDP at some point.

5.5.2. Historical counterfactual (ex-post baseline Macroeconomic Scenario)- Case b

Results are presented in Appendix 5.4.

This case repeats the above exercise assuming that some omniscient policymaker would have based the macroeconomic baseline input scenario on data equal to the actual historical data, as reported at the end of the programme in 2018.

The following remarks are made based on the output of simulated non-indexed and actual public debt ratios: First, a mapping of actual 2010-2018 data to the distribution of simulated non-indexed debt ratios shows that actual data corresponded to the following: the range between the 65th and 95th percentiles in 2011, the 5th percentile in 2012 due to the effect of the PSI on actual data, the 35th percentile in 2013, the range between the 50th and 65th percentiles in 2014-2016, the 65th percentile in 2017, the range between the 65th and 95th percentiles in 2018.   Therefore:

- *In spite of all exogenous interventions, bailout loans and reforms, actual Greek data started off at values corresponding to the 65th to 95th percentile of simulations and ended in the same percentile range at the end of the programmes in 2018.*
- *The PSI was highly successful in placing the Greek debt ratio back into the best 5 percent of possible world outcomes as in 2010, yet the underlying dynamic or possible endogenous feedback effects threreafter proved to be sufficiently detrimental to push the Greek debt ratio into its original location in terms of percentiles of possible outcomes.*

Second, in contrast to the simulated non-indexed debt counterfactual based on the IMF 2010 macroeconomic baseline (i.e. in contrast to case a), which presents the Greek government debt to be stabilizing by 2019 (albeit at high public debt ratios), *non-indexed debt simulations that draw on the actual macroeconomic baseline (case b) show that the 99th percentile of non-indexed debt depicts an explosive dynamic* (i.e. it is constantly increasing for the foreseen years). In retrospect, actual public debt ratios proved to correspond to the worst 99th percentile of simulated non-indexed public debt ratios. Therefore, prior to the contracting of the bailout loans, *if the policymaker had perfectly foreseen the actual macroeconomic path, they would have concluded that the path of the public debt ratio was explosive.*

Third, simulations of non-indexed debt using ex ante macro inputs show that under the 95th and 99th percentile, the Greek debt exceeds 200% GDP as early as in 2011 and reaches 250% GDP by the end of the backtesting horizon for the worst percentile.

Fourth, when examining the 65th-95th percentile of debt-ratio paths (which most closely corresponds to the majority of actual debt outcomes), some degree of indexation may have made sense if and only if the risk premium were capped at k=100bps. The only case when the simulated non-indexed median path is close to a median path that includes some degree of indexation to economic growth occurs when k=100bps and ω=25%. *Beyond k=150bps, the introduction of GDP-linked bonds would have worsened the final debt outcome, even when comparing the worst 1 percent of worlds.*

Fifth, across all outcomes, GDP-linked bonds reduce the 1st-99th percentile range of simulated outcomes, compared to non-indexed debt, as foreseen in the literature.

Sixth, for the Panglossian policymaker, for the approximately 30% best of possible future worlds prior to the first adjustment programme,[204] GDP-growth indexation of the Greek government debt would have resulted in substantially worse debt ratios than actual. The imposition of a novelty premium reduces the benefits of GDP-linked bonds.

Seventh, *a novelty risk premium of 350bps, which according to the literature is internationally possible under the introduction of a new financial product, would have yielded a debt ratio in excess of 300% GDP by 2019 if the Greek debt were made to be fully indexed to GDP growth.*

Eighth, the higher-than-non-indexed debt ratios for GDP-linked debt in median and good outcomes of the world show that from the standpoint of the policymaker in 2010, any gains potentially achieved in a worst percentile path of future government debt ratios are eroded by substantially heavier losses in the event that a median or good state of the world emerges. Therefore, *only under "maxi-min" expectations (i.e. the desire to shield oneself against the worst case) would a policymaker even consider GDP-linked indexation. It is for this reason that the partial indexation sensitivities considered in this study (unlike elsewhere to date)[205] are important.*

Therefore, if economic policy were to rely on this tool for policy decisions in 2010, no policymaker with the benefit of hindsight (perfect foresight of the future macroeconomic scenario) would have opted for the introduction of GDP-linked bonds for Greece. This conclusion is based on a direct comparison of the percentiles to which actual historical data lie for non-indexed debt simulations over time against the equivalent percentiles under GDP-linked debt. Clearly, equivalent percentile debt

[204] Or, for even higher percentage of optimistic paths depending on the assumed risk premium k.
[205] The sole exception is Fratzscher (2014), who however envisages partial indexation to correspond to the indexation of one particular category of debt in the Greek loan structure, namely that corresponding to the Greek Loan Facility (GLF), i.e. no sensitivities of the degree of indexation with respect to future paths are foreseen as in this chapter.

ratios are higher under indexed debt than under non-indexed in the overwhelming majority of future worlds. Nevertheless, nobody could have precluded a very limited probability of a world where some degree of GDP-linked bonds in the government debt structure could have been slightly beneficial.

Conclusions are riddled by a number of limitations, inherent in the methodology applied: The counterfactual analysis is based on a world without the PSI debt write off and its second order endogenous effects, a world without bailout loans, and has not incorporated endogenous effects between simulated public debt ratios and macroeconomic outcomes, nor has it included the growth-enhancing impact of structural reforms that were imposed on Greece in the interim nor the negative impact of austerity and fiscal consolidation measures. More importantly, individual bond data, debt maturities and short-term liquidity effects, which in reality are crucial, have been left outside the scope of this method. Furthermore, the basic insurance effect of lower debt servicing under lower growth outcomes is not explicitly shown, such that simulations of indexed debt are biased asymmetrically towards higher debt outcomes via the novelty premium. This is due to the stock perspective adopted in simulations (as opposed to a complementary flow perspective, which would have been offered in the standard Debt Sustainability Analysis (DSA) excel template analysis with formal inputs of per-period bond data). Lastly, lower degrees of indexation ($\omega<25\%$) or a case under zero novelty risk premia ($k=0$) has not been examined.

Differences across the two counterfactuals (cases a and b) rest on the fact that the underlying macroeconomic inputs in the ex post data case (case b) are far worse than those expected under the baseline in 2010. Overall, across all cases, the shape of the path of the non-indexed government debt ratio (i.e. whether it is increasing, decreasing, single-peaked or multipeaked) depends on the dominance of the terminal growth input assumption over the overindebtedness premium.

At first sight, given the worse actual input scenario for economic growth in case b, it seems counterintuitive that the ex post scenario-based simulations more strongly reject GDP-linked bonds than under case b. However, this result may be attributed to the stronger effect on the increase in the stock of government debt due to the ‘overindebtedness’ risk premium arising from higher levels of public debt against any per-period insurance benefit considerations due to lower levels of economic growth.

The application of judgement across the majority of possible simulations and input scenarios for the ex ante and ex post macroeconomic narrative for Greece would conclude that GDP-linked bonds would not have been beneficial for Greece; yet, due to the Lucas Critique, inter alia, such a claim cannot be made with absolute certainty.

This conclusion for GDP-linked bonds is in line with the literature that recommends GDP-linked bonds for highly indebted advanced economies, but not for "catastrophically" indebted cases (e.g. see Blanchard et al, 2016a). Greece is probably classified as a highly indebted country and requires *ad hoc* treatment. As simulations appear to penalize overindebtedness more heavily than they ease the adversity of the interest-growth dynamic due to GDP-linked bonds, similar conclusions would be expected for Greece as at the end of the Third Economic Adjustment Program in 2018 due to the high starting levels for the public debt to GDP ratio.

5.6. Conclusion

This chapter has probed into the question as to whether historically (prior to the contracting of bailout loans), the introduction of GDP-linked bonds would have had any merit for Greece based on the criterion of the stock of debt outstanding as a ratio to GDP. The methodology of Blanchard et al (2016a, 2016b) has been reformulated to account for partial indexation and sensitivity analysis. An application to the Greek debt and to counterfactual analysis has been offered.

Two sets of historical simulation outcomes of the counterfactual distribution of the Greek government debt ratio for years 2010-2018 are provided: a. based on the pre-programme IMF baseline; and b. based on post-programme actual macroeconomic data. Sensitivity analysis for various degrees of indexation as a percentage of the debt outstanding and for various levels of novelty premia associated with GDP-linked bonds was performed.

In spite of the various limitations of the method applied and expressed in the analysis section 5.5, neither of the historical counterfactuals would have validated the introduction of GDP-linked bonds in

2010. However, GDP-growth-linked debt could prove to act as an insurance against tail outcomes. In contrast, median outcomes would not have validated GDP-growth indexation of the Greek public debt. These results are in line with the literature, which points to indebted but not “catastrophically” indebted advanced economies as best candidates for the introduction of GDP-linked bonds.

The contribution of the chapter has been to provide a historical counterfactual for the Greek public debt ratio both from an ex ante and an ex post perspective. To date, the single GDP-linked bonds study on Greece by Fratzscher et al. (2014) has not enabled such a distinction, nor has it examined the entire Greek debt as from the viewpoint prior to the first bailout loan. Furthermore, this study is the first to provide sensitivity analysis on the percentage of indexation and the GDP-risk premium.

Future research could combine a fiscal reaction function with the model’s features to reveal the relative merits of GDP-linked bonds in countering reform fatigue. Debt Sustainability Analysis (DSA)-based outcomes using more elaborate, and potentially confidential, data on the detailed historical profile of the Greek government debt could prove more illuminating for the per-period stock and flow implications of GDP-linked bonds. Thus, a combination of the above method, with official data in a DSA excel template, could improve the analysis. In addition, medium-term projections over the cycle and potential output growth could be accounted for. Future papers could endogenously search for the level of indexation that yields an optimal outcome according to well-specified criteria and mix of assumptions. Moreover, the effect of GDP-linked bonds on the maximum sustainable debt ratio and the probability of sovereign default could be examined, as in Barr et al. (2014). An application to other less heavily indebted Advanced Economies, with less complicated government debt structures, could prove more insightful and relevant to this instrument.

Notwithstanding the conclusions in this chapter, which relate to a contractual market-based solution, an ad hoc political agreement of lower debt repayment on official loans under worse-than-envisaged economic growth outcomes could still be valid for the long-run debt restructuring measures and growth-adjusted mechanism discussed by policy circles on Greek loans. Furthermore, although the highly indebted status of Greece may not be welcoming to GDP-linked *bonds*, the findings in this chapter do not preclude some degree of future debt indexation of the Greek government, once GDP-linked bonds have become mainstream by other advanced economy debt issuances, such that the novelty premium has been reduced.

Overall, and irrespective of any future simulation-based conclusions on GDP-linked bonds, as highlighted by Chamon and Mauro (2005), "financial engineering is not a substitute for sound institutions and good policies" (Chamon and Mauro, 2005). Clear and undisputed, credible commitment to growth-enhancing reforms and macroeconomic policies, which also facilitate the issuance of longer duration bonds, decreasing liquidity risks, is always a complement to any market-based solution.

Appendix A5.1: A Brief History of State-Contingent Debt Instruments

State-Contingent Debt Instruments (SCDIs) are debt instruments which "bear a contractual debt service obligation tied to a pre-defined state variable and are designed to alleviate pressure on sovereign indebtedness and/or financing needs in a bad state of the world" (IMF, 2017). Different categorizations of state-contingent debt have been used, including inter alia, the distinction between *continuous adjustment debt* and *discrete adjustment debt,* or *indexed debt* versus *Contingent Convertible debt* or the distinction between *linkers* (principal-indexed), *floaters* (coupon-indexed)*, and extendibles (IMF, 2017).*

State contingent bonds are bonds making payments based on the attainment of a particular state.[206] State-contingent bonds specify repayment terms in bond contract clauses ex ante, so as to improve the predictability in burden-sharing between the official sector (de facto senior) and the private sector, and allow for capital markets to incorporate these elements into risk analysis (Brooke et al, 2013). Two primary categories of state-contingent bonds include *sovereign CoCos* and *GDP-linked bonds,* which can be applied in a complementary fashion given that the former deal with liquidity issues while the latter resolve solvency concerns (Brooke et al., 2013).

State contingencies have long been considered in the context of debt instruments, associating repaying profiles with a variety of state variables. The first state-contingent bond, a 'Depreciation Note' was issued in 1780 by the State of Massachusetts (Benford et al., 2016). This constituted the first inflation-linked bond in history, indexing repayments to a basket of goods, such as corn, beef, wool and leather (Benford et al., 2016). In the aftermath of the sovereign debt crisis of the 1980s, academics called for the issuance of instruments tying repayment to exports (Bailey, 1983), commodity prices or GDP (Krugman, 1988; Froot et al., 1989) and evaluated the merits of state variables which are out of the direct control of a sovereign (commodity prices) against those which may be partially influenced by government choices (exports, GDP) (Borensztein and Mauro, 2002).

[206] To some extent, all debt is state-contingent as the sovereign retains the right to default (Barr et al., 2014)

In the 1990s, Shiller (1993) proposed the creation of "macro markets" for a perpetuity, namely claims on one trillionth of a country's GDP, granting creditors an equity-like stake in the economy while broadening the portfolio risk diversification and hedging options for investors (Borensztein and Mauro, 2002). Obstfeld and Peri (1998) further elaborated on Shiller's proposal and called for European governments to issue perpetual euro-denominated liabilities indexed to nominal GDP-per-capita growth (Borensztein and Mauro, 2002).

Given that repayment capacity is more closely associated with other state variables (e.g. tax revenues or the primary balance), Barro (1995) suggested that sovereign debt should be optimally indexed to government expenditure and consumption. Haldane (1999) suggested that debt should be indexed to commodity prices. Caballero (2002) examined the indexation of Chile's debt to the price of copper.

During the late 1990s and early 2000s, academics called for growth-indexation clauses to be introduced into debt instruments. Dreze (2000) examined the use of GDP-indexed bonds for sovereign debt restructuring in poor countries. Similarly, Varsavsky and Braun (2002) called for the conversion of Argentina's debt into GDP-indexed bonds (Borensztein and Mauro, 2002).

During the "Brady bond" deals of the 1980s and 1990s in Latin American countries, so-called "Value Recovery Rights" (VRRs), which were linked to commodity prices were issued (IMF, 2017). Value Recovery Rights allowed commercial banks to swap their holdings of government debt into those tradable instruments, removing these liabilities off their balance sheets (IMF, 2017). VRRs rested on the premise that restructured debt acquire "equity-like" characteristics, such that any improvement in the terms of trade or general economic conditions be associated with increased debt service payments on the part of the debtor (IMF, 2017). Sovereign bonds were essentially swapped into the equivalent of today's warrants, promising repayment only on the upside. VRRs were embedded into bonds or issued as detachable instruments, often including some form of payment cap or call option. The state variables used for indexation were GDP, some commodity prices, or the terms of trade. Oil producers favoured indexation to the price of oil (IMF, 2017). In Chile, private firms issued bonds indexed to the price of oil (Borensztein and Mauro, 2002).

As such, GDP-indexed VRRs were issued by Honduras in 1989, Costa Rica in 1990, Bulgaria in 1993, Cote d' Ivoire in 1997 (IMF, 2017). In 1997, Bosnia & Herzegovina issued a detachable GDP-indexed warrant (IMF, 2017). Detachable commodity-price indexed VRRs were issued by Venezuela in 1990, Nigeria in 1992 and Mexico in 1990 (IMF, 2017). Bolivia in 1992 issued a non-detachable warrant. In 1991, Uruguay also issued a detachable VRR indexed to the terms of trade (IMF, 2017).

In more recent times, GDP-linked warrants were issued in the context of sovereign debt restructurings in Argentina (2005 and 2010), Greece (2012) and Ukraine (2015). Warrants contain contract clauses, according to which the payoff to the holder increases as a critical threshold in the state variable is surpassed. These derivative instruments therefore only share on the upside scenario for the sovereign. In the case of Argentina, indexation was to the level of real GDP, while Greece and Ukraine warrants were linked to the growth in Real GDP. The Ukraine warrant also entailed a more complex structure of caps and floors. A detailed analysis of the Argentinean GDP-linked warrants[207] is offered by Datz (2009) and Guzman (2016), who highlight the lower haircuts on investors who accepted these instruments in the context of sovereign debt restructuring. Xafa (2013) and Zettelmeyer et al. (2012) present the details of the Greek PSI deal, including the warrants issued as "sweeteners".

In 2015, Granada issued a revenue-indexed bond, linked to the revenues of its "Citizenship by Investment Program" (IMF, 2017). In the aftermath of the European sovereign debt crisis, policymakers and academics are further exploring the issuance of state-contingent bonds, particularly in the form of GDP-linked bonds.[208] In addition, as part of the reprofiling of the Greek official sector debt, a state-contingent mechanism was explored for official sector loans.

