BANK OF CANADA
BANQUE DU CANADA

Working Paper/Document de travail
2013-27

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Bank of Canada Working Paper 2013-27

August 2013

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ISSN 1701-9397

Acknowledgements

We thank Craig Burnside and Malik Shukayev for insightful discussions, and participants at the 2012 JME-SNB-SCG conference for many useful comments.

Abstract

The authors study the implications of fiscal policy behaviour for sovereign risk in a framework that determines a country's fiscal limit, the point at which, for economic or political reasons, taxes and spending can no longer adjust to stabilize debt. A real business cycle model maps the economic environment—expected fiscal policy, the distribution of exogenous disturbances and private agents' behaviour—into a distribution for the maximum sustainable debt-to-GDP ratio. Default is possible at any point on this fiscal limit distribution. Calibrations of the model to Greek and Swedish data illustrate how the framework can be used to study actual fiscal reforms undertaken by developed economies facing sovereign risk pressures.

JEL classification: E62, E65, H63
Bank classification: Fiscal policy; Economic models

Résumé

Les auteurs étudient les implications de la politique budgétaire pour le risque souverain au moyen d'un modèle qui détermine la limite budgétaire d'un pays, c'est-à-dire le point à partir duquel il n'est plus possible, pour des raisons économiques ou politiques, de stabiliser la dette publique en rajustant les impôts et les dépenses. Un modèle de cycles réels transpose le contexte économique – politique budgétaire attendue, distribution des chocs exogènes et comportement des agents privés – en une distribution de ratios dette/PIB viables maximaux. Une défaillance est possible en tout point de cette distribution. Le modèle est étalonné en fonction des données relatives à la Grèce et à la Suède afin d'illustrer comment il peut servir à étudier des réformes budgétaires réellement entreprises dans des pays développés dont la prime de risque souverain subit des pressions à la hausse.

Classification JEL : E62, E65, H63
Classification de la Banque : Politique budgétaire; Modèles économiques

1 Introduction

In the recent recession and financial crisis, several advanced economies ran into serious sovereign risk problems. What distinguishes countries with and without sovereign risk troubles today? At the top of the list are the past and prospective fiscal policies they pursue. This is why troubled countries, and even some less troubled nations, are adopting drastic fiscal austerity measures intended to deliver long-lasting fiscal consolidation.

Understanding how fiscal policies determine a country's sovereign risk requires explicit modelling of fiscal behaviour. Every economy faces a fiscal limit, the point at which, for economic or political reasons, taxes and spending can no longer adjust to stabilize debt. In the absence of a shift in monetary policy to a regime that stabilizes debt, at the fiscal limit a government has no choice but to default on its outstanding debt obligations. That limit depends on the entire economic and political environment: expected fiscal policy behaviour, the distribution of exogenous disturbances, and private agents' behaviour. In most cases, a country's fiscal limit will not be revealed by historical policy choices. Rather, the fiscal limit answers the following counterfactual question: After accounting for country-specific economic and political constraints, what is the maximum expected present value of primary surpluses?[1]

This paper answers that question with a simple real business cycle (RBC) model that maps economic environments, especially fiscal policy regimes, into conditional and unconditional distributions of the fiscal limit. A conditional distribution reflects the notion that bondholders' expectations of repayment depend on the current state of the economy, including shock realizations and the policy regime. For some analyses, particularly of long-run fiscal reforms, the unconditional fiscal limit distribution is more appropriate.

By mapping policy behaviour into fiscal limit distributions, this paper provides a tool to examine the efficacy of fiscal reforms pursued by countries that are under sovereign risk pressures. Both the nature and the credibility of proposed reforms matter for their likely success in reducing sovereign risk. Credible shifts to a stabilizing regime can insure against risk premia even when fundamentals are poor. An identical shift that is less than credible does little to bring down debt-service costs. If investors do not have full information about fiscal policy, however, even reforms that are intended to be credible may not produce an immediate drop in sovereign risk premia, since it takes time for investors to become convinced that the reforms will last.

Our framework builds on Bi (2012), a closed-economy RBC model with fixed capital and

[1] Our treatment of the fiscal limit as country-specific contrasts with the more typical analysis, which International Monetary Fund (2012, chapter 3) exemplifies, that extrapolates from past policy behaviour to draw inferences about sovereign debt sustainability.

a proportional tax levied against labour income. For given government purchase and transfer processes, an economic fiscal limit arises from the peak of the dynamic Laffer curve. Because that peak depends on the state of the economy, the joint distribution of the fundamental disturbances and private agents' optimal decision rules induces a distribution for the maximum sustainable government debt that equals the expected discounted present value of maximum primary surpluses. In a stochastic environment, "maximum debt" is a distribution, not a point.

Government transfers in the model may be stationary or grow as a share of GDP, depending on the prevailing regime. Growing transfers reflect either the rapid growth in the government's share of the economy that has occurred in some countries, or demographic shifts and the old-age benefits that governments in advanced economies have promised their citizens. Stationary transfers represent a reform regime. Transition probabilities between the two regimes reflect the likelihood and the persistence of reforms. Non-stationary transfers have several effects. First, they provide a rationale for high and rising debt and tax rates, which push the economy close to its fiscal limit. Second, the distribution of the fiscal limit, conditional on residing in the non-stationary transfer regime, has a fat tail, which carries interesting asset-pricing implications. Finally, even if the prevailing transfer regime is stationary, if agents do not regard the regime as permanent, then a higher probability of returning to the non-stationary regime shifts the fiscal limit and makes debt risky.

We do not model default as a strategic decision made by an optimizing sovereign. Instead, we appeal to political frictions that make default decisions intrinsically uncertain. The distribution of the fiscal limit reports the probability that a particular debt level can be supported by taxing income at the peak of the Laffer curve. The maximum sustainable debt levels in the upper tail of the distribution are obtained only if the economy receives a run of positive shocks. Given the lower probability of receiving such positive shocks, default becomes more likely if current debt is in the upper tail. Analogously, even if the economy receives a run of negative shocks, debt levels in the lower tail can be supported; consequently, default is less likely. Default is possible at any point on the distribution. Randomness inherent in the politically determined default decision is modelled as a random draw of the "effective fiscal limit" from its model-based distribution. Default occurs when the current level of debt exceeds the effective limit; otherwise, debt obligations are fully honoured.

Households base their expectations of default on the model-determined fiscal limit distribution. If the transfer regime is a latent state, households are uncertain about the conditional fiscal limit distribution, and must make a probabilistic inference about the prevailing regime. Households update their beliefs about the transfer regime only gradually. This lack of com-

plete information can generate risk-premium paths that are similar to those observed in euro-area countries: even after a reform that moves policy to the stationary transfer regime, risk premia can continue to rise until agents are convinced the reform is credible.

In section 4, we calibrate the model to Greek data to examine a variety of policy scenarios motivated by fiscal developments in Greece. Those developments include an increase in transfers as a share of GDP since 1970 of about 13 percentage points, along with a seven-fold increase in the government debt-to-GDP ratio. On the heels of steady growth in transfers, low productivity can generate large risk premia. Policy experiments exploit the conditional fiscal limit distributions to focus on short-run matters.

Sweden in the 1990s is a case study of largely credible long-run fiscal reforms that dramatically shifted the country's unconditional fiscal limit distribution and reduced the riskiness of its sovereign debt. When calibrated to Swedish data, the model predicts pre-crisis risk premia arising at debt levels like those that Sweden experienced in the 1990s. After the fiscal reforms, Sweden's fiscal limit shifted out substantially, allowing debt to be risk free even at debt-to-GDP ratios higher than those observed during Sweden's crisis.

2 A Survey of the Literature

We selectively survey the existing work to place our proposed framework in context.[2] An important branch of the literature builds on Eaton and Gersovitz (1981), Aguiar and Gopinath (2006), and Arellano (2008) to model sovereign defaults as strategic decisions made by welfare-maximizing governments in response to negative productivity shocks. Sovereign default risk helps standard RBC models reproduce key business cycle facts in emerging economies, particularly countercylical interest rates and net exports, and volatile consumption. By modelling default as an optimal response to exogenous shocks, however, the strategic default literature is largely silent about the policy behaviour that led the country into a sovereign debt crisis in the first place and also about the policy reforms that might resolve the crisis.[3] These are the issues at the heart of our paper.

Another line of work follows Bohn's (1998) reduced-form regressions of surpluses on debt to infer fiscal policy behaviour. Ghosh, Kim, Mendoza, Ostry, and Qureshi (2011) estimate the responses of primary surpluses to debt levels for 23 advanced economies to argue that the responses are weaker at higher levels of debt, a phenomenon the authors dub "fiscal fatigue." Under the assumption that the government always follows its historically estimated

[2]More complete surveys appear in Eaton and Fernandez (1995), Hatchondo, Martinez, and Sapriza (2007), Hatchondo and Martinez (2010), and Stähler (2011).

[3]Cuadra and Sapriza (2008) is an exception to the silence about fiscal policy. That paper allows two types of governments, each embracing different preferences over public goods, that alternate in power to show that more polarized economies may face higher default rates.

surplus rule, there is a level of debt beyond which the government can no longer service its debt because fatigue sets in. The authors compute a debt limit for each country that is fully determined by the risk-free interest rate, the recovery rate, and the support of the shock to primary balances. "Fiscal space" is defined as the difference between the long-run average debt ratio and the debt limit. These calculations, however, are backward-looking, grounded in past policies that are assumed to be immutable. Changes in policy rules—such as those that European countries are now implementing—would alter the country's debt limit, destabilizing this backward measure of fiscal space.

Juessen, Linnemann, and Schabert (2011) compute a government's debt repayment capacity using a Laffer curve argument, but then impose that the actual tax rate is always constant. Whenever current debt exceeds the debt limit, default occurs in an amount necessary for equilibrium. In this setting, the risk premium is determined solely by the stochastic level of productivity, rather than by policy choices, making their setup inappropriate for the questions we wish to address.