Other forms of sovereign state-contingent debt issued include Turkey's revenue-indexed bonds, which were non-interest-bearing to match the needs of sharia-compliant investors, non-tradable debt by the

[207] The Argentinean GDP-linked warrants paid investors if all three conditions were met: 1. If actual real GDP exceeded the base case GDP of the previous reference year; ii. If the annual rate of real economic growth exceeded the reference rate and iii. payments did not exceed a cap (Costa et al., 2008).

[208] Building on seminars and work by the Bank of England and Bank of Canada, a London Term Sheet has been developed for GDP-linked bonds. In 2016, the G20 explored the primary issues associated with state-contingent debt.

UK, Portugal and India, and the nominal-wage-linked bonds issued by Uruguay's public social security fund to match long-term liabilities (IMF, 2017).

Another major form of indexed debt and precursor to the idea of GDP-linked bonds are inflation-linked bonds. Inflation-linked bonds are a widely traded form of sovereign debt, issued primarily during normal times to ward off the erosion of investments by inflation. Building upon the so-called "Canadian model" design, liquidity costs associated with inflation-linked bonds have been reduced. However, novelty premia are still present despite the large volumes being traded (IMF, 2017). Inflation linked sovereign bonds have, thus, been issued successfully both by Advanced and Emerging Market economies. Argentina, Brazil, Chile, Colombia, Hungary, India, Mexico, Peru, Poland, Russia, South Africa, Thailand and Turkey, as well as Australia, Belgium, Canada, France, Germany, Hong Kong, Israel, Italy, Korea, Spain, Sweden, the United Kingdom and the United States (IMF, 2017). Major investors in inflation-linked bonds are pension funds and other long-term institutional investors. When GDP-linked bonds are linked to nominal GDP (or nominal GDP-growth or nominal GDP-growth per capita), they entail an additional advantage, as they not only protect investors against the shocks to GDP but also offer protection against inflation.

In the context of Official Sector Loans, sovereign debt restructurings have also involved the use of state-contingent sovereign debt: the concessional loans to post-HIPC countries by Agence Francaise de Development (AFD) which involved a "floating grace period" for principal payments, which was not triggered; and Venezuela's Petrocaribe PDVSA loans (IMF, 2017). In 2015, prior to the contracting of the third economic adjustment program by Greece, Fratzscher et al. (2014) suggested that the interest on loans under the Greek Loan Facility (GLF) be linked to the level of GDP growth, while caps and floors could also be included in the design to reduce the overall level of future uncertainty.

More recently, academics have suggested the use of existing instruments to replicate the features of GDP-linked bonds as a "second best" case to GDP-linked bonds. They suggest replicating the effects of GDP-linked bonds through a combination of other existing financial instruments. As such, variable rate debt including inflation-linked debt to hedge against demand and monetary policy shocks and

Euribor-linked debt to hedge against demand and supply shocks could be used. Fenz and Holler (2017) find evidence of the potential for both state-contingent instruments for Austria over 1999 and 2016.

Appendix A5.2: Methodology

The method applied in this chapter follows the code of Blanchard et al. (2016b), albeit with minor modifications. As an overview, semi-parametric Monte-Carlo estimations (Berti et al., 2013). The baseline for non-indexed debt is simulated. An overindebtedness risk-premium is added. Two additional risk premia (a GDP risk premium and a novelty risk premium) are included. 10,000 senarios for the forecast paths of the public debt ratio are simulated for indexed and non-indexed debt. The outcomes of the simulated distributions of indexed and non-indexed debt over time are compared. The above are repeated for sensitivity analysis with respect to the exogenous novelty premium (k) imposed on GDP-linked bonds and with respect to the percentage of debt-to-GDP being indexed to growth (ω).

<u>Exogenous inputs: (for each of sensitivities)</u>

- Number of years (T=10), number of scenarios (N=10,000)
- Data: r, g, pb/GDP (2000-2009 & Baseline forecast for 2010-2019) Baseline (Base)= IMF_2010 (Case a), ex-post data (Case b)
- Exogenously specify percentage of debt-to-GDP to be indexed: ω=0%, 25%, 50%, 75%, 100%
    - For mixed debt-to-GDP: ω % indexed, (1- ω) % non-indexed
- Exogenously specify the formula (not inputs) for GDP-linked effective interest rate:
    - Include a GDP-growth risk premium ($g_t - g_{IMF\,t}$) & an exogenously specified novelty premium (k) (k=100,150, 200, 250, 300, 350 bps)

$$r_{indexed\,t} = r_t + \omega * (g_{i,t} - g_{base\,t}) + k\ , \tag{A5.1}$$

$$r_{non-indexed\,t} = r_t \tag{A5.2}$$

Preliminary Calculations

Stochastic simulations of alternative inputs to scenarios (r, g, pb, r_indexed): apply random-number generation around the variable inputs (real g, real r, pb/GDP)-actual data and IMF baseline; semi-parametric Monte-Carlo & var-covar-based shocks are drawn from historical data (2000-2009).

For each scenario number 1-10,000:

• Set **initial values** ($debt\_sim/GDP_{t=2010}$, $debt\_ind\_sim/GDP_{t=2010}$, $debt\_mix\_sim/GDP_{t=2010}$, $debt\_imf\_sim/GDP_{t=2010}$) for the first data input of the debt-dynamic

• Use actual $debt/GDP_{2009}$ & simulated inputs for the other variables (r, g, pb, r_ind), setting values for t-1=2009 for initial debt/GDP ratios for *equations A5.3-A5.5*

$$d_{non-indexed,t}=\frac{1+r_{non-indexed,t}}{1+g_t}d_{t-1}-pb_t \quad \text{(A5.3)}$$

(non-indexed debt) t-1=2009

$$d_{indexed,\,t}=\frac{1+r_{indexed,t}}{1+g_t}d_{t-1}-pb_t \quad \text{(A5.4)}$$

(indexed debt) t-1=2009

$$d_t=(1-\omega)\left(\frac{1+r_{non-indexed,t}}{1+g_t}d_{non-indexed\ t-1}\right)+\omega*\left(\frac{1+r_{indexed,t}}{1+g_t}d_{indexed,t-1}\right)-pb_t \quad \text{(A5.5)}$$

(partially indexed debt) t-1=2009

$$d_{Base,t}=\frac{1+r_{Base,t}}{1+g_{Base.t}}d_{Base,t-1}-pb_{Base,t} \quad \text{(A5.6)}$$

(Baseline) t-1=2009

• **Endogenous Credit Risk Premium**: For N=2-10, i.e. t=2010-2019 as in Blanchard et al (2016b)

Based on $debt\_sim/GDP_{t-1}$, :

$$\boldsymbol{RP_t}=\beta*\left(debt_{sim_{t-1}}-d_{Base_{t-1}}\right) \quad \text{(A5.7)}$$

where β=0.03 if $debt\_sim_t$>140% and β=0.02 if $debt_sim_t \leq$140%.

Based on $debt\_ind\_sim/GDP_{t-1}$:

$$\boldsymbol{RP\_ind_{i,t}} = \beta * \left(debt\_ind\_sim_{\_t-1} - d_{Base_{t-1}}\right) \quad \text{(A5.8)}$$

where β=0.03 if $debt\_ind\_sim_t$>140% and β=0.02 if $debt\_ind\_sim_t$≤140%.

(also for baseline)

- **Perform debt-simulations** by updating the debt dynamic:

$$d_{non-indexed,\,t}=\frac{1+r_{non-indexed,t}}{1+g_t}\,d_{t-1}\text{ -}pb_t \qquad \text{(non-indexed debt)} \qquad \text{(A5.9)}$$

$$d_{indexed\ t}=\frac{1+r_{indexed,t}}{1+g_t}\,d_{t-1}\text{-}pb_t \qquad \text{(indexed debt)} \qquad \text{(A5.10)}$$

$$d_t=(1-\omega)\left(\frac{1+r_{non-indexed,t}}{1+g_t}\,d_{non-indexed,t-1}\right)+\omega*\left(\frac{1+r_{indexed,t}}{1+g_t}\,d_{indexed\ t-1}\right)\text{-}pb_t \qquad \text{(A5.11)}$$

(partially indexed debt)

$$d_{Base\_\,t}=\frac{1+r_{Base,t}}{1+g_{Base.t}}\,d_{Base,t-1}\text{ -}pb_{Base,t} \qquad \text{(Baseline)} \qquad \text{(A5.12)}$$

- Update r_sim, r_ind_sim using estimated credit risk premium

$$r_{indexed,\,t} = r_{indexed,\,t} + RP_{ind,t}, \quad \text{(A5.13)}$$

$$r_{non-indexed,t} = r_{non-indexed,t}+RP_t \quad \text{(A5.14)}$$

- Update the Baseline with new $\boldsymbol{r\_sim_{\_non-indexed,t}}$
- Repeat for scenario path 2…10,000. **END**
- Estimate percentiles of non-indexed debt, of indexed debt and of mixed debt (simulated distributions)→Use to create **fan charts**
- **Sensitivity Analysis:** Repeat the entire process for alternative combinations of **novelty premia (k)** & **percentage of debt indexed (ω)**
- Repeat entire process and the sensitivity analysis for **alternative baseline scenarios**

Appendix 5.3-Historical Counterfactual Results (Case a)

k=100bps

Greece_Simulations of Non-Indexed Debt-to-GDP (%)								Greece_Simulations of Fully Indexed Debt-to-GDP (%) ω=100%								Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99		0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	109.76	114.07	121.89	124.27	126.74	134.69	139.16	2010	117.54	119.92	124.15	125.46	126.79	130.96	133.24	147.50
2011	119.80	126.22	138.09	141.74	145.68	158.43	166.55	2011	132.35	135.82	142.61	144.67	146.66	153.35	157.17	175.20
2012	116.34	123.48	137.92	142.48	147.25	163.32	173.37	2012	131.90	136.14	144.20	146.75	149.20	157.56	162.36	161.90
2013	109.97	118.48	135.20	140.48	146.22	165.27	177.12	2013	128.78	134.03	143.36	146.36	149.29	159.14	164.48	178.40
2014	101.35	110.21	128.72	135.22	141.31	163.62	178.27	2014	123.11	128.70	139.17	142.61	145.81	157.09	163.77	180.20
2015	91.78	101.22	121.74	128.50	135.35	161.09	177.03	2015	115.92	122.15	133.76	137.53	141.24	153.78	160.76	177.00
2016	82.48	92.12	114.24	121.51	128.97	156.61	175.20	2016	108.80	115.15	127.86	131.90	136.07	150.05	157.68	180.80
2017	73.09	83.39	106.46	114.50	122.11	152.41	172.37	2017	101.11	108.12	121.93	126.33	130.65	146.10	154.36	179.20
2018	65.13	75.55	99.14	107.17	115.68	147.94	169.59	2018	94.17	101.46	116.08	120.64	125.33	142.33	151.32	186.20
2019	56.72	67.49	91.79	100.20	109.16	143.75	166.11	2019	87.21	94.74	110.26	115.01	120.01	138.16	148.31	180.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%								Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99		0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.13	119.86	124.81	126.41	127.91	132.74	135.51	2010	117.13	119.86	124.81	126.41	127.91	132.74	135.51
2011	123.11	128.69	139.26	142.50	145.89	156.90	163.84	2011	126.29	131.19	140.39	143.24	146.16	155.52	161.44
2012	120.23	126.89	139.57	143.49	147.73	161.64	170.07	2012	124.67	130.19	141.14	144.62	148.21	160.12	167.21
2013	115.02	122.58	137.33	141.99	146.93	163.43	173.41	2013	119.81	126.56	139.38	143.50	147.69	161.59	170.08
2014	107.28	115.18	131.48	137.04	142.40	161.30	174.23	2014	113.18	119.95	134.19	138.82	143.47	159.46	169.93
2015	98.60	106.77	124.94	130.74	136.73	158.83	172.20	2015	104.78	112.25	127.96	133.01	138.20	156.61	167.60
2016	89.37	98.23	117.76	124.10	130.68	154.26	170.67	2016	96.27	103.96	121.29	126.81	132.42	152.33	165.96
2017	80.84	90.07	110.51	117.44	124.10	150.16	166.61	2017	88.09	96.45	114.56	120.37	126.24	148.35	161.48
2018	73.16	82.65	103.54	110.53	118.09	146.10	163.59	2018	80.28	89.28	107.90	114.13	120.38	144.39	158.61
2019	65.10	74.70	96.66	104.02	111.79	141.81	160.67	2019	72.47	81.69	101.32	107.70	114.57	140.00	155.80

Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.13	119.86	124.81	126.41	127.91	132.74	135.51
2011	129.58	133.62	141.53	143.95	146.36	154.26	159.16
2012	128.25	133.31	142.70	145.68	148.68	158.57	164.21
2013	124.33	130.60	141.43	144.96	148.39	160.06	166.92
2014	118.48	124.52	136.67	140.69	144.61	157.98	166.25
2015	110.81	117.37	130.97	135.32	139.71	154.79	163.83
2016	102.89	109.68	124.66	129.34	134.15	150.88	160.96
2017	94.92	102.32	118.35	123.35	128.51	147.02	157.03
2018	87.40	95.55	112.04	117.42	122.78	143.02	154.14
2019	80.01	88.21	105.91	111.38	117.22	138.41	151.30

Tables A5.1-A5.5 Simulated Indexed and Non-Indexed Debt Ratios, Case a, k=100bps

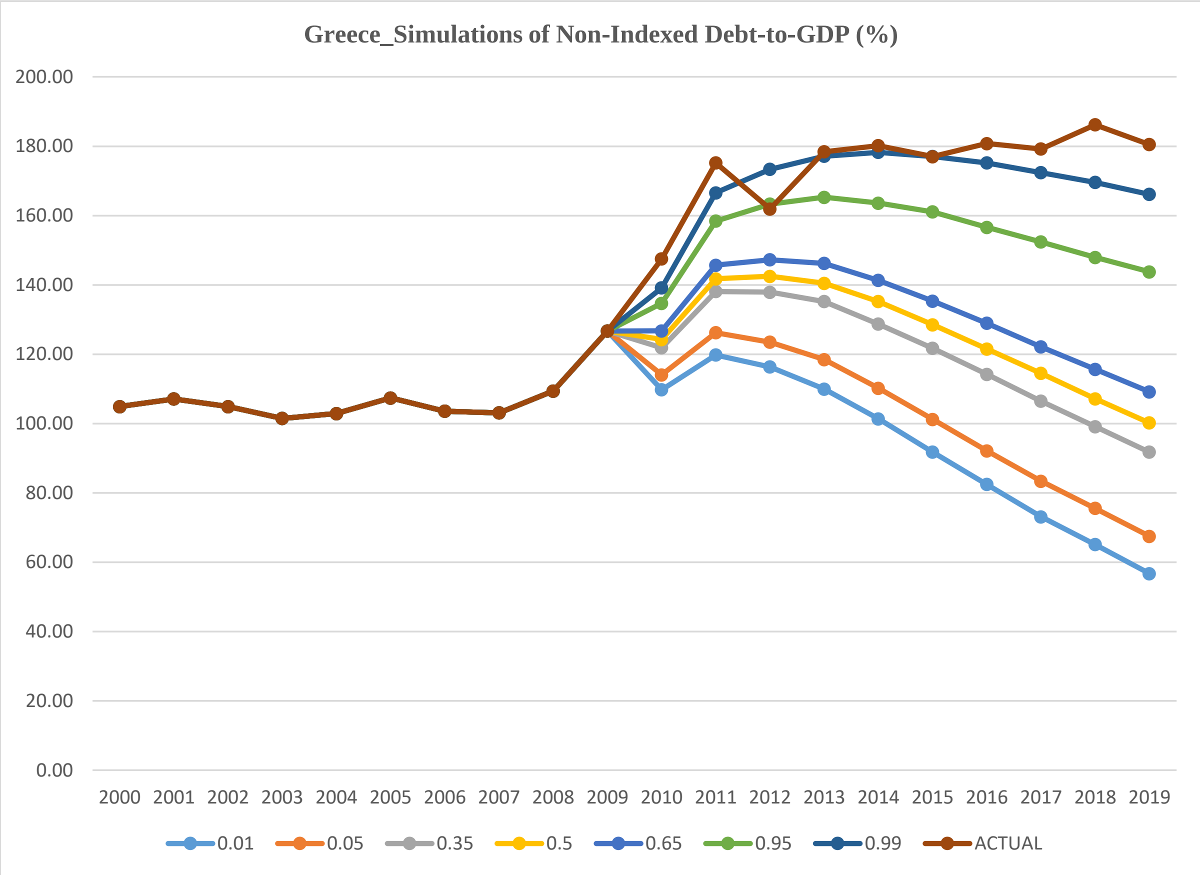

Figure A5.1: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case a, k=100bps

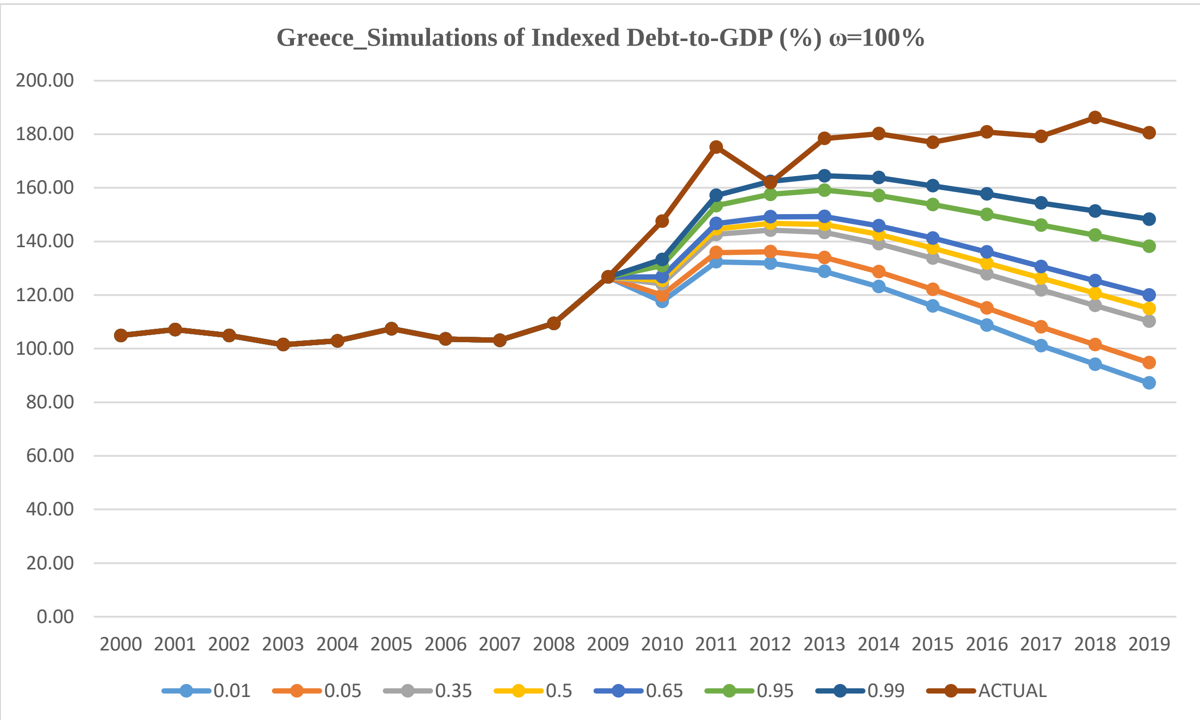

Figure A5.2: Greece_Simulations of Indexed Debt-to-GDP (%), Case a, k=100bps

k=150bps

Greece_Simulations of Non-Indexed Debt-to-GDP (%)							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	109.76	114.07	121.89	124.27	126.74	134.69	139.16
2011	119.80	126.22	138.09	141.74	145.68	158.43	166.55
2012	116.34	123.48	137.92	142.48	147.25	163.32	173.37
2013	109.97	118.48	135.20	140.48	146.22	165.27	177.12
2014	101.35	110.21	128.72	135.22	141.31	163.62	178.27
2015	91.78	101.22	121.74	128.50	135.35	161.09	177.03
2016	82.48	92.12	114.24	121.51	128.97	156.61	175.20
2017	73.09	83.39	106.46	114.50	122.11	152.41	172.37
2018	65.13	75.55	99.14	107.17	115.68	147.94	169.59
2019	56.72	67.49	91.79	100.20	109.16	143.75	166.11

Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%								Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	118.11	120.50	124.75	126.06	127.40	131.57	133.86	147.50
2011	133.64	137.12	143.95	146.01	148.03	154.74	158.59	175.20
2012	133.93	138.20	146.33	148.89	151.38	159.81	164.68	161.90
2013	131.53	136.87	146.34	149.39	152.37	162.32	167.74	178.40
2014	126.67	132.30	143.01	146.52	149.79	161.28	168.12	180.20
2015	120.16	126.52	138.52	142.38	146.17	159.00	166.23	177.00
2016	113.72	120.27	133.48	137.69	141.98	156.29	164.15	180.80
2017	106.83	114.00	128.38	132.97	137.65	153.43	162.00	179.20
2018	100.46	108.10	123.35	128.20	133.17	150.69	160.27	186.20
2019	94.01	101.96	118.29	123.41	128.78	147.94	158.28	180.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	116.84	119.57	124.51	126.11	127.61	132.43	135.20
2011	123.42	129.02	139.60	142.83	146.24	157.25	164.20
2012	120.73	127.39	140.10	144.03	148.27	162.20	170.66
2013	115.71	123.28	138.07	142.74	147.70	164.23	174.23
2014	108.17	116.08	132.44	138.01	143.40	162.35	175.29
2015	99.64	107.88	126.11	131.95	137.96	160.14	173.56
2016	90.62	99.49	119.19	125.55	132.15	155.82	172.30
2017	82.26	91.53	112.12	119.13	125.80	151.96	168.53
2018	74.77	84.26	105.35	112.41	120.05	148.19	165.76
2019	66.79	76.54	98.70	106.13	113.99	144.24	163.22

Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	116.84	119.57	124.51	126.11	127.61	132.43	135.20
2011	126.93	131.84	141.06	143.91	146.84	156.22	162.16
2012	125.67	131.23	142.21	145.69	149.30	161.26	168.37
2013	121.17	127.96	140.87	145.01	149.21	163.19	171.69
2014	114.95	121.75	136.10	140.78	145.47	161.54	172.09
2015	106.92	114.44	130.33	135.44	140.64	159.17	170.30
2016	98.72	106.52	124.09	129.72	135.35	155.47	169.21
2017	90.96	99.39	117.80	123.70	129.75	152.08	165.32
2018	83.40	92.54	111.54	117.91	124.30	148.68	162.95
2019	75.98	85.35	105.36	111.89	118.96	144.82	160.71

Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	116.84	119.57	124.51	126.11	127.61	132.43	135.20
2011	130.53	134.59	142.52	144.96	147.38	155.32	160.25
2012	129.77	134.85	144.30	147.30	150.31	160.28	165.92
2013	126.36	132.72	143.67	147.23	150.70	162.43	169.42
2014	121.12	127.26	139.57	143.64	147.61	161.09	169.47
2015	114.00	120.69	134.54	138.94	143.39	158.70	167.87
2016	106.53	113.60	128.85	133.68	138.57	155.56	165.77
2017	99.21	106.72	123.19	128.37	133.73	152.51	162.73
2018	92.03	100.50	117.51	123.11	128.71	149.37	160.76
2019	85.26	93.69	111.96	117.68	123.83	145.83	158.84

Tables A5.6-A5.10 Simulated Indexed and Non-Indexed Debt Ratios, Case a, k=150bps

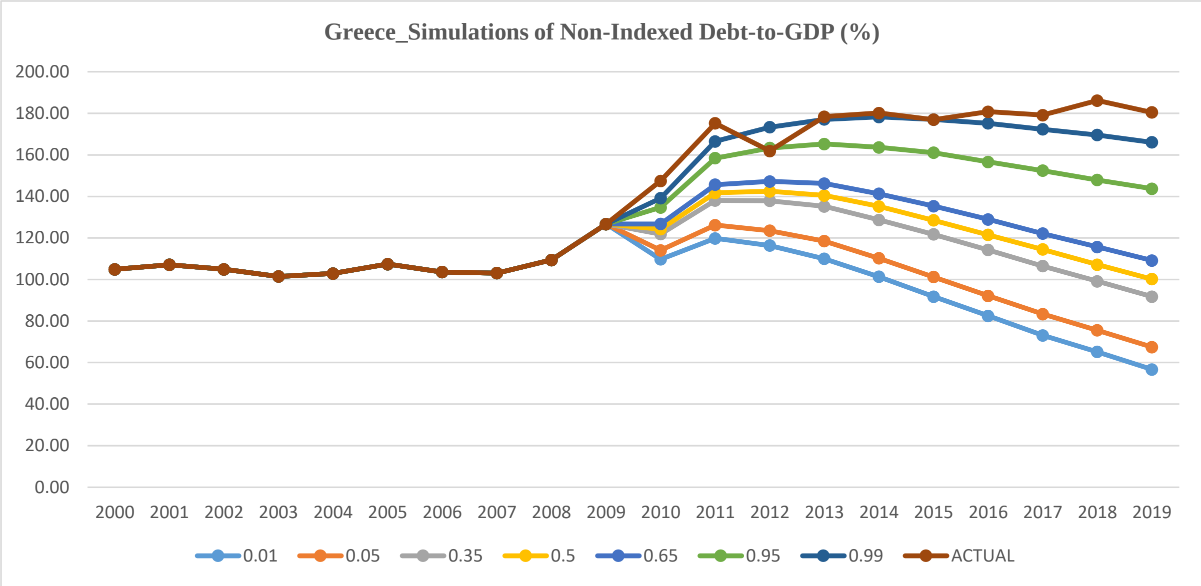

Figure A5.3: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case a, k=150bps

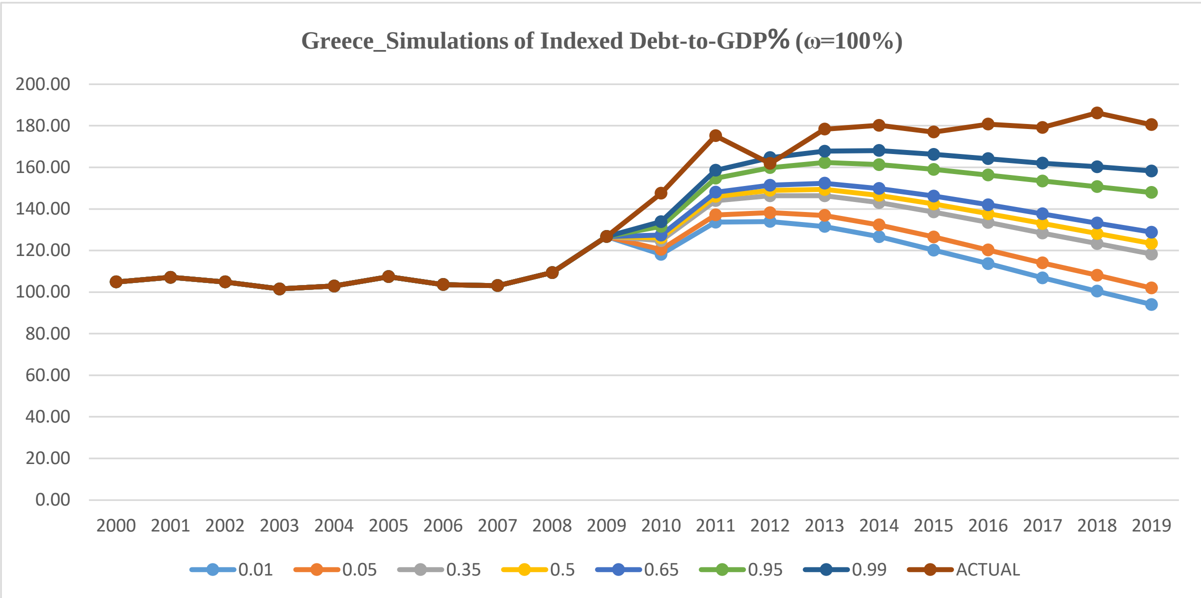

Figure A5.4: Greece_Simulations of Indexed Debt-to-GDP (%), Case a, k=150bps

K=200bps

Greece_Simulations of Non-Indexed Debt-to-GDP (%)							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	109.76	114.07	121.89	124.27	126.74	134.69	139.16
2011	119.80	126.22	138.09	141.74	145.68	158.43	166.55
2012	116.34	123.48	137.92	142.48	147.25	163.32	173.37
2013	109.97	118.48	135.20	140.48	146.22	165.27	177.12
2014	101.35	110.21	128.72	135.22	141.31	163.62	178.27
2015	91.78	101.22	121.74	128.50	135.35	161.09	177.03
2016	82.48	92.12	114.24	121.51	128.97	156.61	175.20
2017	73.09	83.39	106.46	114.50	122.11	152.41	172.37
2018	65.13	75.55	99.14	107.17	115.68	147.94	169.59
2019	56.72	67.49	91.79	100.20	109.16	143.75	166.11

Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%								Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	118.69	121.08	125.34	126.66	128.00	132.19	134.48	147.50
2011	134.92	138.44	145.29	147.37	149.39	156.15	160.02	175.20
2012	135.97	140.29	148.49	151.07	153.58	162.09	167.00	161.90
2013	134.40	139.76	149.37	152.46	155.48	165.56	171.03	178.40
2014	130.32	135.96	146.97	150.52	153.88	165.56	172.54	180.20
2015	124.62	131.10	143.41	147.34	151.23	164.35	171.77	177.00
2016	118.82	125.54	139.40	143.69	148.03	162.74	170.81	180.80
2017	112.83	120.18	135.31	140.12	144.85	161.15	170.09	179.20
2018	107.07	115.04	131.14	136.37	141.67	159.58	169.68	186.20
2019	101.24	109.54	127.11	132.67	138.61	158.28	169.08	180.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.42	120.15	125.11	126.71	128.21	133.05	135.82
2011	123.74	129.35	139.93	143.17	146.58	157.60	164.57
2012	121.23	127.90	140.64	144.58	148.82	162.77	171.25
2013	116.41	124.00	138.83	143.51	148.47	165.03	175.06
2014	109.07	117.01	133.43	139.01	144.41	163.41	176.38
2015	100.73	108.99	127.34	133.20	139.22	161.45	174.93
2016	91.94	100.85	120.65	127.01	133.68	157.46	173.99
2017	83.74	93.04	113.86	120.88	127.61	153.85	170.51
2018	76.42	85.95	107.33	114.44	122.15	150.43	168.05
2019	68.62	78.54	100.89	108.41	116.42	146.84	165.93

Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.42	120.15	125.11	126.71	128.21	133.05	135.82
2011	127.58	132.49	141.72	144.59	147.52	156.92	162.89
2012	126.67	132.27	143.29	146.78	150.40	162.41	169.54
2013	122.58	129.39	142.37	146.56	150.78	164.82	173.35
2014	116.77	123.63	138.09	142.79	147.49	163.70	174.27
2015	109.17	116.72	132.78	137.93	143.17	161.88	173.09
2016	101.32	109.22	127.06	132.71	138.39	158.74	172.45
2017	93.95	102.49	121.27	127.26	133.34	155.88	169.33
2018	86.74	95.97	115.50	122.02	128.50	153.08	167.48
2019	79.76	89.19	109.81	116.54	123.82	149.98	166.13

Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.42	120.15	125.11	126.71	128.21	133.05	135.82
2011	131.49	135.57	143.53	145.98	148.41	156.38	161.34
2012	131.31	136.40	145.91	148.94	151.96	162.00	167.67
2013	128.46	134.87	145.95	149.53	153.04	164.87	171.94
2014	123.78	130.06	142.51	146.65	150.66	164.27	172.77
2015	117.29	124.09	138.21	142.67	147.22	162.76	172.02
2016	110.48	117.58	133.26	138.16	143.11	160.47	170.80
2017	103.71	111.30	128.39	133.68	139.14	158.22	168.82
2018	97.07	105.70	123.37	129.24	135.06	156.03	167.70
2019	90.86	99.45	118.56	124.64	131.17	153.50	166.87

Tables A5.11-A5.15 Simulated Indexed and Non-Indexed Debt Ratios, Case a, k=200bp

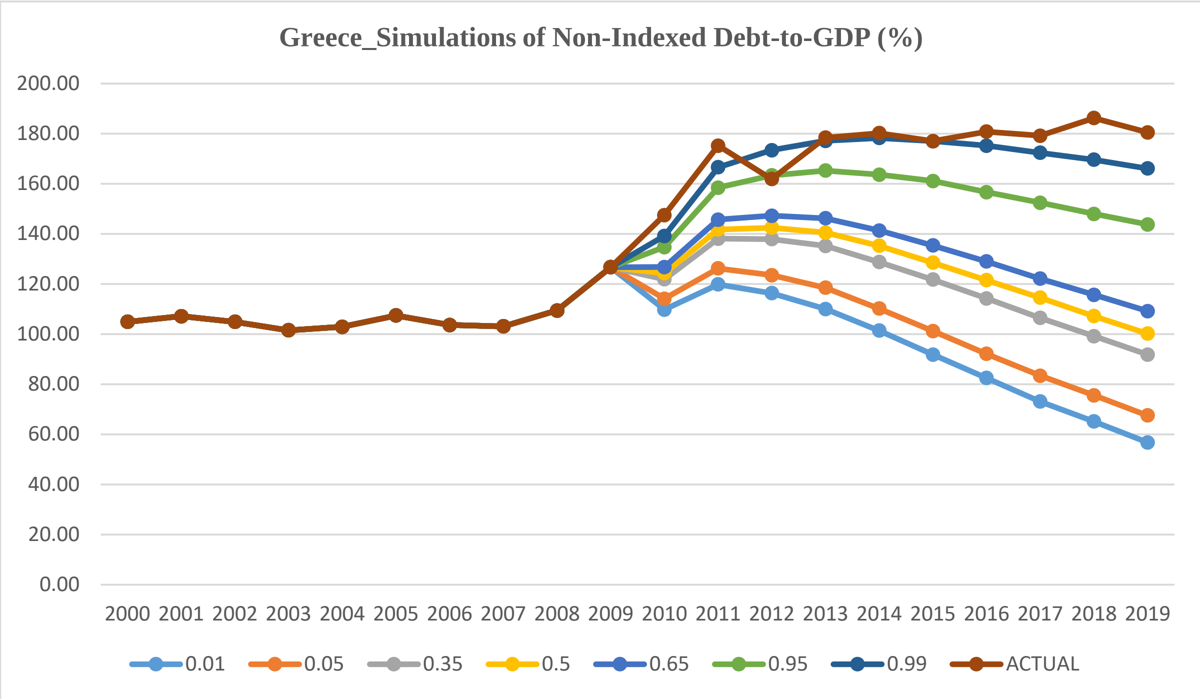

Figure A5.5: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case a, k=200bps