We seek to model how a country's fiscal limit *distribution* varies systematically with the economic environment, including the specification of policy behaviour.

3 Our Approach

Following Bi (2012), we lay out a closed-economy model in which the fiscal limit, a measurement of the government's ability to service its debt, arises endogenously from the economy's dynamic Laffer curve.

3.1 Model

With linear production technology, output is determined by productivity, A_t, and labour supply, $1 - L_t$. Household consumption, c_t, and government purchases, g_t, satisfy the aggregate resource constraint

$$c_t + g_t = A_t(1 - L_t) \tag{1}$$

where the level of productivity follows an $AR(1)$ process, with A being the steady-state level of technology

$$A_t - A = \rho^A(A_{t-1} - A) + \varepsilon_t^A \qquad \varepsilon_t^A \sim \mathcal{N}(0, \sigma_A^2). \tag{2}$$

The government finances exogenous unproductive purchases and lump-sum transfers to households, z_t, by collecting tax revenue and issuing one-period bonds, b_t. Government

purchases obey

$$g_t - g = \rho^g(g_{t-1} - g) + \varepsilon_t^g \qquad \varepsilon_t^g \sim \mathcal{N}(0, \sigma_g^2) \tag{3}$$

where g represents steady-state purchases. Since 1970, government transfers to households have risen as a share of output in many developed economies. We allow transfers to follow one of two regimes: in one regime, transfers are stationary and in the other they grow exponentially. The transfer regime is indexed by rs_t^z:

$$z_t = \begin{cases} (1-\rho^z)z + \rho^z z_{t-1} + \varepsilon_t^z & \text{if } rs_t^z = 1 \\ \mu^z z_{t-1} + \varepsilon_t^z & \text{if } rs_t^z = 2 \end{cases}$$

with $\mu^z > 1$ and $\varepsilon_t^z \sim \mathcal{N}(0, \sigma_z^2)$. The transfer regime, rs_t^z, evolves according to the transition matrix

$$P^z \equiv \begin{pmatrix} p_1^z & 1-p_1^z \\ 1-p_2^z & p_2^z \end{pmatrix}. \tag{4}$$

The government adjusts the tax rate, τ_t, in response to deviations of debt from steady state, according to the rule

$$\tau_t - \tau = \gamma\Big(b_t^d - b\Big) \tag{5}$$

where b_t^d is the post-default level of debt, defined below. The tax adjustment parameter, γ, is positive. This rule captures the idea that fiscal authorities tend to increase tax rates when government debt rises. With lump-sum taxes, any $\gamma > 0$ guarantees that an equilibrium exists, while γ must be sufficiently large to ensure that debt is bounded in equilibrium. Distorting labour taxes, however, are subject to a Laffer curve that imposes an upper bound on tax revenues. When transfers can grow explosively, the feedback rule in equation (5) is not sufficient to ensure that government debt is default-free, as section 3.3 explains.

The default scheme at each period depends on an effective fiscal limit, b_t^*, which is drawn from a distribution, $\mathcal{B}_t^*$. The distribution arises endogenously from the distorting taxes, as discussed below. If the government's obligations at the beginning of period t are less than the effective fiscal limit, it repays its debt in full and no default occurs; otherwise, the government partially defaults by a fraction δ_t. This rule determines the default rate Δ_t

$$\Delta_t = \begin{cases} 0 & \text{if } b_{t-1} < b_t^* \\ \delta_t & \text{if } b_{t-1} \geq b_t^* \end{cases}$$

where $b_t^* \sim \mathcal{B}_t^*$. In the baseline calibration, we consider a fixed default rate of 0.2: whether or not the government defaults depends on the existing debt level and the effective fiscal limit; once default occurs, a fixed fraction of debt is written off. In the alternative scenario,

we also consider stochastic default rates that follow an empirical distribution, $\delta_t \sim \Omega$, where Ω is derived from sovereign debt defaults and restructures observed in emerging-market economies.

Let q_t be the price of a sovereign bond in units of consumption goods at time t. For each unit of bonds, the government promises to pay the household one unit of consumption in the next period. This bond contract is not enforceable: at time t, the government may partially default on its outstanding liabilities, b_{t-1}, by the fraction Δ_t, with post-default government liabilities defined as $b_t^d = (1-\Delta_t)b_{t-1}$. These considerations yield the government's flow budget constraint

$$\tau_t A_t(1-L_t) + b_t q_t = (1-\Delta_t)b_{t-1} + g_t + z_t. \tag{6}$$

3.2 Households With access to the sovereign bond market, a representative household chooses consumption, leisure, and bond purchases to solve

$$\max \qquad E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, L_t\right) \tag{7}$$

$$s.t. \qquad A_t(1-\tau_t)(1-L_t) + z_t - c_t = b_t q_t - (1-\Delta_t)b_{t-1} \tag{8}$$

taking prices, q_t, and policies, (τ_t, z_t, Δ_t), as given. E_t is the mathematical expectation conditional on the information available at time t, including sovereign default information. The utility function is strictly increasing and strictly concave in consumption and leisure. $\beta \in (0,1)$ is the discount factor.

The household's first-order conditions are

$$\frac{u_L(t)}{u_c(t)} = A_t(1-\tau_t) \tag{9}$$

$$q_t = \beta E_t\Big[(1-\Delta_{t+1})\frac{u_c(t+1)}{u_c(t)}\Big]. \tag{10}$$

The marginal rate of substitution between consumption and leisure equals the after-tax wage. Bond prices in equation (10) reflect the household's expectation about the probability and magnitude of sovereign default in the next period. The optimal solution to the household's maximization problem also implies the transversality condition

$$\lim_{j\to\infty} E_t \beta^{j+1} \frac{u_c(t+j+1)}{u_c(t)}(1-\Delta_{t+j+1})b_{t+j} = 0. \tag{11}$$

3.3 Distribution of Fiscal Limit Distorting taxes have important implications for how much revenue the government can collect. Consider an increase in the tax on labour

income. If the household's work effort remained unchanged, the tax base would also remain fixed and tax revenues would rise unambiguously. A higher income tax, however, reduces the after-tax return and induces households to work less. The resulting impact on revenue collections is ambiguous, but generally at low tax rates, an increase in tax rates raises revenues, while at high tax rates, tax hikes can actually reduce revenues. This phenomenon is the basis of the "Laffer curve." In this model, the Laffer curve is dynamic, as the shape of the Laffer curve depends on the state of the economy. For given levels of productivity and government purchases, (A_t, g_t), a tax rate exists that maximizes revenues. At the tax rate at the peak of the Laffer curve, denoted by $\tau^{max}(A_t, g_t)$, the government collects the maximum level of tax revenue for the given state, denoted by $T^{max}(A_t, g_t)$.

The government's ability to service its debt also depends on the size of government purchases and lump-sum transfers, which are political decisions that grow out of conflicts and compromises among parties with different ideologies [Persson and Svensson (1989) and Alesina and Tabellini (1990)]. To avoid developing a structural political economy model, we specify the processes for government purchases and transfers to capture the trends and fluctuations of government expenditures observed in the data.

The fiscal limit is the maximum level of debt that the government is able to pay back, defined as the sum of discounted expected maximum primary surpluses in all future periods. The dynamic and stochastic nature of the Laffer curve and shock processes imply that the fiscal limit is stochastic, with a probability distribution that depends on all the features of the economy, including private sector behaviours, the nature of policy behaviour, and the properties of the random disturbances in the economy.

3.3.1 Conditional Distribution We first consider the conditional, or state-dependent, distribution of fiscal limits, defined as

$$\mathcal{B}^*(A_t, g_t, rs_t^z) \sim \sum_{j=0}^{\infty} \beta^j \frac{u_c^{max}(A_{t+j}, g_{t+j})}{u_c^{max}(A_t, g_t)} \left(T^{max}(A_{t+j}, g_{t+j}) - g_{t+j} - z(rs_{t+j}^z, A_{t+j})\right). \quad (12)$$

u_c^{max} is the marginal utility of consumption when the tax rate is at the peak of the Laffer curve, τ^{max}. Given the parameters of the model and the specifications of the shock processes, a unique mapping between the peak of the dynamic Laffer curve and the exogenous state of the economy determines the state-dependent distribution of the fiscal limit. The *conditional* distribution implies that households' expectations about the government's ability to pay back its debt depend on the current state of the economy, including the transfer regime, as the notation $\mathcal{B}^*(A_t, g_t, rs_t^z)$ makes explicit.

3.3.2 Unconditional Distribution In the long run, the state of the economy today plays a less significant role in determining the government's ability to service its debt. The unconditional distribution $\mathcal{B}^*$ is no longer time-varying and is defined by

$$\mathcal{B}^* \sim E\left(\sum_{h=1}^{\infty} \beta^h \frac{u_c^{\max}(t+h)}{u_c^{\max}(t)}(T_{t+h}^{\max} - g_{t+h} - z_{t+h})\right). \tag{13}$$

3.3.3 Discussion In linearized models, where transfers are stationary, positive feedback from government debt to taxes, like the tax rule specified in equation (5), can keep sovereign debt from exploding unless the tax adjustment parameter is too small [Leeper (1991); Bohn (1998)]. This is not guaranteed, however, if the tax rate is approaching the peak of the Laffer curve or if transfers follow the Markov regime-switching process specified in section 3.1. Trabandt and Uhlig (2011) use a neoclassical growth model to show that Denmark and Sweden are already on the "slippery side" of their curves, where lower tax rates will raise revenues. Even if the average tax rate is far from the peak of the Laffer curve, which is arguably more relevant for most countries, rising transfers raise debt and by the specified tax rule, the tax rate. With regime-switching transfers, there can be prolonged periods during which rising transfers steadily raise government debt. Forward-looking agents may still be willing to purchase sovereign debt if they expect the explosive transfer regime to end. If transfers stay in that regime for too long, however, debt may rise to such a level that the government will be unable to repay its debt in full, even if it consistently follows a tax rule designed to stabilize debt. A positive probability of eventually hitting the peak of the Laffer curve in the future can spur sovereign default fears today even if the current tax rate is well below the peak of the Laffer curve.