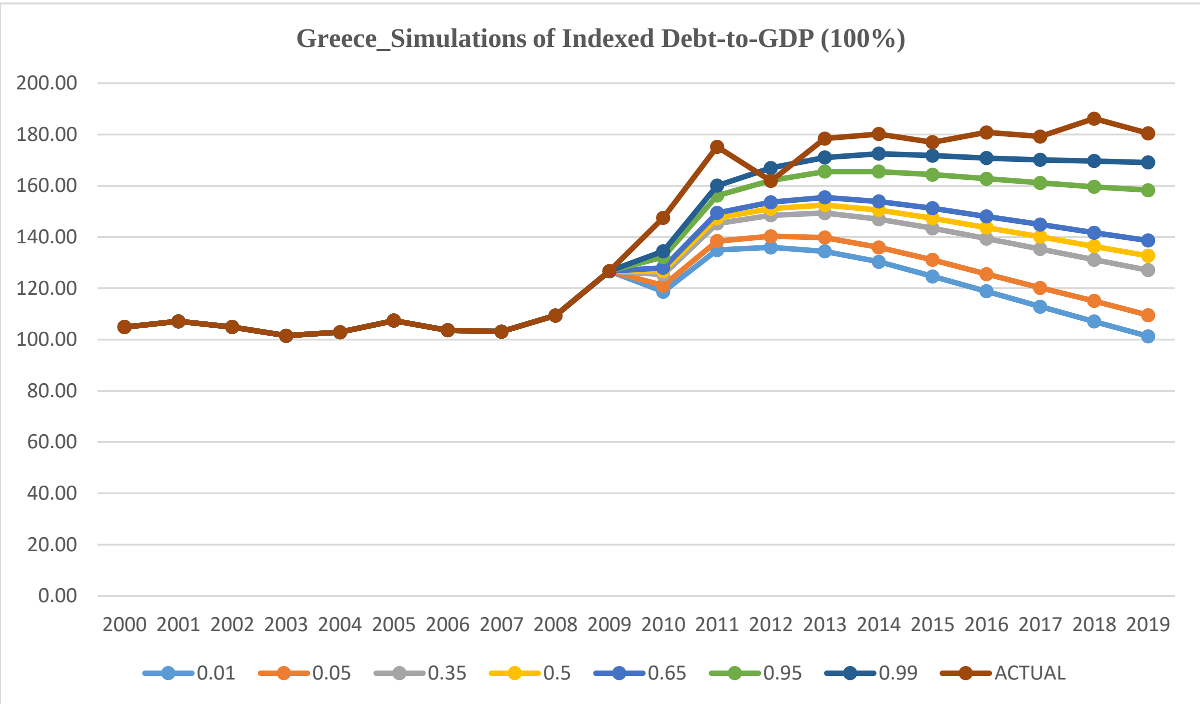

Figure A5.6: Greece_Simulations of Indexed Debt-to-GDP (%), Case a, **k=200bps**

K=250 bps

	Greece_Simulations of Non-Indexed Debt-to-GDP (%)								Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%							Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99		0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	109.76	114.07	121.89	124.27	126.74	134.69	139.16	2010	119.27	121.67	125.94	127.26	128.61	132.80	135.11	147.50
2011	119.80	126.22	138.09	141.74	145.68	158.43	166.55	2011	136.19	139.75	146.64	148.73	150.77	157.57	161.45	175.20
2012	116.34	123.48	137.92	142.48	147.25	163.32	173.37	2012	138.04	142.38	150.68	153.28	155.80	164.39	169.31	161.90
2013	109.97	118.48	135.20	140.48	146.22	165.27	177.12	2013	137.28	142.68	152.45	155.57	158.63	168.84	174.36	178.40
2014	101.35	110.21	128.72	135.22	141.31	163.62	178.27	2014	133.99	139.77	151.00	154.61	158.05	169.95	177.04	180.20
2015	91.78	101.22	121.74	128.50	135.35	161.09	177.03	2015	129.01	135.86	148.43	152.46	156.44	169.85	177.44	177.00
2016	82.48	92.12	114.24	121.51	128.97	156.61	175.20	2016	124.09	131.11	145.47	149.85	154.35	169.48	177.76	180.80
2017	73.09	83.39	106.46	114.50	122.11	152.41	172.37	2017	119.11	126.63	142.50	147.43	152.31	169.22	178.45	179.20
2018	65.13	75.55	99.14	107.17	115.68	147.94	169.59	2018	113.98	122.29	139.67	145.02	150.38	169.04	179.62	186.20
2019	56.72	67.49	91.79	100.20	109.16	143.75	166.11	2019	109.20	117.79	136.88	142.88	148.72	169.22	180.82	180.50

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.99	120.74	125.71	127.31	128.80	133.66	136.44
2011	124.06	129.68	140.27	143.51	146.92	157.96	164.93
2012	121.74	128.42	141.19	145.13	149.37	163.34	171.83
2013	117.13	124.74	139.61	144.28	149.25	165.84	175.91
2014	110.01	117.97	134.44	140.04	145.44	164.50	177.49
2015	101.85	110.19	128.59	134.48	140.54	162.82	176.33
2016	93.33	102.29	122.16	128.56	135.26	159.15	175.74
2017	85.25	94.65	115.67	122.71	129.49	155.82	172.54
2018	78.11	87.76	109.45	116.59	124.31	152.80	170.46
2019	70.59	80.63	103.33	110.89	119.01	149.57	168.78

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.99	120.74	125.71	127.31	128.80	133.66	136.44
2011	128.23	133.14	142.40	145.27	148.21	157.63	163.62
2012	127.68	133.31	144.38	147.88	151.51	163.56	170.71
2013	124.00	130.83	143.92	148.12	152.36	166.46	175.05
2014	118.60	125.54	140.10	144.83	149.56	165.89	176.50
2015	111.43	119.05	135.30	140.49	145.76	164.64	175.94
2016	104.01	112.02	130.09	135.81	141.51	162.13	175.92
2017	97.08	105.71	124.84	130.91	137.07	159.91	173.58
2018	90.23	99.57	119.72	126.31	132.86	157.78	172.31
2019	83.81	93.30	114.73	121.58	128.92	155.39	171.85

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	117.99	120.74	125.71	127.31	128.80	133.66	136.44
2011	132.46	136.55	144.54	147.00	149.44	157.46	162.42
2012	132.87	137.95	147.54	150.58	153.63	163.71	169.45
2013	130.61	137.05	148.25	151.86	155.41	167.30	174.49
2014	126.54	132.96	145.55	149.74	153.77	167.54	176.15
2015	120.57	127.65	141.98	146.50	151.13	166.91	176.23
2016	114.45	121.78	137.82	142.80	147.84	165.51	176.00
2017	108.41	116.21	133.82	139.19	144.73	164.27	175.05
2018	102.33	111.17	129.74	135.73	141.55	163.17	175.01
2019	96.77	105.76	125.87	132.24	138.75	161.61	175.39

Tables A5.16-A5.20 Simulated Indexed and Non-Indexed Debt Ratios, Case a, k=250bps

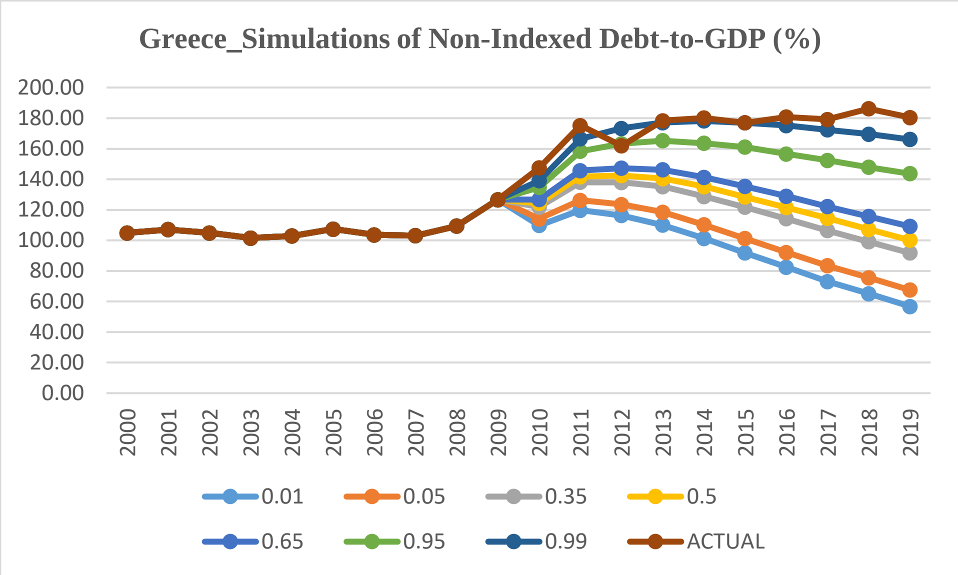

Figure A5.7: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case a, k=250bps

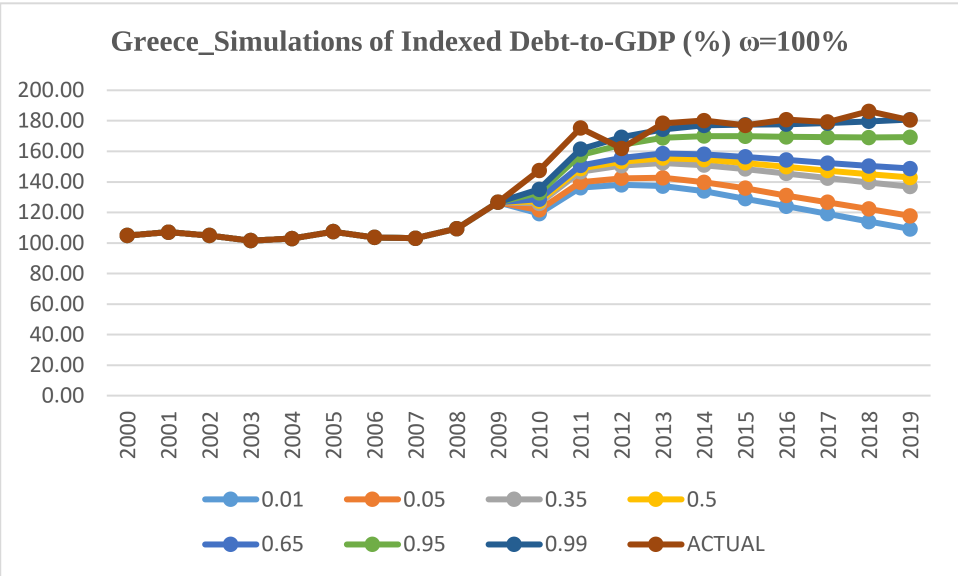

Figure A5.8: Greece_Simulations of Indexed Debt-to-GDP (%), Case a, k=150bps**k=250bps**

K=300bps

Greece_Simulations of Non-Indexed Debt-to-GDP (%)							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	109.76	114.07	121.89	124.27	126.74	134.69	139.16
2011	119.80	126.22	138.09	141.74	145.68	158.43	166.55
2012	116.34	123.48	137.92	142.48	147.25	163.32	173.37
2013	109.97	118.48	135.20	140.48	146.22	165.27	177.12
2014	101.35	110.21	128.72	135.22	141.31	163.62	178.27
2015	91.78	101.22	121.74	128.50	135.35	161.09	177.03
2016	82.48	92.12	114.24	121.51	128.97	156.61	175.20
2017	73.09	83.39	106.46	114.50	122.11	152.41	172.37
2018	65.13	75.55	99.14	107.17	115.68	147.94	169.59
2019	56.72	67.49	91.79	100.20	109.16	143.75	166.11

Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%								Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	119.84	122.26	126.53	127.86	129.21	133.41	135.73	147.50
2011	137.49	141.07	148.00	150.10	152.15	159.00	162.88	175.20
2012	140.10	144.49	152.87	155.51	158.07	166.73	171.65	161.90
2013	140.17	145.69	155.59	158.75	161.84	172.16	177.78	178.40
2014	137.76	143.71	155.14	158.80	162.31	174.38	181.62	180.20
2015	133.68	140.74	153.61	157.72	161.79	175.46	183.25	177.00
2016	129.69	137.11	151.70	156.24	160.85	176.49	184.95	180.80
2017	125.63	133.49	149.96	155.02	160.09	177.57	187.20	179.20
2018	121.26	130.23	148.40	153.89	159.48	179.01	189.93	186.20
2019	117.73	126.82	147.20	153.24	159.30	180.85	193.03	180.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	118.56	121.33	126.31	127.91	129.41	134.28	137.07
2011	124.38	130.01	140.61	143.86	147.27	158.32	165.29
2012	122.26	128.95	141.74	145.68	149.93	163.92	172.43
2013	117.88	125.48	140.39	145.08	150.06	166.67	176.77
2014	110.94	118.95	135.47	141.08	146.51	165.62	178.63
2015	103.00	111.41	129.88	135.78	141.87	164.20	177.78
2016	94.75	103.75	123.76	130.17	136.91	160.92	177.55
2017	86.92	96.36	117.55	124.62	131.42	157.94	174.72
2018	79.95	89.79	111.65	118.85	126.60	155.29	173.02
2019	72.73	82.92	105.86	113.47	121.67	152.52	171.71

Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	118.56	121.33	126.31	127.91	129.41	134.28	137.07
2011	128.89	133.80	143.08	145.95	148.90	158.35	164.36
2012	128.70	134.37	145.47	148.99	152.62	164.72	171.89
2013	125.43	132.31	145.48	149.70	153.95	168.13	176.76
2014	120.48	127.51	142.16	146.92	151.69	168.13	178.77
2015	113.78	121.55	137.89	143.11	148.43	167.45	178.86
2016	106.75	114.99	133.21	139.01	144.74	165.56	179.48
2017	100.38	109.17	128.56	134.74	140.96	164.06	178.06
2018	93.96	103.55	124.12	130.78	137.42	162.75	177.39
2019	88.02	97.76	119.86	126.73	134.18	161.17	177.86

Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	118.56	121.33	126.31	127.91	129.41	134.28	137.07
2011	133.42	137.54	145.55	148.02	150.47	158.53	163.51
2012	134.44	139.53	149.18	152.25	155.32	165.46	171.24
2013	132.86	139.26	150.60	154.25	157.81	169.81	177.07
2014	129.42	135.90	148.67	152.89	156.97	170.93	179.65
2015	123.98	131.36	145.87	150.45	155.13	171.19	180.60
2016	118.61	126.24	142.52	147.62	152.74	170.69	181.31
2017	113.36	121.44	139.41	144.89	150.55	170.56	181.56
2018	107.91	117.14	136.37	142.41	148.37	170.54	182.79
2019	102.91	112.39	133.64	139.95	146.66	170.24	184.44

Tables A5.21-A5.25 Simulated Indexed and Non-Indexed Debt Ratios, Case a, k=300bps

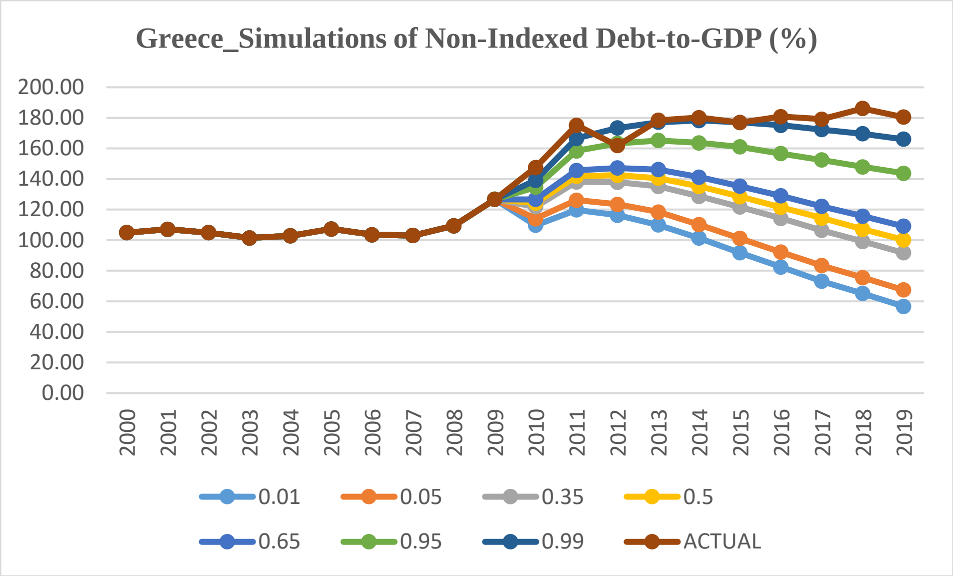

Figure A5.9: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case a, k=300bps

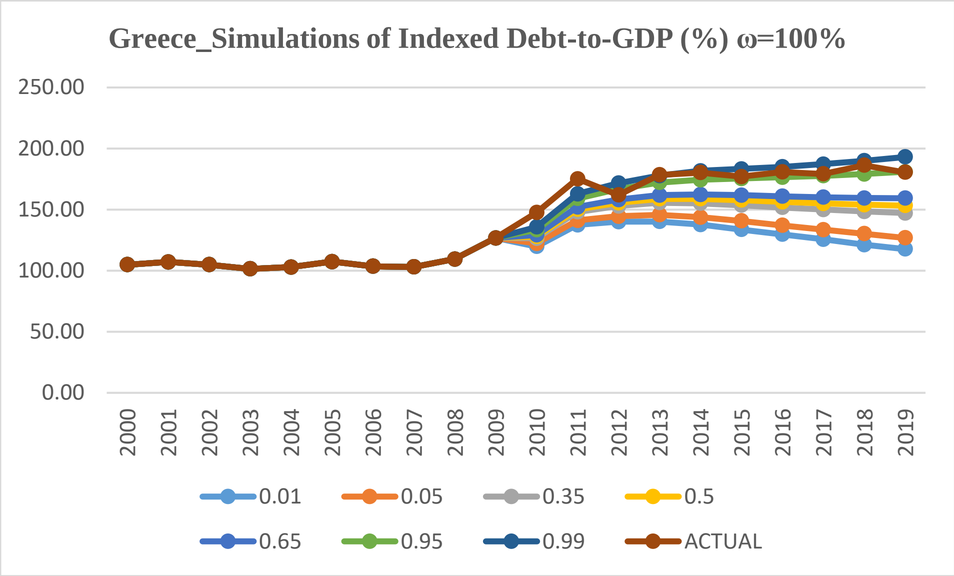

Figure A5.10: Greece_Simulations of Indexed Debt-to-GDP (%), Case a, k=150bpsk=300bps

k=350bps

	Greece_Simulations of Non-Indexed Debt-to-GDP (%)								Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%							Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99		0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	109.76	114.07	121.89	124.27	126.74	134.69	139.16	2010	120.42	122.85	127.12	128.46	129.82	134.03	136.36	147.50
2011	119.80	126.22	138.09	141.74	145.68	158.43	166.55	2011	138.80	142.39	149.37	151.47	153.54	160.41	164.32	175.20
2012	116.34	123.48	137.92	142.48	147.25	163.32	173.37	2012	142.16	146.62	155.09	157.76	160.33	169.07	174.03	161.90
2013	109.97	118.48	135.20	140.48	146.22	165.27	177.12	2013	143.10	148.75	158.76	161.97	165.11	175.53	181.28	178.40
2014	101.35	110.21	128.72	135.22	141.31	163.62	178.27	2014	141.72	147.69	159.37	163.07	166.66	178.95	186.29	180.20
2015	91.78	101.22	121.74	128.50	135.35	161.09	177.03	2015	138.56	145.77	158.91	163.12	167.32	181.26	189.23	177.00
2016	82.48	92.12	114.24	121.51	128.97	156.61	175.20	2016	135.51	143.23	158.19	162.85	167.57	183.69	192.39	180.80
2017	73.09	83.39	106.46	114.50	122.11	152.41	172.37	2017	132.49	140.81	157.72	162.94	168.17	186.29	196.31	179.20
2018	65.13	75.55	99.14	107.17	115.68	147.94	169.59	2018	129.22	138.90	157.52	163.25	169.05	189.44	200.70	186.20
2019	56.72	67.49	91.79	100.20	109.16	143.75	166.11	2019	126.54	136.63	157.80	164.08	170.56	193.39	205.95	180.50

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	119.14	121.91	126.90	128.51	130.01	134.91	137.69
2011	124.70	130.34	140.95	144.20	147.61	158.68	165.66
2012	122.79	129.49	142.29	146.25	150.49	164.52	173.03
2013	118.64	126.24	141.18	145.89	150.88	167.51	177.64
2014	111.88	119.95	136.52	142.15	147.60	166.76	179.79
2015	104.21	112.66	131.21	137.12	143.25	165.61	179.26
2016	96.26	105.28	125.39	131.85	138.59	162.71	179.42
2017	88.77	98.22	119.49	126.64	133.45	160.13	177.02
2018	81.94	91.92	113.94	121.21	129.00	157.89	175.73
2019	74.96	85.46	108.51	116.20	124.45	155.64	174.96

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	119.14	121.91	126.90	128.51	130.01	134.91	137.69
2011	129.54	134.46	143.76	146.63	149.59	159.06	165.10
2012	129.76	135.43	146.58	150.10	153.75	165.90	173.09
2013	126.94	133.80	147.06	151.31	155.58	169.79	178.50
2014	122.41	129.50	144.29	149.03	153.87	170.38	181.12
2015	116.26	124.08	140.54	145.81	151.19	170.31	181.90
2016	109.69	118.11	136.47	142.36	148.11	169.18	183.10
2017	103.86	112.82	132.44	138.72	145.01	168.41	182.66
2018	98.05	107.88	128.70	135.39	142.20	167.94	182.83
2019	92.53	102.83	125.18	132.19	139.81	167.29	184.22

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	119.14	121.91	126.90	128.51	130.01	134.91	137.69
2011	134.38	138.53	146.57	149.06	151.51	159.60	164.60
2012	136.04	141.12	150.84	153.93	157.01	167.22	173.06
2013	135.10	141.54	152.99	156.66	160.25	172.35	179.68
2014	132.31	138.94	151.82	156.11	160.25	174.30	183.20
2015	127.58	135.12	149.85	154.52	159.24	175.57	185.04
2016	123.08	130.86	147.35	152.60	157.82	176.10	186.86
2017	118.62	126.94	145.24	150.83	156.64	177.12	188.41
2018	114.05	123.60	143.23	149.45	155.60	178.41	190.82
2019	109.69	119.75	141.58	148.17	155.06	179.56	194.25

Tables A5.26-A5.30 Simulated Indexed and Non-Indexed Debt Ratios, Case a, k=350bps

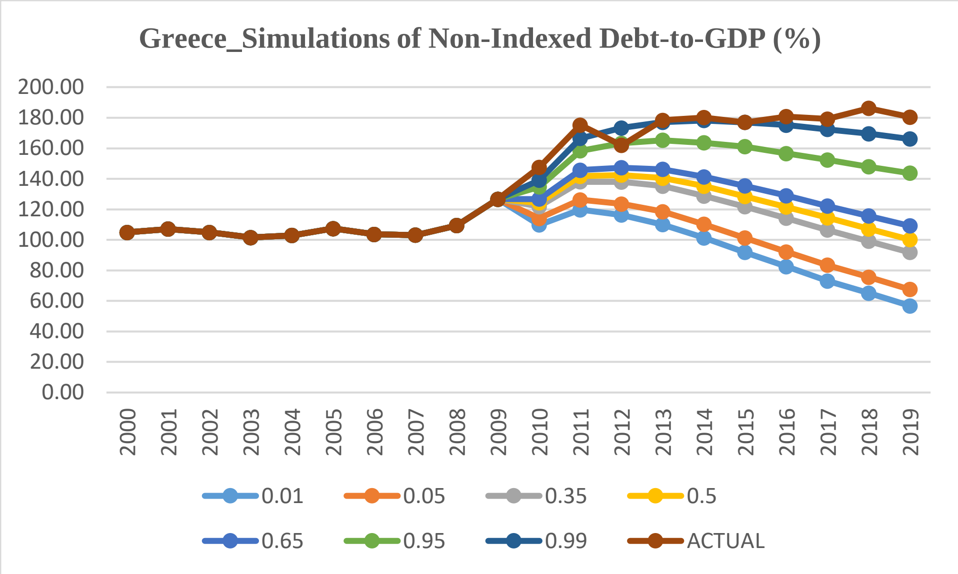

Figure A5.11: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case a, k=350bps

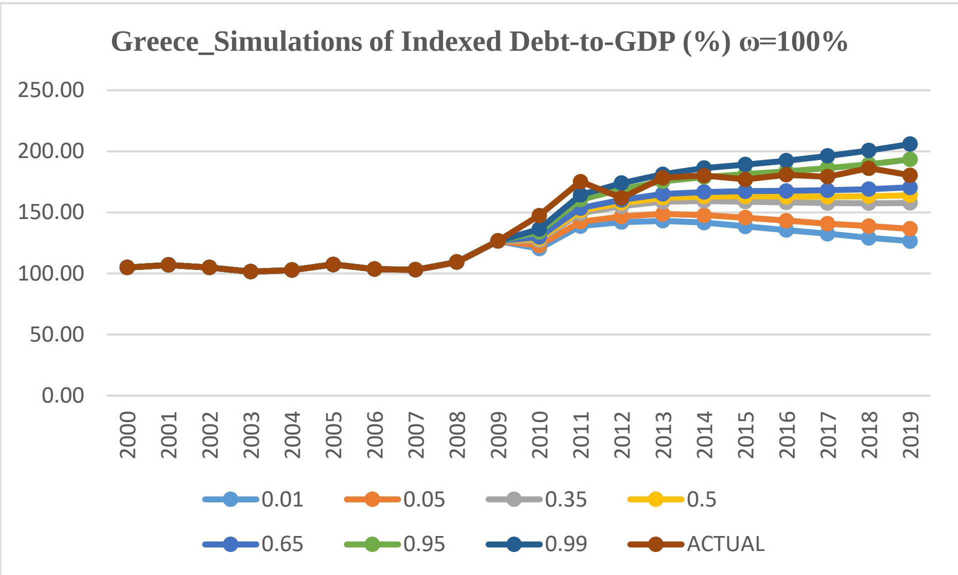

Figure A5.12: Greece_Simulations of Indexed Debt-to-GDP (%), Case a, k=350bps

Appendix 5.4: Historical Counterfactual (Case b), k=100bps

Greece_Simulations of Non-Indexed Debt-to-GDP (%)							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	125.62	130.57	139.21	142.13	144.94	154.78	160.38
2011	136.76	143.47	157.58	161.98	166.58	183.00	191.80
2012	149.97	160.07	179.62	185.99	192.61	215.50	228.88
2013	144.12	154.71	177.96	185.40	193.17	220.25	235.95
2014	131.08	142.53	167.04	175.18	183.71	213.88	231.95
2015	127.20	140.43	167.61	176.93	186.05	221.12	241.72
2016	120.70	134.69	164.46	174.75	185.81	225.85	249.50
2017	112.24	126.15	158.31	169.60	181.55	224.97	253.41
2018	103.49	118.18	151.32	163.30	176.05	222.95	254.61
2019	95.07	109.86	144.23	157.04	170.80	221.20	255.32

Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%								Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	134.55	137.18	141.97	143.45	144.91	149.85	152.68	147.50
2011	151.39	155.41	163.00	165.22	167.55	175.42	179.71	175.20
2012	172.31	177.66	188.35	191.70	194.88	205.84	211.64	161.90
2013	170.99	177.12	189.49	193.18	197.09	209.39	216.31	178.40
2014	161.27	167.66	180.96	184.87	188.87	202.40	209.55	180.20
2015	161.51	169.45	184.56	188.89	193.48	209.13	217.51	177.00
2016	158.87	167.83	184.58	189.81	194.84	212.34	221.78	180.80
2017	153.10	162.90	181.27	186.87	192.53	211.74	222.08	179.20
2018	147.19	157.19	176.99	182.91	189.28	209.79	221.24	186.20
2019	140.63	151.84	172.55	178.98	185.72	208.13	220.33	180.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	135.31	137.76	142.09	143.43	144.78	149.24	151.75
2011	140.65	146.67	158.97	162.81	166.73	181.02	188.36
2012	155.97	164.63	181.89	187.41	193.13	212.70	224.30
2013	151.34	160.72	180.94	187.38	194.08	217.27	230.59
2014	139.37	149.21	170.74	177.62	184.86	210.51	225.89
2015	136.49	148.20	172.03	179.90	187.79	217.43	235.29
2016	131.11	143.21	169.72	178.61	187.87	221.50	242.38
2017	122.80	136.17	164.29	174.00	183.97	221.06	244.61
2018	115.00	128.64	157.84	168.51	179.32	218.56	245.01
2019	107.43	120.80	151.53	162.62	174.28	216.50	245.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	135.31	137.76	142.09	143.43	144.78	149.24	151.75
2011	144.30	149.89	160.34	163.64	166.97	178.90	185.24
2012	161.78	169.18	184.06	188.78	193.73	210.08	219.78
2013	158.47	166.35	183.85	189.33	195.07	214.37	224.97
2014	147.16	155.67	174.32	180.01	186.06	207.16	219.53
2015	145.68	155.69	176.31	182.82	189.69	214.35	228.57
2016	141.22	151.82	174.86	182.35	190.10	218.22	234.61
2017	133.60	145.80	170.19	178.44	186.71	217.36	235.69
2018	127.11	138.68	164.33	173.37	182.56	214.92	235.67
2019	119.10	131.69	158.71	168.15	177.96	212.65	236.59

Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	135.31	137.76	142.09	143.43	144.78	149.24	151.75
2011	147.95	152.64	161.73	164.46	167.25	177.02	182.32
2012	167.22	173.63	186.27	190.21	194.30	207.84	215.34
2013	164.94	171.84	186.75	191.26	196.05	211.64	220.08
2014	154.72	162.04	177.74	182.45	187.49	204.46	213.68
2015	153.87	162.69	180.51	185.92	191.51	211.61	222.28
2016	150.63	159.92	179.84	186.00	192.63	214.34	227.19
2017	143.83	154.57	175.93	182.55	189.53	214.02	228.22
2018	137.36	148.18	170.94	178.07	186.08	211.78	227.58
2019	130.35	141.93	165.90	173.59	181.84	209.54	227.64

Tables A5.31-A5.35 Simulated Indexed and Non-Indexed Debt Ratios, Case b, k=100bps