We assume that the effective fiscal limit, b_t^*, is a draw in each period t from the fiscal limit distribution. As shown in the numerical analysis in sections 4 and 5, the distribution can be quite dispersed, especially when transfers currently reside in the explosive regime. The distribution reports the probability that a particular debt level can be supported by taxing income at the peak of the Laffer curve, given the stochastic processes for transfers, government purchases, and productivity. The maximum sustainable debt levels in the upper tail of the distribution are obtained only if the economy receives a run of positive shocks. Given the lower probability of receiving such positive shocks, default becomes more likely if current debt is in the upper tail. Similarly, the debt levels in the lower tail can be supported even if the economy receives a run of negative shocks, and therefore default is less likely. Default is possible at any point on the distribution. If a debt level of b^{**} is associated with a probability of p^{**} in the distribution, it implies that with the probability p^{**}, a run of shocks

may occur that makes a debt level that is equal to or higher than b^{**} unsustainable. Full details of how the fiscal limit distributions are computed appear in appendix A.

We use the case of Greece to explore conditional distributions of fiscal limits in section 4, and the case of Sweden to understand unconditional distributions in section 5.

4 Debt Crisis in Greece

4.1 Timeline

Through the early and mid-2000s, the view seemed to be that the discipline instilled by membership in the euro area would force the Greece's government to conform to the region's fiscal standards. Despite robust economic growth during this period, persistent deficits in Greece maintained debt at about 100 per cent of GDP. A series of U.S.-based financial events in 2008—the subprime mortgage crisis and the failures of Bear Stearns and Lehman Brothers—induced investors to more carefully assess the riskiness of Greek sovereign debt and drove Greek-German interest rate spreads to a couple of hundred basis points.

The impact on Greek rates of these global shocks may have been contained had it not been for the "data revisions" the Greek Ministry of Finance began to announce in 2009. The 2009 budget deficit, initially forecast to be 2 per cent of GDP, was revised upward to 3.7 per cent in January, to 5.1 per cent in a mid-year review, and to 12.7 per cent by late November. Eurostat eventually announced a final value of 15.8 per cent of GDP. This fiscal news alerted markets to the true state of fiscal policy in Greece and triggered a steady rise in risk premia throughout 2010. Figure 1 reports daily spreads between 10-year yields on Greek sovereign bonds and German Bunds.

In May 2010, Greece's government narrowly approved sweeping fiscal changes that cut public sector wages, reformed pensions, and raised taxes. These austerity measures were part of a bailout agreement between Greece and the "troika" (the International Monetary Fund, the European Commission, and the European Central Bank). Because the changes did not grow out of a clear political consensus among Greeks on the need for fiscal consolidation, they triggered violent public protests and widespread criticism that raised doubts about the ruling government's ability to complete its term, which ended in 2011, much less see the reforms through. Greek risk premia confirm these doubts, as they continued their relentless rise through 2010, reaching nearly 10 percentage points by year-end.

Since the first troika agreement, in each quarter, Greece missed its fiscal targets, and the Greece's government has announced additional austerity actions. None of these actions tempered the rise in risk premia. An October 2011 summit of the European Union sought to calm financial markets by reasserting the commitment of member countries to sustainable fiscal policies. Summit leaders called on Private Sector Involvement (PSI) to help Greece

reach a 120 per cent debt-to-GDP ratio. Under PSI, private investors would agree to a 50 per cent haircut on Greek bond holdings, while euro-area countries would provide 30 billion euros to the PSI package and contribute to recapitalizing Greek banks [Council of the European Union (2011)]. Within a month of the summit, premia had risen by more than 500 basis points.

Figure 1 makes clear that risk premia behaved quite differently beginning in the second half of 2011. Over the 21 months from September 2009 to June 2011, the premium rose 1,164 basis points—55 basis points per month on average. But in just the six months from July through December 2011, the increase was 1,655 basis points, averaging 276 basis points per month. Very little news about the *current* state of Greek finances arrived in the latter period, but plenty of news arrived about the stability of the Greek government and prospective *future* fiscal states.

With Prime Minister Papandreou's resignation in early November 2011, Lucas Papademos, former governor of the Bank of Greece and former Vice-President of the European Central Bank (ECB), became prime minister of a caretaking coalition government. On 13 February 2012, the new government approved the terms of the second troika bailout. Conditions included a 22 per cent cut in the minimum wage, large reductions in public employment, and substantial cuts in pension, health, and defence spending. The agreement also included an increase to 53.5 per cent for the haircut taken by private bondholders, a schedule for coupon payments on Greek bonds through 2042, a reduction of interest rates of the Greek Loan Facility, and a promise by national central bank holders of Greek bonds to pass earnings from those bonds back to Greece [Council of the European Union (2012)].[4]

4.2 Model Calibration We calibrate the quarterly model to Greek data from 1971–2007 to illustrate uses of the conditional (or state-dependent) fiscal limit.[5] Steady-state government purchases are 17 per cent of GDP, lump-sum transfers are 14 per cent of GDP, and government debt-to-GDP ratio is close to 60 per cent, which produces a tax rate of 0.34 in the steady state. The productivity shock has a persistence of 0.9721 and a standard deviation of 0.47 per cent of the steady-state level; and the transfers shock has persistence of 0.9634 and a standard deviation of 0.8 per cent of the steady-state level.[6] The parameter γ is calibrated to 0.1 to match the Greek data, implying that the government raises the tax

[4]In September 2012, the ECB announced its Outright Monetary Transactions program, which consists of potentially unlimited purchases by the ECB of short-term sovereign debt issued by qualifying member nations. Our analysis does not examine this or similar actions taken by the European Union to assist Greece.

[5]Due to lack of quarterly data for fiscal measures, we calibrate the model using interpolated data. Appendix B describes the data sources.

[6]For simplicity, we keep government spending at its steady state to compute the fiscal limit distribution. Bi (2012) shows that in a similar set-up, time-varying spending has a limited impact on the fiscal limit distribution.

rate by 1 percentage point in response to an increase of government debt by 10 per cent of GDP. Transfers follow a Markov regime-switching process. In the explosive regime, transfers growth, μ^z, is 1.0037 to match the observation that transfers from the Greek government to the private sector rose by 13 percentage points of GDP over the 40-year sample. In the baseline case, regime persistence, parameterized by p_1^z and p_2^z, is set at 0.9937 so that the regimes are symmetric, with an expected duration of 40 years. Table 1 summarizes the parameter settings.

Parameter	Value
Discount rate (β)	0.99
Steady-state leisure (L)	0.75
Persistence of productivity (ρ^A)	0.9721
Standard deviation of productivity (σ_A)	$0.0047A$
Persistence of transfers (ρ^z)	0.9634
Standard deviation of transfers (σ_z)	$0.008z$
Response of taxes to debt (γ)	0.1
Spending-to-GDP ratio (g/y)	0.17
Transfers-to-GDP ratio (z/y)	0.14
Tax rate (τ)	0.34
Transfers growth (μ^z)	1.0037
Regime-switching parameters (p_1^z/p_2^z)	0.9937/0.9937

Table 1: Baseline Calibration for the Greek Economy

As the results reveal, even this very simple model generates non-linearities that play a critical role in pricing sovereign debt. We solve the full non-linear model, coupled with the fiscal limit described in section 3.3, using the monotone mapping method. The solution method, based on Coleman (1991) and Davig (2004), discretizes the state space and conjectures candidate decision rules that reduce the system to a set of first-order expectational difference equations. Decision rules map the state at period t into the end-of-period government debt, denoted as $b_t = f^b(\psi_t)$ with $\psi_t = (b_t^d, A_t, z_t, rs_t^z)$. After finding the decision rules, we solve for the bond-pricing rule, $q_t = f^q(\psi_t)$, using the government budget constraint, and the interest rate rule, $R_t = f^R(\psi_t)$. Details appear in appendix C.

4.3 Decision Rules In the benchmark calibration, the default rate is fixed at 20 per cent. The top panels of Figure 2 show the cumulative conditional distributions (CDFs) for fiscal limits, and the bottom panels are the corresponding risk premia. The top left panel reports the CDFs, $\mathcal{B}^*(A_t = A^i, rs_t^z = 1)$, when current productivity is at different levels $(i = low, ss, high)$, while current transfers reside in the stationary regime. All future states

(A_{t+i}, rs^z_{t+i}) evolve according to their stochastic specifications. Since the effective fiscal limit at each period is a random draw from the conditional distribution, the CDF illustrates the default probability at each debt level scaled by the steady-state output: if the amount of debt the government issues at period t is b_t, then the CDF illustrates the probability that the government will default in the following period, $\Phi(b_t \geq b^*_{t+1})$. The solid line is the probability when current productivity is at the steady state, while the dashed line and the dashed-dotted lines are CDFs when current productivity is 8 per cent below and above the steady state. Current productivity changes contemporaneous tax revenues directly and future tax revenues indirectly, depending on the shock persistence; consequently, productivity has a significant impact on the distributions. At the debt ratio of 200 per cent, for example, the default probability is 0.25 when productivity is at the steady state, and less than 0.1 when productivity is 8 per cent above the steady state, but rises to 0.9 when productivity is 8 per cent below the steady state. Symmetric changes in productivity produce asymmetric changes in default probabilities, because possibly explosive transfers in the future generate fat tails in the fiscal limit distribution.

The risky interest rate on government bond R_t can be computed in terms of the current state $\psi_t = (b^d_t, A_t, z_t, rs^z_t)$, as appendix C describes. The risk-free rate R^f_t is computed from an identical specification, but is conditional on the assumption that the government never defaults. The risk premium, r_t, is defined

$$r_t \equiv R_t - R^f_t \tag{14}$$

$$= \frac{1}{q_t} - \frac{1}{q_t^{\Delta_t \equiv 0}} \tag{15}$$

where $q_t^{\Delta_t \equiv 0}$ is the bond-pricing function when government debt is perfectly safe.

The bottom left panel of Figure 2 shows the risk premia that the government has to pay at different debt levels. Sovereign risk premia follow the fiscal limit distribution closely: they are flat when the debt level is far from the fiscal limit and begin to rise, sometimes rapidly, when default becomes possible. The maximum risk premium can actually go above 20 percentage points. This happens because a higher Δ_{t+1} reduces the debt burden and tax rate next period, reducing the marginal utility of consumption next period and the discount factor. The risky discount rate, $\frac{u_c(t+1)}{u_c(t)}|(\Delta_{t+1} > 0)$, is lower than the risk-free discount rate, $\frac{u_c(t+1)}{u_c(t)}|(\Delta_{t+1} \equiv 0)$.

The top right panel of Figure 2 reports the conditional distributions when current transfers are either in the stationary or the explosive regime, while current productivity is at the steady state. All else being equal, the default probability can be significantly higher in the explosive regime: when debt is 150 per cent of output, default occurs with 30 per cent proba-

bility when the current transfers grow exponentially, but less than 5 per cent when transfers are stationary. Importantly, the distribution has a fat tail even when current transfers are stationary—the possibility that future transfers may switch to the explosive regime implies that future fiscal surpluses could be significantly lower, constraining the government's ability to service its debt today even if current transfers are stationary.

4.3.1 Alternative Default Rate Defaulting countries and creditors typically engage in prolonged debt negotiations whose outcomes are uncertain. In the benchmark calibration, the default rate is fixed at 20 per cent. As an alternative, we assume that the default rate is stochastic and follows an empirical distribution.

We derived the distribution from empirical evidence on sovereign debt defaults and restructurings observed in emerging-market economies from 1983 to 2005. Moody's (2009) reports the total amounts of defaulted debt during rated sovereign bond defaults since 1983, Panizza (2008) provides a thorough data set on public debt in developing countries, and Sturzenegger and Zettelmeyer (2008) estimate the haircuts associated with sovereign debt restructurings. Based on these three sources, we compute the default rate, defined as the share of actual defaulted debt over total public debt. The default rate falls between 0 and 0.1 with 70 per cent probability, between 0 and 0.3 with 90 per cent probability, and between 0 and 0.5 with 100 per cent probability [see Bi (2012) for more details]. Figure 3 shows the decision rules for risk premia when default rates are stochastic. They follow the baseline case closely, but with different magnitudes of risk premia. Since the distribution has a mean of 0.1, risk premia peak a little above 10 percentage points.

4.4 Fiscal Reform Greece has experienced persistent transfer growth during the past three decades which, in combination with rampant tax evasion, has led to soaring government debt. Mounting pressure from financial markets has forced the Greek government to adopt a variety of fiscal austerity measures. On 10 February 2012, the Greek cabinet approved a new austerity plan, which is estimated to improve the 2012 budget deficit by 3.3 billion euros. It remains an open question whether the fiscal austerity measures are credible.

We consider two extreme scenarios against the baseline case—a less credible versus a more credible reform. The smaller is the regime-switching probability p_1^z; the more likely transfers will switch from the stationary regime to the explosive regime, and the less credible is the fiscal reform. We consider a non-credible reform with $p_1^z = 0.9306, p_2^z = 0.9937$—even if transfers are stationary today, with 7 per cent probability the government will renege on the fiscal reform and revert to the explosive regime next period. This yields an expected duration for the stationary regime of only 4 years. We contrast this to a credible reform with $p_1^z = 0.9987, p_2^z = 0.9937$—once the transfers are stationary, the probability of leaving

that regime is less than 0.2 per cent, giving the reform an expected duration of 200 years.

Figure 4 compares the fiscal limit distributions for these two reform scenarios to the baseline calibration with an expected duration of 40 years. The top panel illustrates the comparison when current transfers are stationary while current productivity is at the steady state. For a stark contrast, the dotted line is the fiscal limit when transfers are always zero. The solid line is the baseline case; the dashed line shows the non-credible reform, and the dashed-dotted line illustrates the credible reform. Everything is identical across the four scenarios except the expectation of future transfers. The area between the dashed line and the solid line measures how much the fiscal limit shrinks as a result of the non-credible reform, and equals the expected present value of future transfers increases as a result of a higher probability of switching to the explosive regime. Similarly, the area between the solid line and the dashed-dotted line is the expansion in the fiscal limit due to the credible reform. The bottom panel repeats the same comparisons except that current transfers are in the explosive regime.

Figure 4 makes clear that if fiscal reform is credible, the current transfer regime matters a great deal in determining the default probability, as the dashed-dotted line is much less dispersed in the top panel than in the bottom. On the other hand, if fiscal reform is not credible, containing transfer growth temporarily does little to reduce the default probability and risk premia, as shown by the dashed lines in both panels. Speculation that the general election in Greece in 2013 may overturn many fiscal austerity measures suggests that markets may not be confident in the credibility of Greek fiscal reforms.

An alternative way to model the fiscal reforms is through changes in the persistence of the explosive regime. The higher the parameter p_2^z, the more likely transfers will stay in the explosive regime, and the less credible is the fiscal reform. We consider a non-credible reform with $p_1^z = 0.9937, p_2^z = 0.9987$, which yields an expected duration for the explosive regime of 200 years, and also a credible reform with $p_1^z = 0.9937, p_2^z = 0.9306$, giving the explosive transfer regime an expected duration of only 4 years. Figure 5 compares the fiscal limit distributions for these two reform scenarios to the baseline calibration. A non-credible fiscal reform reduces the fiscal limit, captured by the area between the dashed line and the solid line. More interesting, if the government can commit to reducing the duration of the explosive regime, such a fiscal reform can raise the fiscal limit regardless of whether current transfers are stationary or explosive, because the explosive regime is expected to be short-lived. In contrast, the credible reform in Figure 4, modelled as a more persistent stationary regime, can raise the fiscal limit if the government can switch transfers to the stationary regime, but has limited impact if current transfers come from the explosive regime.

4.5 Signal Extraction We have so far assumed that households can observe the transfer regime; therefore, there is no uncertainty about the distribution of the fiscal limit at any point in time.

Now we extend the model to explore the implications of confronting agents with a signal-extraction problem: they cannot observe the transfer regime and instead make a probabilistic inference regarding the regime in place. We continue to assume that agents know the transfer process and its transition probabilities. They behave as Bayesian updaters and form their inference by combining the current realization of transfers, z_t, with their prior beliefs. We denote the updated probability that the current transfer regime is stationary by $\omega_t = P[rs_t^z = 1|z_t]$, which can be calculated recursively from

$$\omega_t = \frac{\omega_{t-1} p_{11}^z \eta_t(1) + (1-\omega_{t-1}) p_{21}^z \eta_t(1)}{\sum_{i=1,2} \omega_{t-1} p_{1i}^z \eta_t(i) + (1-\omega_{t-1}) p_{2i}^z \eta_t(i)} \tag{16}$$

with $\eta_t(1) = \eta(z_t - (1-\rho^z)z - \rho^z z_{t-1})$ and $\eta_t(2) = \eta(z_t - \mu^z z_{t-1})$. $\eta(\cdot)$ represents the normal density with variance σ_z^2.

The transfer regime, rs_t^z, is a latent state variable to households, who observe current and past realizations of transfers, but not the regime that generated the realizations. Agents update their beliefs about how likely the transfer realizations come from the stationary regime this period, ω_t, based on observations of $(z_t, z_{t-1}, \omega_{t-1})$. They then compute the likelihood of transiting to each of the transfer regimes next period, based on the transition probabilities and their updated belief, ω_t. Since the conditional distribution of the fiscal limit depends on the transfer regime, households decide the quantity of bonds to purchase in each period conditional on the updated belief, so ω_t becomes a relevant state for the decision rules.

A comparison of decision rules illustrates how uncertainty about the transfer regime affects risk premia. In the baseline case without a signal-extraction problem, Figure 6 compares risk premia when current transfers are at different levels: the left panel is conditional on the current transfer regime being stationary and the right panel on the regime being explosive. Regardless of the transfer regime, the current *level* of transfers has a negligible impact on risk premia. This is because the lump-sum transfers do not change households' decisions directly, except that higher (lower) transfers may raise (reduce) the level of government debt at the end of the period.

But if households need to infer the transfer regime, past transfers and the shocks to transfers can play an important role in shaping their inferences about the distribution of the fiscal limit, which feeds into risk premia. Now the state space becomes $(b_t^d, A_t, z_t^{shock}, z_{t-1}, \omega_{t-1})$, where $z_t^{shock} = z_t - z_{t-1}$. The decision rules in Figure 7 illustrate that transfer shocks of the same size can change risk premia by different amounts, depending on households' prior

beliefs. The left panel reports the case when agents currently have a strong belief that the stationary regime (regime 1) prevails; the right panel reports the outcome when agents place a low prior probability on being in the stationary regime. For instance, when the debt level is 200 per cent of GDP, a negative transfer shock of 3.6 per cent of the steady-state level reduces the risk premium by 3 percentage points if the prior belief of being in the stationary regime, ω_{t-1}, is high (0.75), but by 8 percentage points if ω_{t-1} is low (0.25). Similarly, a positive shock of 3.6 per cent of steady-state transfers raises the risk premium by 7 percentage points if ω_{t-1} is high, but by only 2 percentage points if ω_{t-1} is low. This asymmetry illustrates that a given shock to transfers can lead to very different assessments of the riskiness of sovereign debt, depending on agents' prior beliefs about the nature of the prevailing transfer regime.