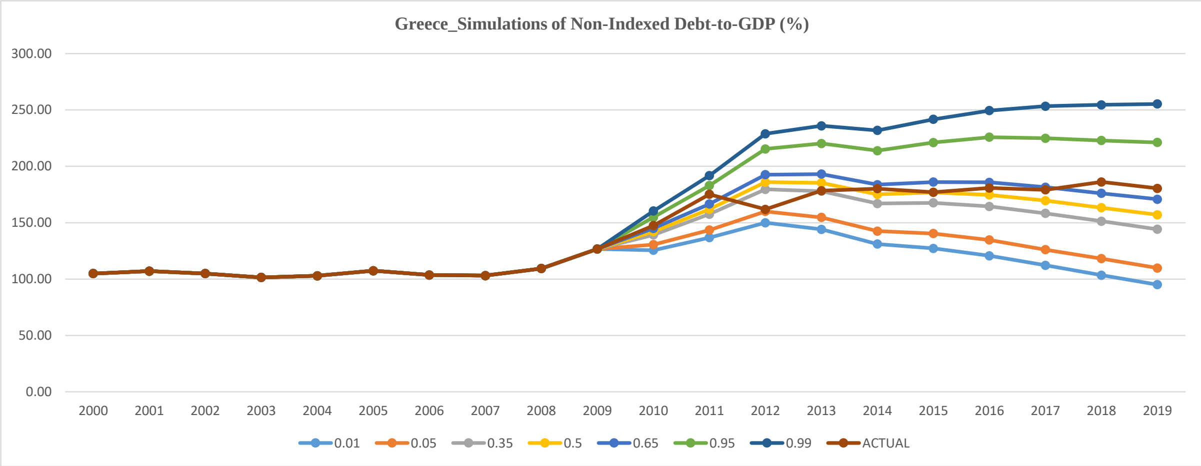

Figure A5.13: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=100bps

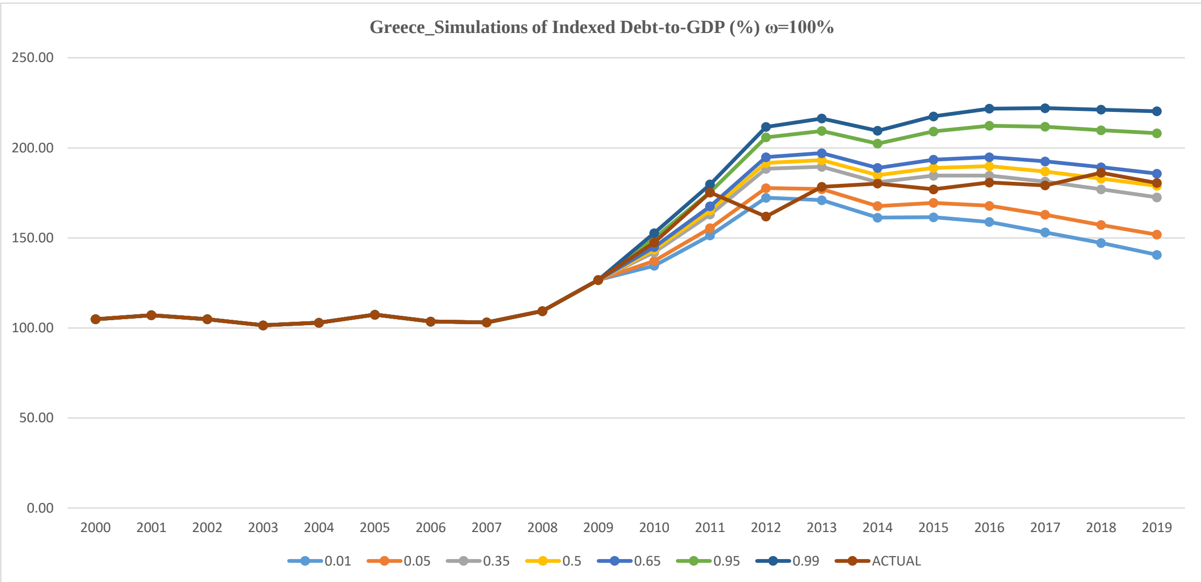

Figure A5.14: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=100bps

k=150bps

Greece_Simulations of Non-Indexed Debt-to-GDP (%)							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	125.62	130.57	139.21	142.13	144.94	154.78	160.38
2011	136.76	143.47	157.58	161.98	166.58	183.00	191.80
2012	149.97	160.07	179.62	185.99	192.61	215.50	228.88
2013	144.12	154.71	177.96	185.40	193.17	220.25	235.95
2014	131.08	142.53	167.04	175.18	183.71	213.88	231.95
2015	127.20	140.43	167.61	176.93	186.05	221.12	241.72
2016	120.70	134.69	164.46	174.75	185.81	225.85	249.50
2017	112.24	126.15	158.31	169.60	181.55	224.97	253.41
2018	103.49	118.18	151.32	163.30	176.05	222.95	254.61
2019	95.07	109.86	144.23	157.04	170.80	221.20	255.32

Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%								Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	135.18	137.82	142.64	144.12	145.58	150.56	153.38	147.50
2011	152.86	156.91	164.56	166.80	169.15	177.09	181.45	175.20
2012	174.88	180.29	191.11	194.49	197.73	208.84	214.67	161.90
2013	174.66	180.84	193.43	197.20	201.18	213.74	220.73	178.40
2014	165.78	172.35	185.96	189.91	194.03	207.86	215.10	180.20
2015	167.18	175.32	190.85	195.31	200.03	216.06	224.68	177.00
2016	165.80	174.96	192.33	197.74	203.00	221.09	230.78	180.80
2017	161.26	171.42	190.46	196.26	202.22	222.21	233.20	179.20
2018	156.34	166.89	187.61	193.85	200.58	222.22	234.20	186.20
2019	150.82	162.63	184.62	191.38	198.52	222.47	235.59	180.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	135.95	138.40	142.75	144.11	145.46	149.94	152.46
2011	141.01	147.04	159.36	163.20	167.13	181.44	188.79
2012	156.60	165.28	182.58	188.12	193.84	213.45	225.06
2013	152.27	161.67	181.93	188.38	195.09	218.35	231.68
2014	140.52	150.38	171.97	178.88	186.15	211.89	227.29
2015	137.96	149.67	173.60	181.53	189.41	219.20	237.06
2016	132.79	145.04	171.67	180.62	189.92	223.75	244.68
2017	124.75	138.27	166.62	176.38	186.36	223.73	247.29
2018	117.29	131.12	160.53	171.20	182.10	221.64	248.22
2019	110.05	123.53	154.58	165.70	177.50	219.96	249.28

Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	135.95	138.40	142.75	144.11	145.46	149.94	152.46
2011	145.03	150.63	161.12	164.43	167.77	179.74	186.11
2012	163.06	170.48	185.45	190.18	195.15	211.58	221.32
2013	160.29	168.22	185.81	191.33	197.11	216.50	227.22
2014	149.39	158.01	176.81	182.53	188.63	209.87	222.38
2015	148.57	158.61	179.43	186.03	192.96	217.85	232.29
2016	144.68	155.46	178.75	186.33	194.16	222.57	239.10
2017	137.58	150.05	174.79	183.12	191.52	222.59	241.26
2018	131.67	143.59	169.66	178.79	188.16	221.13	242.11
2019	124.28	137.14	164.83	174.36	184.41	219.76	244.16

Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	135.95	138.40	142.75	144.11	145.46	149.94	152.46
2011	149.03	153.76	162.89	165.65	168.46	178.27	183.60
2012	169.15	175.61	188.35	192.31	196.43	210.10	217.64
2013	167.61	174.65	189.71	194.27	199.10	214.87	223.37
2014	158.12	165.57	181.44	186.24	191.33	208.59	217.88
2015	158.21	167.09	185.21	190.71	196.45	216.87	227.68
2016	155.82	165.33	185.66	191.96	198.72	220.90	234.04
2017	149.87	160.84	182.82	189.61	196.84	221.94	236.49
2018	144.31	155.46	178.94	186.31	194.48	221.03	237.30
2019	138.15	150.23	174.98	183.01	191.53	220.30	238.96

Tables A5.36-A5.40 Simulated Indexed and Non-Indexed Debt Ratios, Case b, k=150bps

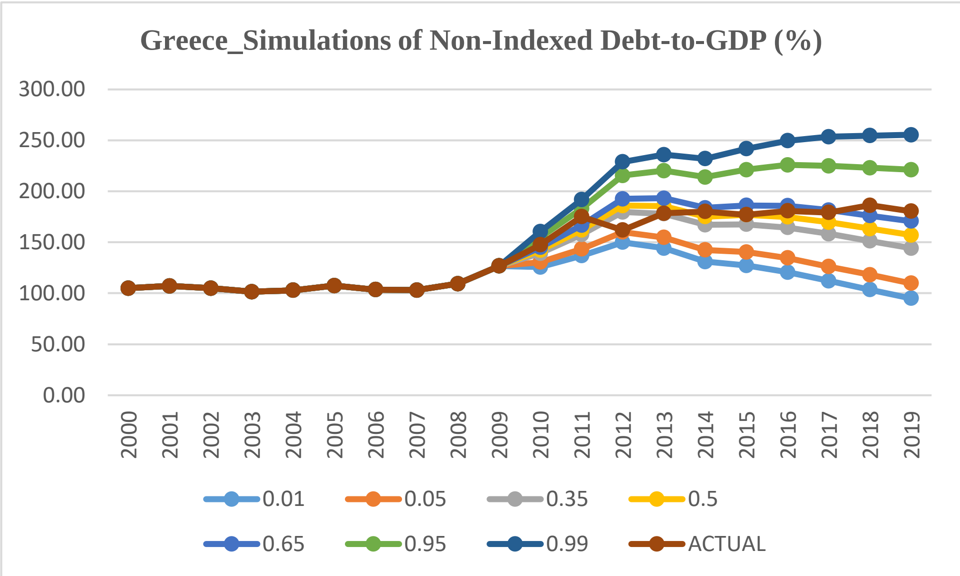

Figure A5.15: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=150bps

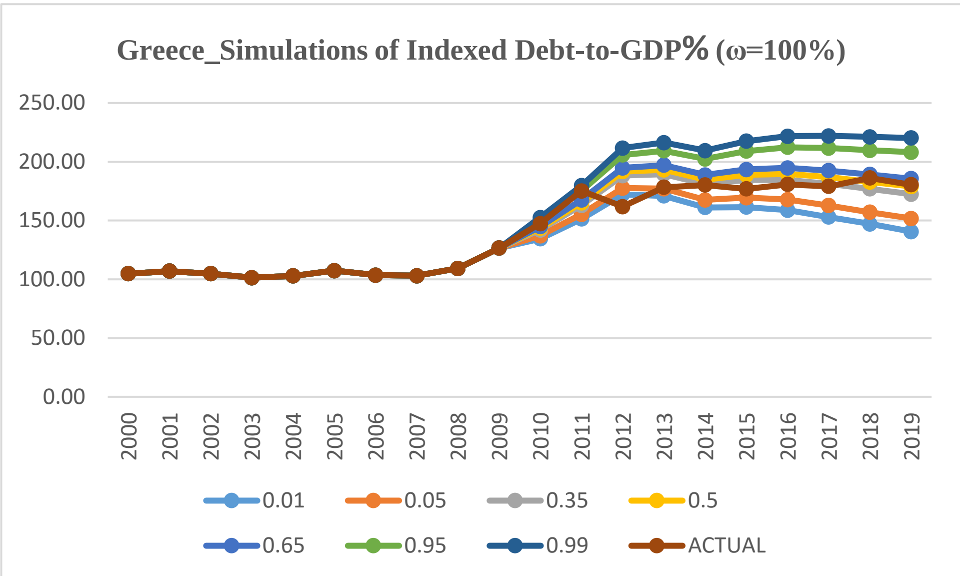

Figure A5.16: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=150bpsv

k=200bps

	Greece_Simulations of Non-Indexed Debt-to-GDP (%)								Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%							Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99		0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	125.62	130.57	139.21	142.13	144.94	154.78	160.38	2010	135.81	138.48	143.30	144.79	146.25	151.26	154.10	147.50
2011	136.76	143.47	157.58	161.98	166.58	183.00	191.80	2011	154.34	158.40	166.13	168.39	170.77	178.76	183.16	175.20
2012	149.97	160.07	179.62	185.99	192.61	215.50	228.88	2012	177.42	182.94	193.90	197.33	200.60	211.83	217.76	161.90
2013	144.12	154.71	177.96	185.40	193.17	220.25	235.95	2013	178.36	184.66	197.45	201.26	205.33	218.07	225.23	178.40
2014	131.08	142.53	167.04	175.18	183.71	213.88	231.95	2014	170.37	177.21	191.05	195.04	199.31	213.40	220.89	180.20
2015	127.20	140.43	167.61	176.93	186.05	221.12	241.72	2015	173.01	181.33	197.35	201.92	206.80	223.30	232.18	177.00
2016	120.70	134.69	164.46	174.75	185.81	225.85	249.50	2016	172.98	182.37	200.42	205.99	211.38	230.24	240.47	180.80
2017	112.24	126.15	158.31	169.60	181.55	224.97	253.41	2017	169.58	180.24	200.09	206.14	212.37	233.24	244.77	179.20
2018	103.49	118.18	151.32	163.30	176.05	222.95	254.61	2018	166.15	177.19	198.88	205.37	212.47	235.20	248.22	186.20
2019	95.07	109.86	144.23	157.04	170.80	221.20	255.32	2019	161.78	174.20	197.50	204.72	212.32	237.76	251.56	180.50

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%						
	0.01	0.05	0.35	0.50	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	136.59	139.04	143.41	144.78	146.14	150.64	153.18
2011	141.38	147.41	159.75	163.60	167.54	181.86	189.22
2012	157.24	165.94	183.27	188.82	194.56	214.21	225.84
2013	153.20	162.62	182.94	189.41	196.10	219.45	232.79
2014	141.69	151.59	173.24	180.18	187.46	213.30	228.74
2015	139.44	151.20	175.21	183.16	191.09	220.99	238.89
2016	134.57	146.95	173.69	182.66	192.04	226.06	247.06
2017	126.87	140.50	169.05	178.86	188.91	226.47	250.10
2018	119.78	133.70	163.33	174.11	185.06	224.87	251.57
2019	112.79	126.40	157.84	169.06	180.98	223.73	253.34

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	136.59	139.04	143.41	144.78	146.14	150.64	153.18
2011	145.76	151.38	161.90	165.23	168.57	180.59	186.98
2012	164.34	171.80	186.85	191.60	196.59	213.10	222.87
2013	162.13	170.14	187.82	193.35	199.18	218.68	229.50
2014	151.69	160.39	179.34	185.13	191.27	212.66	225.29
2015	151.51	161.65	182.69	189.36	196.32	221.46	236.00
2016	148.27	159.27	182.75	190.45	198.38	227.12	243.64
2017	141.74	154.46	179.60	188.03	196.56	228.02	247.13
2018	136.36	148.62	175.34	184.53	194.09	227.65	249.14
2019	129.73	142.90	171.33	181.00	191.31	227.25	252.29

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	136.59	139.04	143.41	144.78	146.14	150.64	153.18
2011	150.12	154.88	164.06	166.84	169.68	179.53	184.89
2012	171.07	177.63	190.44	194.43	198.59	212.36	219.95
2013	170.37	177.49	192.73	197.32	202.22	218.17	226.72
2014	161.61	169.11	185.26	190.11	195.30	212.84	222.18
2015	162.56	171.63	190.08	195.68	201.51	222.33	233.28
2016	161.25	171.01	191.73	198.17	205.07	227.75	241.05
2017	156.27	167.51	190.08	197.04	204.43	230.22	245.24
2018	151.61	163.17	187.37	194.97	203.40	230.80	247.58
2019	146.36	158.89	184.59	192.99	201.86	231.81	251.13

Tables A5.41-A5.45 Simulated Indexed and Non-Indexed Debt Ratios, Case b, k=200bp

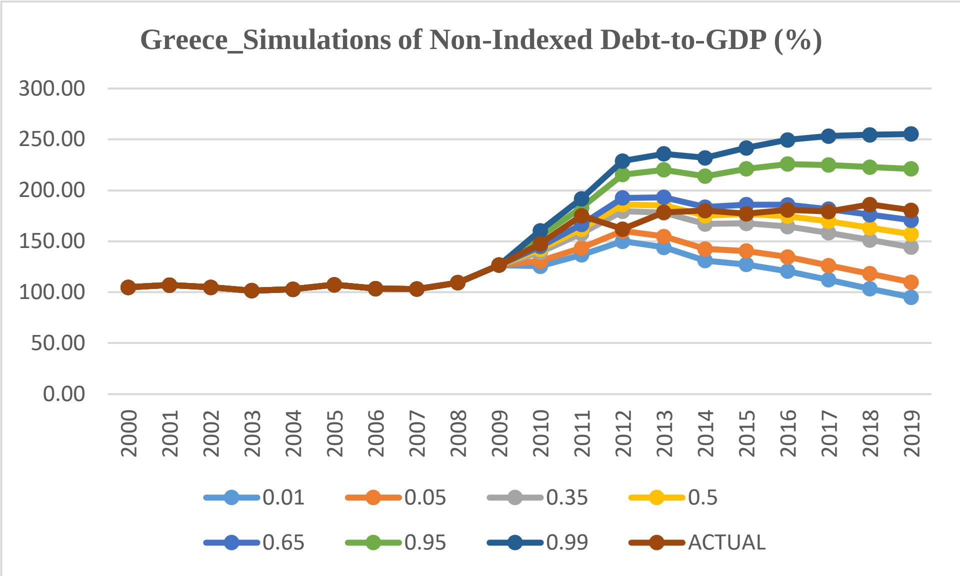

Figure A5.17: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=200bps

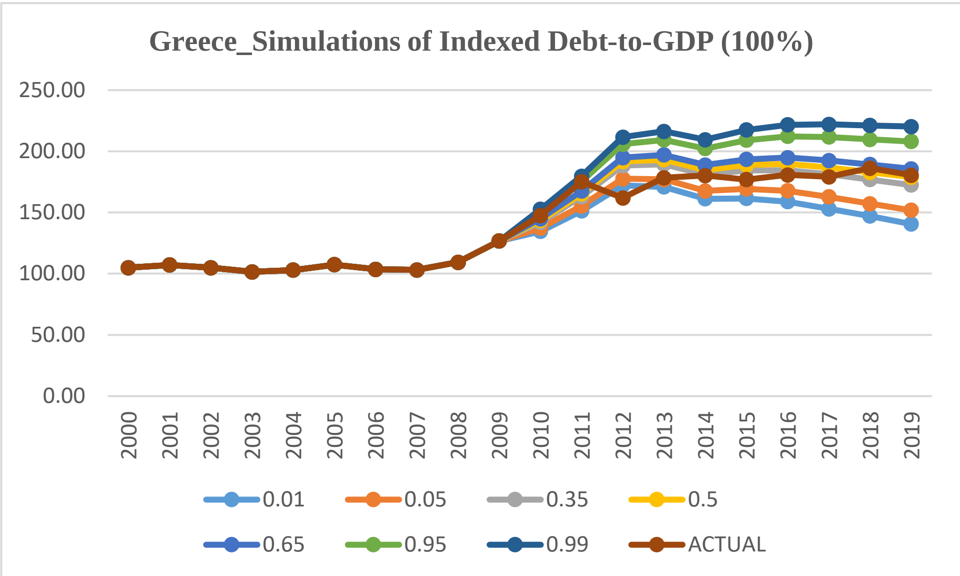

Figure A5.18: Greece_Simulations of Indexed Debt-to-GDP (%), Case b, k=200bps

k=250bps

Greece_Simulations of Non-Indexed Debt-to-GDP (%)							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	125.62	130.57	139.21	142.13	144.94	154.78	160.38
2011	136.76	143.47	157.58	161.98	166.58	183.00	191.80
2012	149.97	160.07	179.62	185.99	192.61	215.50	228.88
2013	144.12	154.71	177.96	185.40	193.17	220.25	235.95
2014	131.08	142.53	167.04	175.18	183.71	213.88	231.95
2015	127.20	140.43	167.61	176.93	186.05	221.12	241.72
2016	120.70	134.69	164.46	174.75	185.81	225.85	249.50
2017	112.24	126.15	158.31	169.60	181.55	224.97	253.41
2018	103.49	118.18	151.32	163.30	176.05	222.95	254.61
2019	95.07	109.86	144.23	157.04	170.80	221.20	255.32

Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%								Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	136.44	139.14	143.97	145.47	146.93	151.97	154.82	147.50
2011	155.83	159.92	167.70	170.00	172.39	180.45	184.92	175.20
2012	179.99	185.66	196.75	200.21	203.51	214.88	220.90	161.90
2013	182.15	188.52	201.52	205.39	209.56	222.54	229.77	178.40
2014	175.13	182.11	196.22	200.31	204.71	219.11	226.84	180.20
2015	179.10	187.52	204.02	208.74	213.75	230.76	239.75	177.00
2016	180.41	190.07	208.80	214.55	220.18	239.69	250.35	180.80
2017	178.50	189.52	210.14	216.50	222.97	244.76	256.73	179.20
2018	176.34	188.04	210.78	217.57	225.00	249.14	262.84	186.20
2019	173.70	186.57	211.31	218.97	226.98	254.03	268.67	180.50

Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	136.59	139.04	143.41	144.78	146.14	150.64	153.18
2011	141.74	147.78	160.14	164.00	167.95	182.28	189.65
2012	157.89	166.60	183.97	189.54	195.29	214.97	226.62
2013	154.14	163.58	183.96	190.44	197.16	220.57	233.92
2014	142.87	152.81	174.54	181.49	188.80	214.74	230.21
2015	140.96	152.78	176.87	184.86	192.84	222.85	240.80
2016	136.43	148.86	175.76	184.81	194.24	228.49	249.48
2017	129.14	142.84	171.58	181.46	191.55	229.38	253.05
2018	122.46	136.43	166.27	177.15	188.24	228.31	255.08
2019	115.69	129.57	161.31	172.64	184.62	227.80	257.69

Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	136.59	139.04	143.41	144.78	146.14	150.64	153.18
2011	146.49	152.13	162.69	166.03	169.37	181.43	187.85
2012	165.63	173.14	188.25	193.04	198.04	214.63	224.44
2013	164.00	172.06	189.85	195.42	201.29	220.94	231.83
2014	154.05	162.79	181.93	187.77	193.98	215.50	228.27
2015	154.51	164.77	186.06	192.78	199.79	225.20	239.70
2016	152.04	163.18	186.94	194.72	202.76	231.79	248.53
2017	146.17	159.07	184.64	193.24	201.86	233.78	253.19
2018	141.43	154.08	181.28	190.67	200.35	234.50	256.40
2019	135.65	149.11	178.26	188.09	198.68	235.26	260.80

Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%							
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	136.59	139.04	143.41	144.78	146.14	150.64	153.18
2011	151.22	156.00	165.24	168.04	170.89	180.80	186.17
2012	173.02	179.62	192.56	196.58	200.77	214.63	222.28
2013	173.18	180.39	195.77	200.41	205.40	221.50	230.13
2014	165.17	172.76	189.15	194.07	199.35	217.14	226.58
2015	167.06	176.28	195.07	200.75	206.75	227.88	239.07
2016	166.75	176.82	197.97	204.58	211.64	234.85	248.57
2017	162.88	174.54	197.65	204.82	212.37	238.92	254.27
2018	159.42	171.27	196.28	204.14	212.80	241.15	258.47
2019	155.18	168.15	194.88	203.64	212.92	244.22	263.97

Tables A5.46-A5.50 Simulated Indexed and Non-Indexed Debt Ratios, Case b, k=250bps

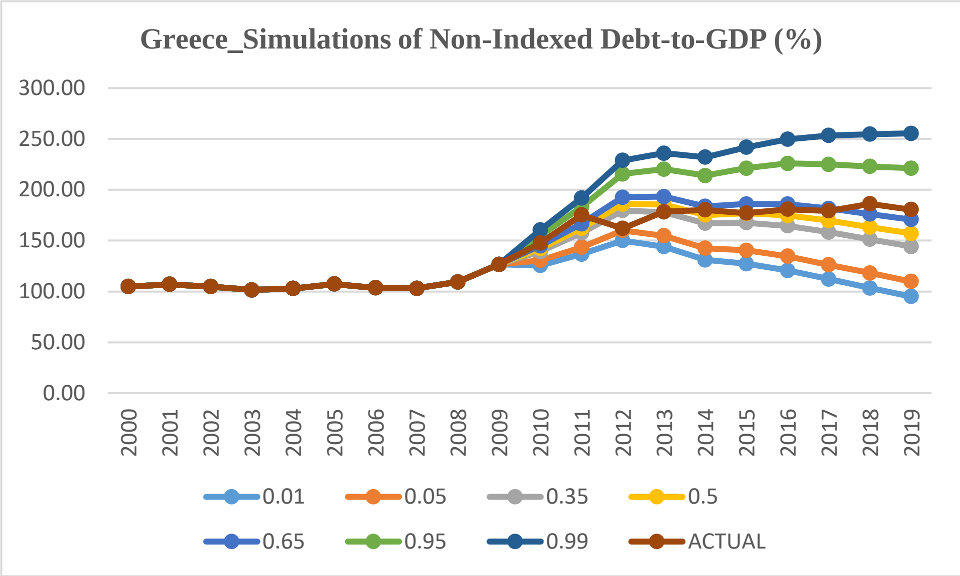

Figure A5.19: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=250bps

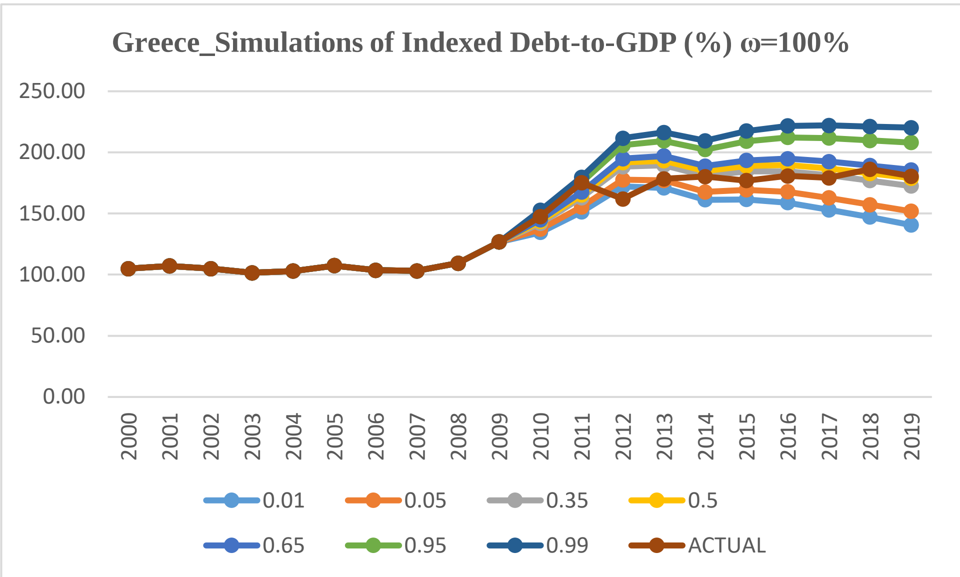

Figure A5.20: Greece_Simulations of Indexed Debt-to-GDP (%), Case b, k=250bps

k=300bps

	Greece_Simulations of Non-Indexed Debt-to-GDP (%)								Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%							Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99		0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	125.62	130.57	139.21	142.13	144.94	154.78	160.38	2010	137.08	139.79	144.63	146.14	147.62	152.67	155.53	147.50
2011	136.76	143.47	157.58	161.98	166.58	183.00	191.80	2011	157.31	161.44	169.30	171.61	174.02	182.14	186.69	175.20
2012	149.97	160.07	179.62	185.99	192.61	215.50	228.88	2012	182.64	188.39	199.62	203.09	206.44	217.96	224.12	161.90
2013	144.12	154.71	177.96	185.40	193.17	220.25	235.95	2013	185.97	192.44	205.65	209.58	213.84	227.12	234.37	178.40
2014	131.08	142.53	167.04	175.18	183.71	213.88	231.95	2014	180.00	187.13	201.54	205.72	210.24	225.01	232.87	180.20
2015	127.20	140.43	167.61	176.93	186.05	221.12	241.72	2015	185.29	194.01	210.90	215.76	220.91	238.41	247.65	177.00
2016	120.70	134.69	164.46	174.75	185.81	225.85	249.50	2016	188.11	198.08	217.52	223.40	229.24	249.48	260.59	180.80
2017	112.24	126.15	158.31	169.60	181.55	224.97	253.41	2017	187.59	199.17	220.71	227.37	234.12	256.87	269.35	179.20
2018	103.49	118.18	151.32	163.30	176.05	222.95	254.61	2018	187.20	199.36	223.30	230.51	238.30	263.82	278.25	186.20
2019	95.07	109.86	144.23	157.04	170.80	221.20	255.32	2019	186.31	199.71	225.95	234.11	242.72	271.58	287.32	180.50

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	137.85	140.32	144.74	146.12	147.50	152.05	154.63
2011	142.11	148.15	160.54	164.40	168.35	182.71	190.08
2012	158.55	167.28	184.68	190.26	196.02	215.75	227.41
2013	155.09	164.55	185.01	191.50	198.22	221.71	235.07
2014	144.07	154.05	175.86	182.83	190.17	216.19	231.72
2015	142.51	154.38	178.60	186.61	194.62	224.76	242.80
2016	138.37	150.89	177.94	187.05	196.51	230.98	252.01
2017	131.46	145.25	174.21	184.18	194.31	232.38	256.16
2018	125.23	139.33	169.38	180.36	191.56	231.94	258.80
2019	118.86	132.89	164.93	176.44	188.50	232.10	262.21

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	137.85	140.32	144.74	146.12	147.50	152.05	154.63
2011	147.23	152.89	163.48	166.83	170.18	182.27	188.72
2012	166.93	174.52	189.68	194.48	199.51	216.18	226.03
2013	165.90	174.00	191.92	197.52	203.43	223.23	234.19
2014	156.49	165.25	184.56	190.47	196.73	218.42	231.33
2015	157.61	168.01	189.49	196.32	203.37	229.03	243.57
2016	156.00	167.22	191.31	199.15	207.32	236.63	253.66
2017	150.90	163.88	189.94	198.60	207.41	239.90	259.32
2018	146.68	159.78	187.58	197.15	207.04	241.78	264.15
2019	141.93	155.65	185.63	195.70	206.47	243.92	269.93

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	137.85	140.32	144.74	146.12	147.50	152.05	154.63
2011	152.32	157.15	166.42	169.25	172.11	182.08	187.47
2012	175.04	181.63	194.69	198.74	202.98	216.93	224.64
2013	176.06	183.32	198.87	203.57	208.60	224.90	233.64
2014	168.77	176.51	193.12	198.11	203.50	221.57	231.08
2015	171.66	181.07	200.23	206.02	212.12	233.66	244.97
2016	172.49	182.87	204.45	211.29	218.45	242.19	256.20
2017	169.80	181.76	205.55	212.92	220.67	248.00	263.73
2018	167.63	179.85	205.66	213.80	222.78	252.16	270.05
2019	164.38	178.01	206.00	214.96	224.69	257.39	277.83

Tables A5.51-A5.55 Simulated Indexed and Non-Indexed Debt Ratios, Case b, k=300bps

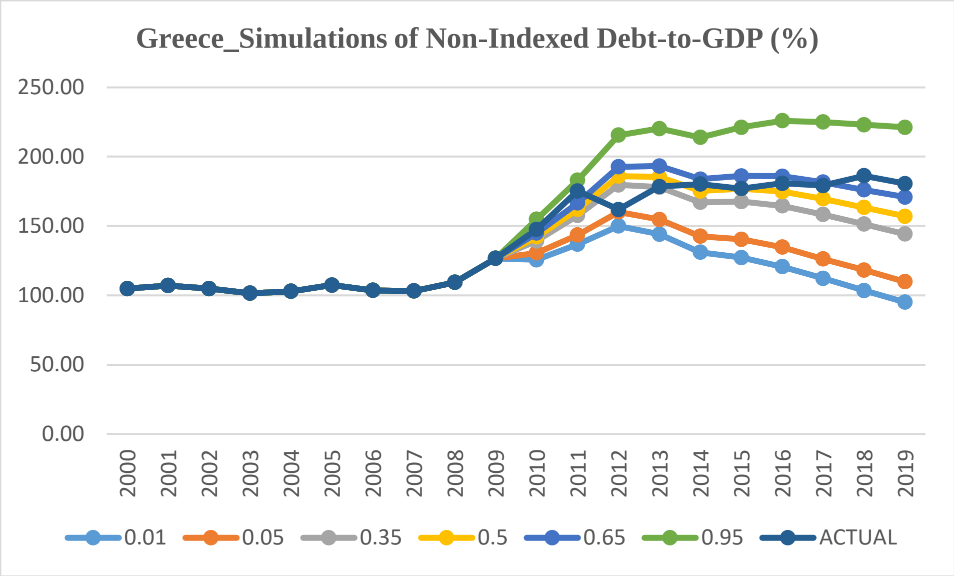

Figure A5.21: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=300bps

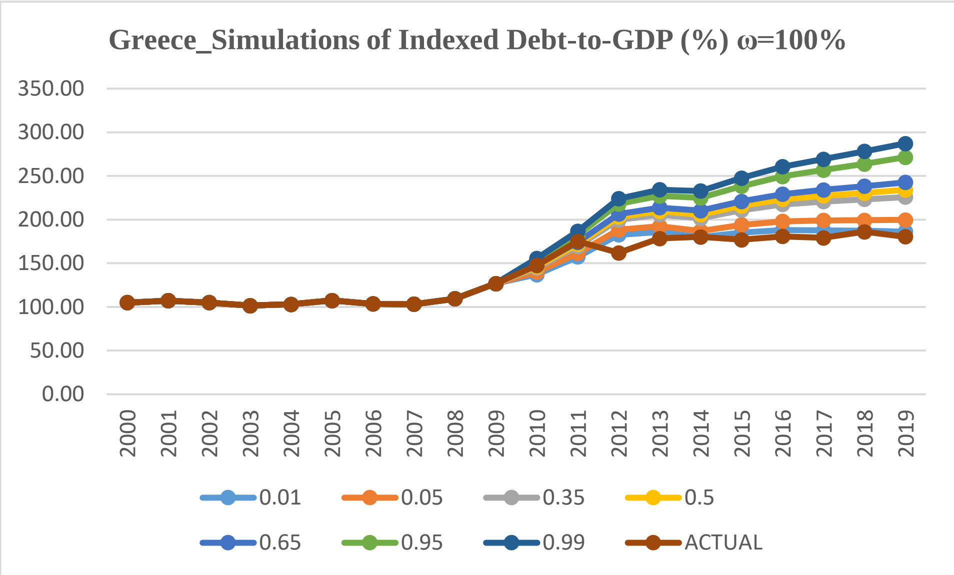

Figure A5.22: Greece_Simulations of Indexed Debt-to-GDP (%), Case b, k=300bps

k=350bps

	Greece_Simulations of Non-Indexed Debt-to-GDP (%)								Greece_Simulations of Indexed Debt-to-GDP (%) ω=100%							Actual
	0.01	0.05	0.35	0.5	0.65	0.95	0.99		0.01	0.05	0.35	0.5	0.65	0.95	0.99	
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	125.62	130.57	139.21	142.13	144.94	154.78	160.38	2010	137.71	140.43	145.29	146.81	148.29	153.37	156.25	147.50
2011	136.76	143.47	157.58	161.98	166.58	183.00	191.80	2011	158.78	162.97	170.89	173.21	175.65	183.84	188.43	175.20
2012	149.97	160.07	179.62	185.99	192.61	215.50	228.88	2012	185.34	191.13	202.50	206.01	209.40	221.08	227.37	161.90
2013	144.12	154.71	177.96	185.40	193.17	220.25	235.95	2013	189.82	196.40	209.84	213.85	218.19	231.70	239.03	178.40
2014	131.08	142.53	167.04	175.18	183.71	213.88	231.95	2014	185.00	192.25	206.98	211.25	215.90	231.01	239.08	180.20
2015	127.20	140.43	167.61	176.93	186.05	221.12	241.72	2015	191.70	200.67	217.94	223.00	228.29	246.35	255.87	177.00
2016	120.70	134.69	164.46	174.75	185.81	225.85	249.50	2016	196.18	206.43	226.54	232.59	238.69	259.73	271.29	180.80
2017	112.24	126.15	158.31	169.60	181.55	224.97	253.41	2017	197.22	209.30	231.77	238.68	245.79	269.55	282.65	179.20
2018	103.49	118.18	151.32	163.30	176.05	222.95	254.61	2018	198.78	211.46	236.51	244.18	252.35	279.28	294.63	186.20
2019	95.07	109.86	144.23	157.04	170.80	221.20	255.32	2019	199.52	213.71	241.65	250.37	259.55	290.53	307.11	180.50