Figures 8–10 show three sets of simulations to further explore the impact of the signal-extraction problem. Figure 8 reports the baseline calibration with low volatility in transfer shocks—only 0.8 per cent of the steady-state level. Transfers stay in the explosive regime until period 135 and then switch to the stationary regime. After the regime switch, the true default probability drops from 0.04 to almost zero immediately, but households do not reduce the risk premium to zero immediately because they are uncertain that a regime change has occurred. Instead, risk premia decrease in the following three quarters as households gradually learn about the regime change.

Figure 9 shows the same experiment but with a larger standard deviation of transfer shocks—1.6 per cent of the steady-state level. Again, transfers switch in period 135, but it takes another 10 quarters for households to learn the regime switch as the inference index slowly rises from 0 to 1. After the transfer regime switch, the risk premium actually increases for another 2 quarters before coming down gradually. Figure 10 illustrates a more extreme case: other than transfers switching from the explosive regime to the stationary regime at period of 135, the economy also receives a run of negative productivity shocks for 8 quarters from period 133 to 140. Lower productivity shrinks the tax base and further deteriorates the government budget, raising risk premia.

5 Swedish Fiscal Reform in the 1990s

Large and seemingly permanent changes in fiscal behaviour in Sweden following the recession and banking crisis in the early 1990s illustrate uses of the unconditional distribution of fiscal limits.

5.1 Timeline In the early 1990s, Sweden experienced a boom-bust cycle that severely tested the prevailing policy regime.[7] After deregulating the financial system, the economy boomed in the late 1980s, with rapid growth in GDP and employment. By 1989–90, the boom had ended and the bust began. The resulting recession was comparable to Sweden's experience in the Great Depression, with GDP falling for three consecutive years and unemployment rising from 1.5 per cent in 1989 to over 8 per cent in 1993. Large automatic stabilizers built into Swedish fiscal rules swung the general government balance from a 5 per cent surplus in 1989 to nearly a 12 per cent deficit in 1993. The Swedish government responded with a thorough policy reform.

The fiscal framework that was introduced in 1993 consists of three components covering both central and local governments. First, a ceiling on total expenditures, excluding interest payments, was introduced at the central government level. Sweden's Ministry of Finance prepares the budget and presents it to the Riksdag, which votes on the expenditure ceiling and how to divide the budget into 27 expenditure areas. Second, a budget surplus target of 1 per cent of GDP over the business cycle was adopted at the general government level to partially pre-fund benefits to Sweden's aging population. Third, a balanced budget at the local government level was introduced in 2000.

Under this fiscal framework, the Swedish government was able to reduce public expenditures from 60 per cent of GDP in 1993 to 45 per cent of GDP in 2007 by cutting social benefits, public subsidies, capital expenditures and public consumption. The successful fiscal reform has earned plaudits from sovereign debt rating agencies. After the 1993 downgrade of Swedish debt, Standard & Poor's (1997) revised its long-term foreign currency rating outlook for Sweden from negative to stable, largely due to "expected fiscal strengthening" arising from the reforms. In the context of the 2007–09 economic downturn, Standard & Poor's (2009) wrote, "the established fiscal rules have served Sweden well" and, "the Kingdom's substantial fiscal buffers support its creditworthiness in the current adverse economic environment." Despite the decline in fiscal performance as a result of rising government spending and declining tax revenue, rating agencies believe that the deterioration in public finances will be temporary, since the Swedish government has a solid history of fiscal discipline and credible rules in place.

Figure 11 suggests that a shift in the level of transfers and government spending occurred between 1992 and 1997. Sweden's financial crisis started in 1992, while the expenditure ceiling on central government spending was introduced in 1997. Claeys (2008) identifies the breakpoint for government spending as the third quarter of 1995 and for transfers as

[7]This section draws liberally from Sweden's Ministry of Finance (2001), Jonung and Hagberg (2005), Jonung (2009), Reinhart and Rogoff (2008), and Wetterberg (2009).

the second quarter of 1996. We set the breakpoint to be 1997 in order to highlight the comparison before and after the fiscal reform, but different breakpoints do not affect our results qualitatively.

Countercyclical fiscal policy is an important feature of the Swedish data, and we allow government spending and transfers to respond to the countercyclical changes of output, measured by the parameters α^g and α^z, that is estimated for the period of 1980 to 2007.[8]

$$\ln \frac{g_t}{g} = \alpha^g \ln \frac{A_t}{A} \tag{17}$$

$$\ln \frac{z_t}{z} = \alpha^z \ln \frac{A_t}{A} \tag{18}$$

Table 2 shows the estimated α^g and α^z, the average tax rate, and the ratios of government spending and transfers to GDP in different episodes. First, there was a sharp decline in the level of transfer payments, from 22 per cent to about 19 per cent of GDP. Second, government spending shifted from being countercyclical in the early period ($\alpha^g < 0$) to being procyclical in the latter period ($\alpha^g > 0$), which may be a consequence of the 1997 expenditure ceiling policy.

	1980–2007	1980–97	1997–2007
Response of spending to productivity (α^g)	−0.142	−0.183	0.196
Response of transfers to productivity (α^z)	−1.65	−1.70	−1.066
Average tax rate (τ)	49.7	49.6	49.9
Spending-to-GDP ratio (g/y)	27.3	27.6	26.7
Transfers-to-GDP ratio (z/y)	21	22	19.1

Table 2: Swedish Fiscal Data (1980–2007)

5.2 Parameter Calibration To discuss the unconditional distributions in the long run, the model is calibrated to annual data. Table 3 summarizes the calibration of the parameters. The productivity shock has a persistence of 0.661 and a standard deviation of 0.015. The degree of countercyclical government spending and lump-sum transfers, α^g and α^z, the transfers-to-GDP ratio, z/y, and the government spending-to-GDP ratio are calibrated to pre-crisis (1980–97) and post-crisis (1997–2007) data. The steady-state tax rate, τ, is calibrated to the average level of the tax ratio in the data.

[8] We assume the transfers always follow a stationary process, since they have been stable over time in Sweden.

Parameter	Value	
Discount rate (β)	0.95	
Steady-state leisure (L)	0.75	
Persistence of productivity (ρ^A)	0.661	
Standard deviation of productivity (σ_A)	0.015	
Average tax rate (τ)	0.5	
	Pre-Crisis	Post-Crisis
Response of spending to productivity (α^g)	-0.183	0.196
Response of transfers to productivity (α^z)	-1.70	-1.066
Spending-to-GDP ratio (g/y)	0.276	0.267
Transfers-to-GDP ratio (z/y)	0.22	0.19

Table 3: Calibration for the Swedish Economy

5.3 Policy Experiments We treat as the baseline the calibration from the pre-crisis period when Swedish sovereign bonds were downgraded by the rating agencies, government spending and transfers are countercyclical, and the average tax rate and the share of transfers are relatively high. We simulate the distribution of the fiscal limit for this baseline scenario and then contrast it to the distributions obtained under three alternative calibrations that are designed to capture the post-crisis fiscal reforms.

Table 4 summarizes the policy settings in the baseline model and in the three alternatives. The first alternative scenario, labelled "post-crisis," is a counterfactual exercise that asks what the fiscal limit would be if the government were to reduce the tax rate and the share of transfers in GDP to their post-crisis levels, but continued to follow the pre-crisis countercyclical expenditure rules.

The second and third alternative scenarios, labelled "post-crisis procyclical" and "post-crisis ceiling," respectively, offer two explanations for government expenditure data from 1997 to 2007. In the "post-crisis procyclical" case, the government spending policy is assumed to have shifted from countercyclical to procyclical. In the "post-crisis ceiling" case, on the other hand, expenditure ceilings on government spending and transfers are imposed, while countercyclical spending and transfer policies are calibrated to the pre-crisis levels. The ceiling rules are given by

$$\log \frac{g_t}{g} = \min \left(\alpha^g \log \frac{A_t}{A}, -\alpha^g \sigma_A \right) \tag{19}$$

$$\log \frac{z_t}{z} = \min \left(\alpha^z \log \frac{A_t}{A}, -\alpha^z \sigma_A \right) \tag{20}$$

where σ_A is one standard deviation for the technology shock. Equations (19) and (20)

operate asymmetrically. When productivity is high, expenditures tend to be low and the constraints do not bind. When productivity is low, however, expenditures automatically tend to be higher than normal. If the productivity shock is sufficiently negative, the automatic expansion in expenditures may be bounded above as the ceiling binds, implying that the government can conduct countercyclical expenditure policies only within some range.

Parameter	Pre-Crisis	Post-Crisis	Post-Crisis (procyclical)	Post-Crisis (ceiling)
	Baseline	Case 1	Case 2	Case 3
Response of spending to productivity (α^g)	-0.183	-0.183	0.196	-0.183
Response of transfers to productivity (α^z)	-1.70	-1.70	-1.066	-1.70
Spending-to-GDP ratio (g/y)	0.276	0.267	0.267	0.267
Transfers-to-GDP ratio (z/y)	0.215	0.19	0.19	0.19
Expenditure ceiling	n.a.	n.a.	n.a.	$g_t \leq g^{ceil}$ $z_t \leq z^{ceil}$

Table 4: Alternative Swedish Fiscal Policies

5.3.1 Fiscal Limits Figure 12 compares the distributions of the fiscal limit under the baseline and the three alternative scenarios. The top panel compares the pre-crisis and post-crisis cases. In the pre-crisis baseline calibration, the distribution, centred at a debt-output ratio of 70 per cent, is quite dispersed, implying that Swedish sovereign debt holders may have had good reasons to place probability on default in the early 1990s, even when the debt was at relatively modest levels. This, of course, was the time when Swedish sovereign debt was downgraded. On the other hand, fiscal reform that led to a smaller government in terms of the share of transfers in GDP and the average level of taxation shifted the fiscal limit markedly to the right, with the mean moving to 140 per cent, as shown by the solid line labelled "post-crisis."

The dotted-dashed line, labelled "post-crisis (procyclical)," uses identical policy settings as "post-crisis," except that government spending switches from countercyclical to procyclical, with α^g changing from -0.183 to 0.196, and transfers become somewhat less countercyclical, with α^z changing from -1.70 to -1.066. Altering the cyclical nature of government expenditures has little effect on the mean of the distribution, but reduces its dispersion. Expenditure ceilings have a more subtle influence on the distribution of the fiscal limit, as the dashed line shows. Asymmetry in expenditure rules induces asymmetry in the fiscal limit: the upper tail is substantially fatter than the lower tail, shifting risk away from moderate

debt-output ratios. Taken together, the results for procyclical spending and expenditures ceiling policies provide some support for the argument that such policies can cushion the Swedish economy from risk premia on government debt.

6 Conclusion

By mapping policy behaviour into a country's fiscal limit distribution, this paper provides a tool to evaluate fiscal reforms that are undertaken in countries under sovereign risk pressures.

The next step is to model monetary policy. Recent work has found that interactions between monetary and fiscal policies—particularly the possibility that monetary policy may be operating at or near the lower bound on nominal interest rates—can play an important role in determining the impact of fiscal policies [Christiano, Eichenbaum, and Rebelo (2011); Davig and Leeper (2011); and others]. Moreover, in the presence of a fiscal limit, monetary policy's ability to control inflation can be jeopardized [Sims (2004, 2011); Cochrane (2011); Davig, Leeper, and Walker (2010); and Leeper (2011)].

A more ambitious extension is to endogenize fiscal policy choices in a structural political economy framework and, therefore, to relate a country's fiscal limit to its underlying political factors and institutions. By modelling the political costs of fiscal austerity measures and sovereign defaults, this extension can help to bridge the fiscal policy literature and the strategic default literature [Eaton and Gersovitz (1981); and Arellano (2008)].

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A Simulation Procedure for Fiscal Limits

In this model, the choices of household consumption and labour supply only depend on the income tax rate and the exogenous state variables (A_t, g_t). Assume the utility function is $u(c, L) = \log c + \phi \log L$. The household first-order conditions can be written as

$$1 - L_t = \frac{A_t(1-\tau_t) + \phi g_t}{A_t(1+\phi-\tau_t)} \tag{21}$$

$$c_t = \frac{(A_t - g_t)(1-\tau_t)}{1+\phi-\tau_t} \tag{22}$$

The tax revenue, T_t, is

$$\begin{aligned} T_t &= \tau_t \frac{A_t(1-\tau_t) + \phi g_t}{1+\phi-\tau_t} \\ &= (1+2\phi)A_t - \phi g_t - \Big(A_t(1+\phi-\tau_t) + \frac{(1+\phi)\phi(A_t - g_t)}{1+\phi-\tau_t}\Big). \end{aligned} \tag{23}$$

The tax revenue reaches to the maximum level, T_t^{max}, when the tax rate reaches the peak point of the Laffer curve, τ_t^{max}.

$$\tau_t^{max} = 1 + \phi - \sqrt{\frac{(1+\phi)\phi(A_t - g_t)}{A_t}} \tag{24}$$

$$T_t^{max} = (1+2\phi)A_t - \phi g_t - 2\sqrt{(1+\phi)\phi A_t(A_t - g_t)} \tag{25}$$

A.1 Conditional Fiscal Limit

Since there exists a unique mapping between the exogenous state space (A_t, g_t) to τ_t^{max} and T_t^{max}, the conditional distribution of the fiscal limit, $\mathcal{B}^*(A_t, g_t, rs_t^z)$, can be obtained using a Markov chain Monte Carlo simulation:

1. For each simulation i, we randomly draw the shocks for productivity, A_{t+j}, government purchases, g_{t+j}, and the transfer regime, rs_{t+j}^z, for 200 years conditional on the starting state (A_t, g_t, rs_t^z). Assuming that the tax rate is always at the peak of the dynamic Laffer curves, we compute the paths of all other variables using the household's first-order conditions and the budget constraints, and the discounted sum of maximum fiscal surplus.

$$B_i^*(t) = \sum_{j=0}^{\infty} \beta^j \frac{u_c^{max}(A_{t+j}, g_{t+j})}{u_c^{max}(A_t, g_t)} \left(T^{max}(A_{t+j}, g_{t+j}) - g_{t+j} - z(rs_{t+j}^z, A_{t+j})\right) \tag{26}$$

2. Repeat the simulation for $100,000$ times and obtain the conditional distribution of

$\mathcal{B}^*(A_t, g_t, rs_t^z)$ using the simulated $B_i^*(t)$ $(i = 1, ..., 100000)$.

3. Repeat the first and second steps for all possible exogenous states (A_t, g_t, rs_t^z) within the discretized state space.

A.2 Unconditional Fiscal Limit The unconditional distribution ($\mathcal{B}^*$) can be obtained in a similar way:

1. For each simulation i, we randomly draw the shocks for productivity (A_j), government purchases (g_j), and the transfer regime (rs_j^z) for 400 years and drop the first 200 as a burn-in period. Assuming that the tax rate is always at the peak of the dynamic Laffer curves, we compute the discounted sum of maximum fiscal surplus B_i^*.

2. Repeat the simulation for $100,000$ times and obtain the unconditional distribution of $\mathcal{B}^*$ using the simulated B_i^* $(i = 1, ..., 100000)$.

B Greek Data

The data of government debt are from European Commission (2009), while the rest of the fiscal data are from the OECD Economic Outlook No. 84 for the period between 1971 and 2010. We interpolate the annual frequency data to obtain a quarterly frequency series using the method of Chow and Lin (1971) and the seasonally adjusted quarterly real GDP series for the interpolation. The average tax rate is defined as the ratio of the total tax revenue over the GDP, including social security and indirect and direct taxes. The government purchases are government final consumption of expenditures. Lump-sum transfers are defined as the sum of social security payments, net capital transfers and subsidies. We detrend the data of the real GDP per worker from Penn World Table Version 6.2 [Heston, Summers, and Aten (2009)] to estimate the shock process of productivity.

C Solving the Non-linear Model

C.1 Baseline Model without Signal Extraction Other than the end-of-period government debt, all other variables are either exogenous or can be computed in terms of the current state $\psi_t = (b_t^d, A_t, z_t, rs_t^z)$.

$$\tau_t = \tau + \gamma\left(b_t^d - b\right) \tag{27}$$

$$A_t - A = \rho^A(A_{t-1} - A) + \varepsilon_t^A \tag{28}$$

$$c_t = \frac{(A_t - g_t)(1 - \tau_t)}{1 + \phi - \tau_t} \tag{29}$$

$$z_t = \begin{cases} (1-\rho^z)z + \rho^z z_{t-1} + \varepsilon_t^z & \text{if } rs_t^z = 1 \\ \mu^z z_{t-1} + \varepsilon_t^z & \text{if } rs_t^z = 2 \end{cases}$$

$$\Delta_t = \begin{cases} 0 & \text{if } b_{t-1} < b_t^* \\ \delta & \text{if } b_{t-1} \geq b_t^* \end{cases}$$

The decision rule for government debt, $b_t = f^b(\psi_t)$, is solved in the following steps:

1. Define the grid points by discretizing the state space ψ_t. Make an initial guess of the decision rule f_0^b over the state space.

2. At each grid point, solve the following core equation and obtain the updated rule f_i^b using the given rule f_{i-1}^b.

$$\frac{b_t^d + z_t + g_t - \tau_t A_t n(\psi_t)}{f_i^b(\psi_t)} = \beta E_t \frac{c(\psi_t)}{c(\psi_{t+1})}(1-\Delta_{t+1}) \tag{30}$$

   where $\psi_{t+1} = \left([f_{i-1}^b(\psi_t), b_{t+1}^*, \delta_{t+1}], A_{t+1}, g_{t+1}, z_t, rs_{t+1}^z\right)$. The integral on the right-hand side is evaluated using numerical quadrature.

$$\begin{aligned} E_t \frac{1-\Delta_{t+1}}{c_{t+1}} &= \int_{\varepsilon_{t+1}^A}\int_{\varepsilon_{t+1}^z}\int_{rs_{t+1}^z}\int_{b_{t+1}^*}\int_{\delta_{t+1}} \frac{1-\Delta_{t+1}}{c_{t+1}} \\ &= \int_{\varepsilon_{t+1}^A}\int_{\varepsilon_{t+1}^z}\int_{rs_{t+1}^z} \left(1-\Phi(b_t \geq b_{t+1}^*)\right)\frac{1}{c_{t+1}}|_{\text{no default}} + \\ &\quad + \int_{\varepsilon_{t+1}^A}\int_{\varepsilon_{t+1}^z}\int_{rs_{t+1}^z} \Phi(b_t \geq b_{t+1}^*)\int_{\delta_{t+1}} \frac{1-\delta_{t+1}}{c_{t+1}}|_{\text{default}} \end{aligned}$$

3. Check the convergence of the decision rule. If $|f_i^b - f_{i-1}^b|$ is above the desired tolerance (set to $1e-6$), go back to step 2; otherwise, f_i^b is the decision rule.

C.2 Model with Signal Extraction The state space becomes $(b_t^d, A_t, z_t^{shock}, z_{t-1}, \omega_{t-1})$, where $z_t^{shock} = z_t - z_{t-1}$. Solving the model with signal extraction follows similar steps to the baseline model.

1. Define the grid points by discretizing the state space ψ_t. Make an initial guess of the decision rule f_0^b over the state space.