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=25%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	138.48	140.95	145.40	146.78	148.17	152.75	155.35
2011	142.48	148.53	160.94	164.81	168.76	183.14	190.52
2012	159.22	167.96	185.39	190.99	196.77	216.52	228.22
2013	156.05	165.55	186.07	192.56	199.30	222.86	236.24
2014	145.30	155.35	177.23	184.22	191.58	217.66	233.26
2015	144.12	156.02	180.37	188.41	196.45	226.72	244.86
2016	140.38	153.07	180.20	189.37	198.86	233.53	254.64
2017	133.84	147.84	176.97	187.04	197.21	235.57	259.52
2018	128.10	142.39	172.71	183.76	195.06	235.84	262.75
2019	122.30	136.52	168.88	180.52	192.67	236.81	267.03

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=50%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	138.48	140.95	145.40	146.78	148.17	152.75	155.35
2011	147.98	153.65	164.28	167.63	171.00	183.13	189.59
2012	168.24	175.86	191.10	195.95	200.99	217.74	227.63
2013	167.84	175.98	194.03	199.66	205.61	225.52	236.58
2014	158.94	167.79	187.30	193.23	199.57	221.44	234.42
2015	160.81	171.34	193.02	199.91	207.07	233.00	247.66
2016	160.06	171.35	195.78	203.79	212.05	241.73	259.02
2017	155.67	168.98	195.41	204.26	213.25	246.30	266.01
2018	152.46	165.86	194.23	203.99	214.10	249.47	272.41
2019	148.65	162.72	193.49	203.78	214.91	253.22	279.76

	Greece_Simulations of Indexed Debt-to-GDP (%) ω=75%						
	0.01	0.05	0.35	0.5	0.65	0.95	0.99
2000	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2001	107.10	107.10	107.10	107.10	107.10	107.10	107.10
2002	104.90	104.90	104.90	104.90	104.90	104.90	104.90
2003	101.50	101.50	101.50	101.50	101.50	101.50	101.50
2004	102.90	102.90	102.90	102.90	102.90	102.90	102.90
2005	107.40	107.40	107.40	107.40	107.40	107.40	107.40
2006	103.60	103.60	103.60	103.60	103.60	103.60	103.60
2007	103.10	103.10	103.10	103.10	103.10	103.10	103.10
2008	109.40	109.40	109.40	109.40	109.40	109.40	109.40
2009	126.70	126.70	126.70	126.70	126.70	126.70	126.70
2010	138.48	140.95	145.40	146.78	148.17	152.75	155.35
2011	153.44	158.29	167.62	170.46	173.33	183.38	188.78
2012	177.06	183.66	196.85	200.92	205.21	219.26	227.03
2013	178.95	186.31	202.01	206.78	211.86	228.35	237.25
2014	172.45	180.33	197.19	202.28	207.73	226.08	235.68
2015	176.43	186.03	205.53	211.44	217.69	239.64	251.06
2016	178.49	189.11	211.20	218.21	225.53	249.82	264.27
2017	177.04	189.29	213.79	221.40	229.46	257.59	273.61
2018	176.28	188.92	215.67	224.01	233.34	263.81	282.21
2019	174.41	188.61	217.79	227.18	237.22	271.61	292.78

Tables A5.56-A5.60 Simulated Indexed and Non-Indexed Debt Ratios, Case b, k=350bps

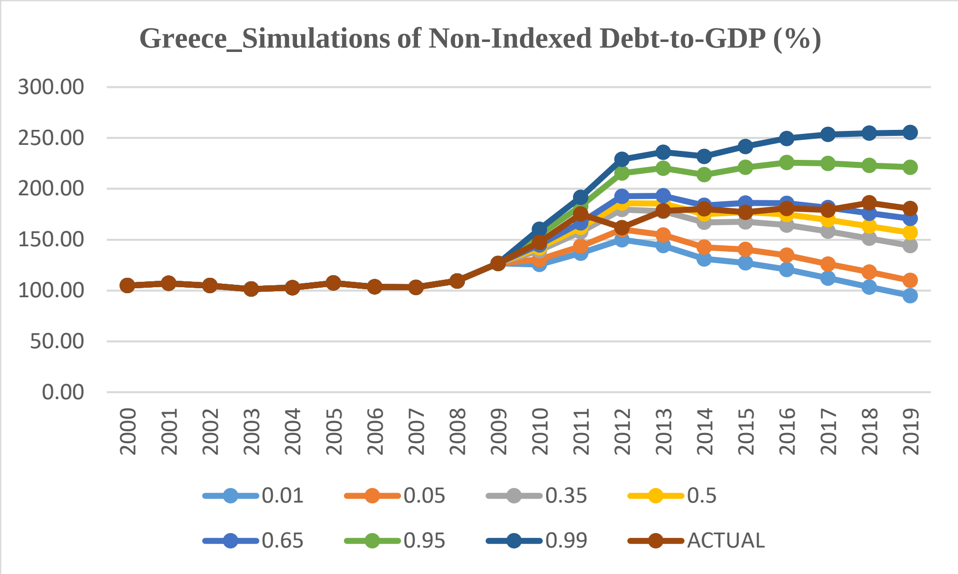

Figure A5.23: Greece_Simulations of Non-Indexed Debt-to-GDP (%), Case b, k=350bps

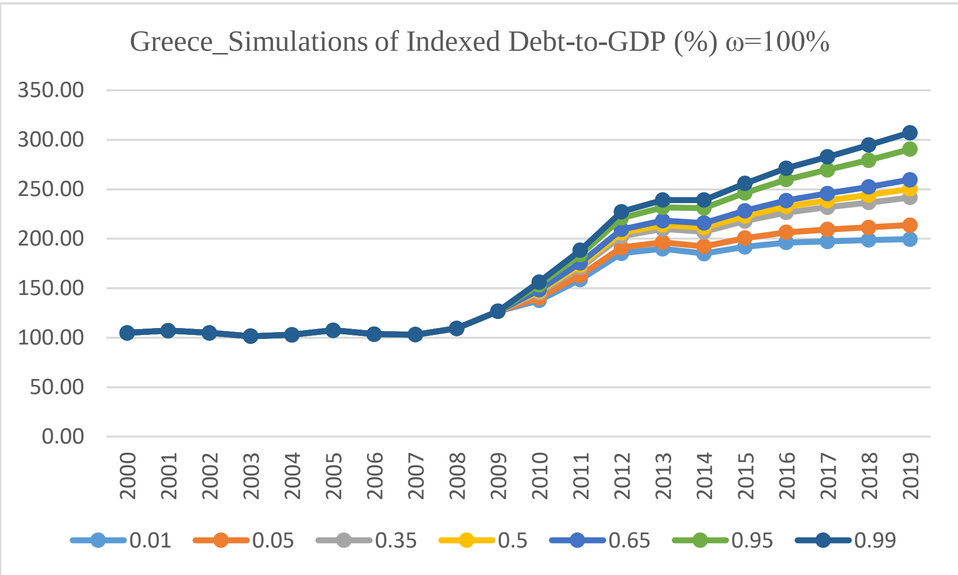

Figure A5.24: Greece_Simulations of Indexed Debt-to-GDP (%), Case b, k=350bps

Chapter 6: Conclusion

This thesis has pursued quantitative answers to highly theoretical and elusive questions about sovereign risk, market sentiment and uncertainty. The state-contingency of sovereign debt sustainability in the EMU has been examined via a *financial-markets-based perspective* for the probability of default and according to a threshold of uncertainty. Uncertainty and market-sentiment effects have been credited a central role in short-run self-fulfilling crisis dynamics, over and above economic fundamentals-both via a theoretical model and empirically. A market-based policy solution against uncertainty, namely GDP-linked bonds, has been examined. Although 'bad equilibria' in the Greek government debt emerge with uncertainty and are associated with declines in the index of economic activity, the historical counterfactual exercise in this thesis concludes that a rational policymaker would not have chosen the introduction of GDP-linked bonds for Greece in 2010.

The simple static theoretical model proposed in Chapter 3, a variant of which has long been applied to currency crises, has offered a novel portrayal of sovereign debt crises within a monetary union when sovereign debt is denominated in the domestic currency. The proposed framework-borrowed from second-generation currency crisis models-contributes to the literature on sovereign debt crises, as it provides a complementary market-based explanation for self-fulfilling debt crises, focusing solely on the *belief process formation* in financial markets. The model has explained how within an intermediate zone of multiple equilibria (and, thus, of questionable fundamentals), *uncertainty* is the force that leads to a uniquely bad outcome for sovereign risk. The effects of uncertainty relate to informational *noise* about fundamentals; to subsequent 'higher order beliefs 'and to coordination failures among market traders, which in turn, induce liquidity effects that precipitate the bad outcome; and to *sunspots.* A market-based policy solution that increases transparency and financial market confidence while contractually reducing uncertainty is called for. According to the proposed model, when fundamentals are questionable, any policies that increase uncertainty, such as the 'ambiguous stance' of Germany in the early phase of the Greek debt crisis, or the 'constructive ambiguity' of the

Greek government at the end of the Second Economic Adjustment Programme, are bound to lead to the 'bad equilibrium' for debt sustainability: *constructive ambiguity is bad.*

Chapter 4 has applied econometric techniques to the Greek sovereign spread, as a proxy of debt sustainability. A novel measure of idiosyncratic Greek debt-sustainability-related uncertainty has been provided. In line with the prescriptions of Chapter 3, time-varying coefficient methods have confirmed the presence of multiple equilibria for Greek sovereign risk. A threshold of uncertainty has been calculated based on the time-varying conditional volatility of the Greek sovereign spread, above which both fundamentals and market-sentiment indicators drive Greek sovereign risk pricing behavior and outcomes. Model-based estimates of the months during which Greek sovereign risk is in the uncertainty regime correspond to periods associated with crisis outcomes in the narrative of the Greek debt crisis. As such, the proposed methodology and critical threshold of uncertainty could be applied by policymakers to distinguish whether the Greek government debt has entered the crisis regime based on the level of uncertainty in the Greek economy.

Uncertainty in the Greek sovereign spread is driven by a short-term market-sentiment component, particularly during major crises (PSI, 2015), which operates through liquidity conditions in the government bond market. Model results have shown that major crisis points for Greece display a self-fulfilling *liquidity component*. At the intermediate zone of fundamentals for debt sustainability, crisis instances are associated with liquidity dynamics arising due to uncertainty. In the 'uncertainty' regime, Greek sovereign risk increases through adverse market liquidity effects, through decreases in the Economic Sentiment Index (a proxy for economic activity), through increased spillover effects in the periphery of the Eurozone and through increases in market uncertainty. During crisis states, the impact of ECB unconventional operations has worked to the detriment of Greek sovereign risk relative to Germany, a finding attributed to the long-standing non-eligibility of Greek securities in Quantitative Easing: QE lowered market risk across core and periphery countries, thereby rendering excluded Greek bonds relatively riskier, even though systemic risk may have been reduced. As ECB actions affect sovereign risk pricing behavior during bad outcomes, the estimated threshold model could be used as an argument in favor of extending the current Pandemic Emergency Purchase

Programme (PEPP) for Greece, if necessary, to retroactively undo the competitive disadvantage introduced in the Greek sovereign risk market during the crisis period.

At first sight, the finding that market-sentiment effects work over and above fundamentals in determining sovereign risk pricing outcomes may lead to the impression that forecasts of sovereign spreads resemble crystal-ball readings. However, the strong *ex-post* fit of the proposed methods and model in Chapter 4 to actual data up to the end of 2020 points to the usefulness of models to policymakers. Nevertheless, the nature of market sentiment and uncertainty and the instantaneous short-lived impact of certain events, as evidenced in this thesis, should work as a word of caution when applying models for *ex-ante* forecasts. The results of the event study analysis in Chapter 4 have shown that key events have significantly affected Greek sovereign spreads. The revelation of the true size of the Greek budget deficit in 2009, the rating downgrade of the Greek government in anticipation of the PSI in 2012, the election of a leftist government in 2015, the announcement of the Greek referendum in 2015, and the announcement of the first general COVID-induced lockdown in 2020, all proved to be statistically significant events for Greek sovereign risk.

Noting the state-contingency in debt outcomes, the state-contingent contractual solution of GDP-linked bonds was probed into as a solution to ward against the impact of both market sentiment and adverse economic-growth outcomes on sovereign risk. In the application of GDP-linked bonds to Greece, the period immediately prior to the contracting of the first official bailout loan in 2010 was considered to provide a historical counterfactual both from the standpoint of the policymaker in 2010 and with the benefit of hindisight. Probabilistic fan-charts of the simulated possible future debt-to-GDP ratio paths suggest that despi*te the PSI, reforms and bailout loans in the interim, the actual debt-to-GDP ratio at the end of the Third Economic Adjustment Programme in 2018 ended at higher levels than those foreseen for worst 1 percent of possible probability distributions for the Greek public debt in 2010.*

Sensitivity analysis of simulated GDP-indexed, non-indexed and partially indexed debt under two distinct baseline scenarios in Chapter 5 point to the conclusion that *from the standpoint of the policymaker in 2010, the adoption of GDP-linked bonds would not have made sense for the* *policymaker in 2010, ceteris paribus.* In line with the literature, Chapter 5 concludes that *Greece is not a good candidate for the introduction of GDP-linked bonds.* Therefore, rather than suggesting the adoption of GDP-indexation for the Greek government, this thesis calls for the examination of GDP-linked bonds by other indebted advanced economies (yet not "catastrophically" so, as suggested by Blanchard et al. (2016a)), to remove any first-mover novelty premia associated with GDP-linked bonds.

In the long run, factors beyond the scope of this thesis, such as the maintenance of a low-interest-rate global environment or structural reforms that enhance the potential output of Greece will take the driver's seat in the dynamics of the Greek government debt, though some form of uncertainty will always be present as a co-driver. The theoretical model has prescribed a role for transparency and for credible government commitment to debt-reducing policies. Credibility and clarity on macroeconomic and fical policies is key to the reduction in the sources of information asymmetries, which in turn can limit the impact of higher-order-beliefs and short-selling behavior among traders in government bonds.

In the short-run, the following additional policies could improve debt sustainability and abate the effect of the market-based liquidity crisis dynamics presented in this thesis: ad hoc public debt management operations such as the build-up of a substantial cash buffer in an escrow account dedicated to debt repayment; prudent fiscal policy in the context of the European Semester and Post-Programme Enhanced Surveillance; further agreements on low interest rates and longer maturities in official sector loans. Should other advanced indebted economies adopt GDP-linked bonds and reduce the global novelty premium associated with the introduction of such an instrument, future Greek government debt dynamics may stand to benefit from this state-contingent measure. Beyond GDP-linked bonds, short-run liquidity credit lines could be made *automatically* available, or debt management operations, particularly in the form of maturity extensions, could be devised. The *statutory* provision of such liquidity-supporting measures would serve to appease both any future liquidity crises but also the expectations of a liquidity shortfall that may generate it (at least partially). The finding that adverse regimes are associated with financial-market effects over and beyond fundamentals (in Chapter 4), could be used as an additional argument in support of the fairness of *unconditional* automatic statutory access to short-term liquidity assistance for Greece.

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