2. At each grid point, update the household's inference ω_t,

$$\omega_t = \frac{\omega_{t-1}p_{11}^z\eta_t(1) + (1-\omega_{t-1})p_{21}^z\eta_t(1)}{\sum_{i=1,2}\omega_{t-1}p_{1i}^z\eta_t(i) + (1-\omega_{t-1})p_{2i}^z\eta_t(i)} \tag{31}$$

with $\eta_t(1) = \eta(z_t - (1-\rho^z)z - \rho^z z_{t-1})$ and $\eta_t(2) = \eta(z_t - \mu^z z_{t-1})$. $\eta(.)$ represents the normal density with variance σ_z^2.

3. At each grid point, solve the following core equation and obtain the updated rule f_i^b using the given rule f_{i-1}^b.

$$\frac{b_t^d + z_t + g_t - \tau_t A_t n(\psi_t)}{f_i^b(\psi_t)} = \beta E_t \frac{c(\psi_t)}{c(\psi_{t+1})}(1 - \Delta_{t+1}) \tag{32}$$

The integral on the right-hand side is evaluated using numerical quadrature.

$$E_t \frac{1-\Delta_{t+1}}{c_{t+1}} = \int_{\varepsilon_{t+1}^A} \int_{\varepsilon_{t+1}^z} \left(X_{t+1}^1 + X_{t+1}^2\right) \Xi_{t+1} \tag{33}$$

with

$$X_{t+1}^1 = \eta_{t+1}(1)(\omega_t p_1^z + (1-\omega_t)(1-p_1^z)) \tag{34}$$

$$X_{t+1}^2 = \eta_{t+1}(2)(\omega_t(1-p_2^z) + (1-\omega_t)p_2^z) \tag{35}$$

$$\Xi_{t+1} = \left(1 - \Phi(b_t \geq b_{t+1}^*)\right) \frac{1}{c_{t+1}}|_{\text{no default}} + \Phi(b_t \geq b_{t+1}^*) \int_{\delta_{t+1}} \frac{1-\delta_{t+1}}{c_{t+1}}|_{\text{default}} \tag{36}$$

4. Check the convergence of the decision rule. If $|f_i^b - f_{i-1}^b|$ is above the desired tolerance (set to $1e-6$), go back to step 2; otherwise, f_i^b is the decision rule.

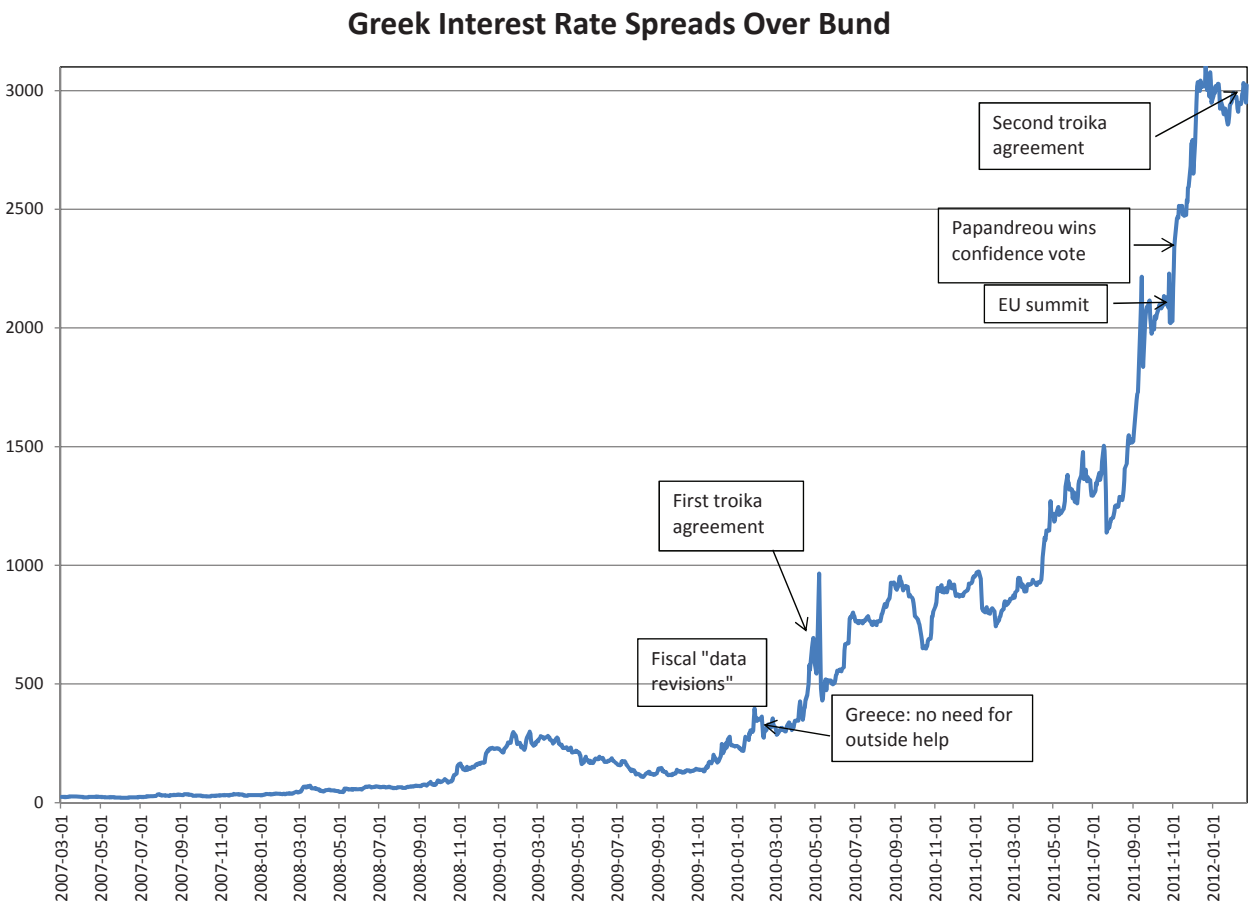

Figure 1: Greek risk premia: daily Greek sovereign bond yield spreads over German bund (10-year yields)

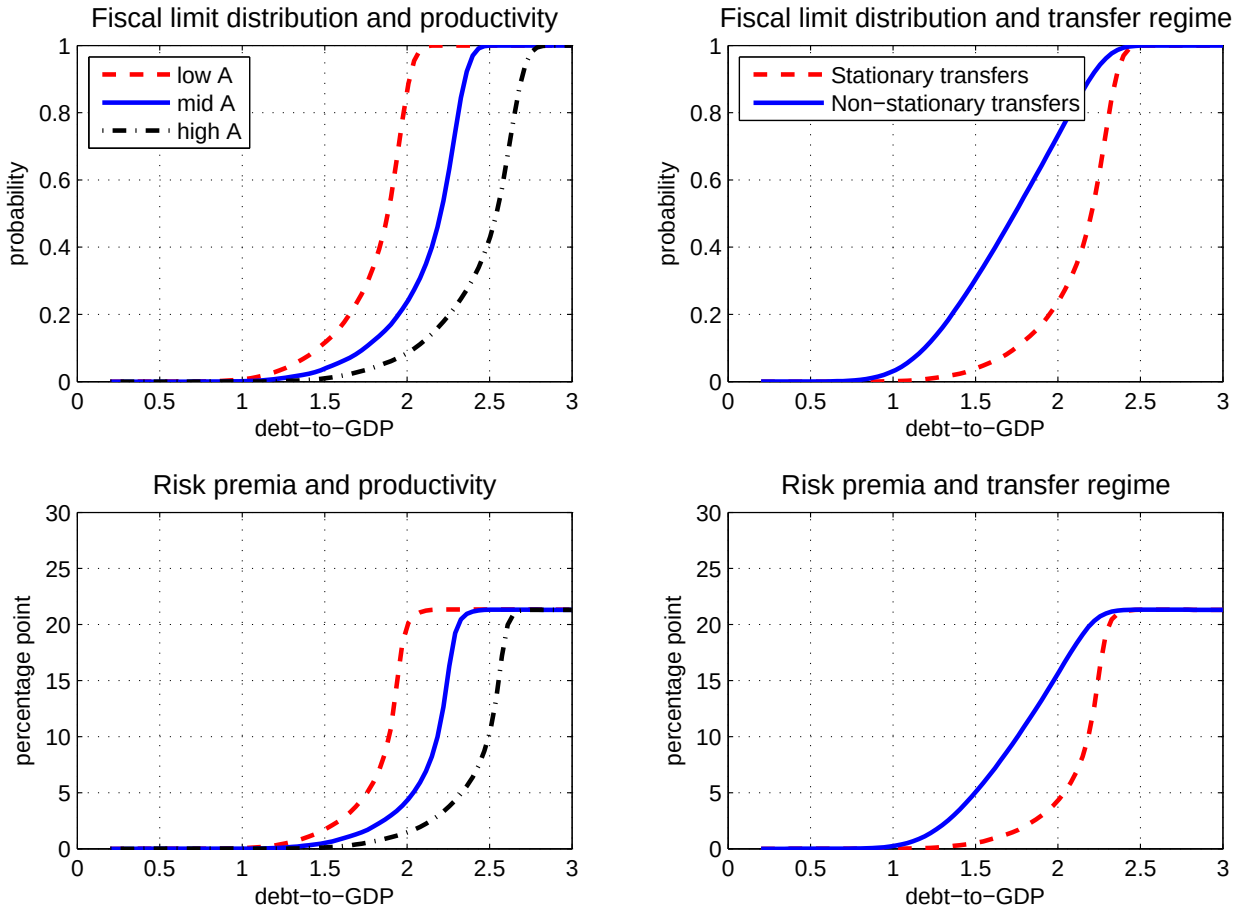

Figure 2: Risk premia and conditional (state-dependent) distributions of fiscal limits when calibrating to Greek data: baseline case. Distributions of fiscal limit are estimated from Markov chain Monte Carlo simulations.

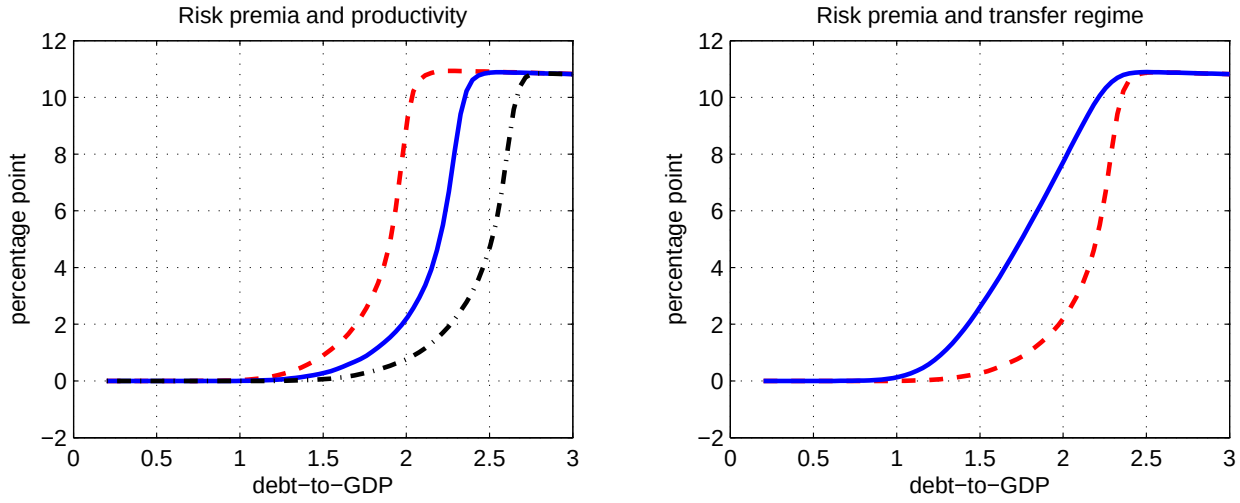

Figure 3: Risk premia for model calibrated to Greek data: alternative default rate case

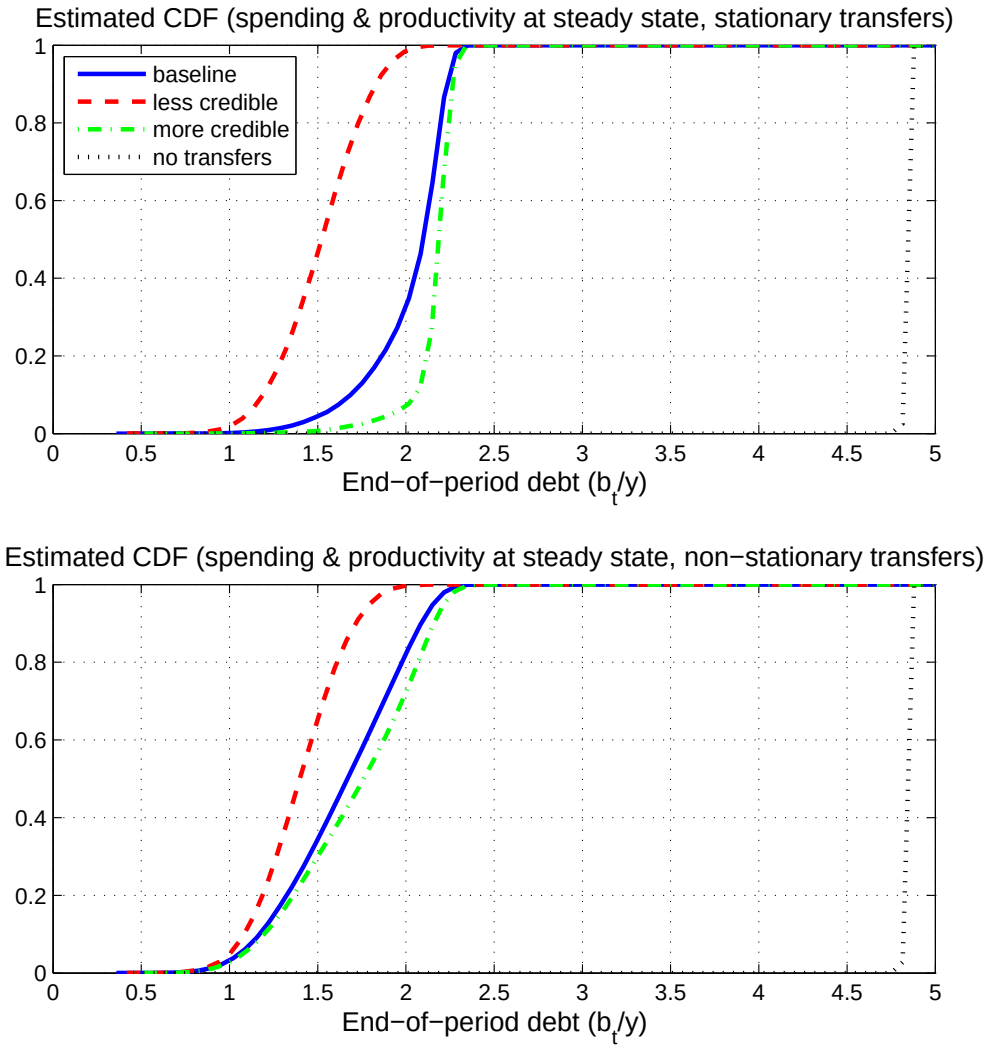

Figure 4: State-dependent distributions of fiscal limits for Greece calibration: fiscal reforms with different p_1^z. Baseline is specified as $p_1^z = p_2^z = 0.9937$, a less credible reform features $p_1^z = 0.9306, p_2^z = 0.9937$, and a more credible reform is specified as $p_1^z = 0.9987, p_2^z = 0.9937$. Dotted lines depict the fiscal limit when transfers are identically zero.

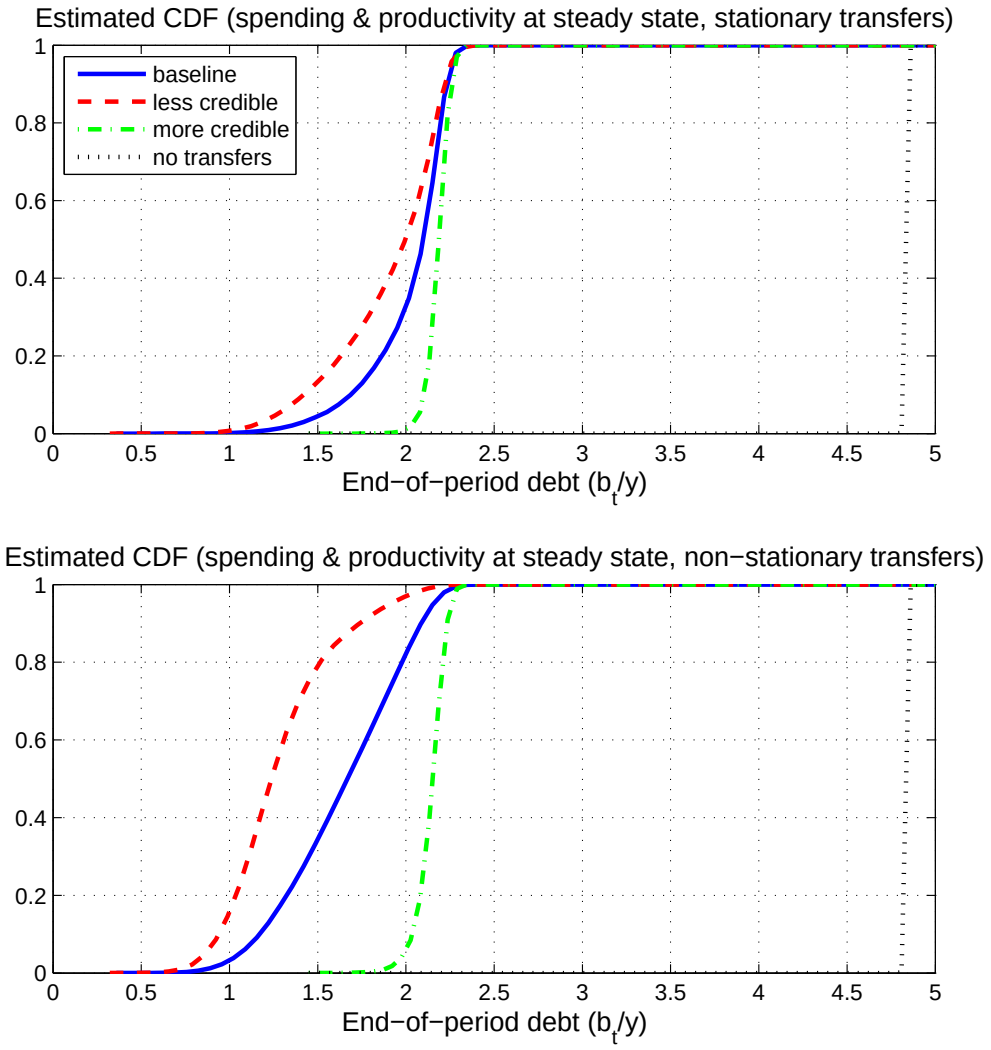

Figure 5: State-dependent distributions of fiscal limits for Greece calibration: fiscal reforms with different p_2^z. Baseline is specified as $p_1^z = p_2^z = 0.9937$, a less credible reform features $p_1^z = 0.9937, p_2^z = 0.9987$, and a more credible reform is specified as $p_1^z = 0.9937, p_2^z = 0.9306$. Dotted lines depict the fiscal limit when transfers are identically zero.

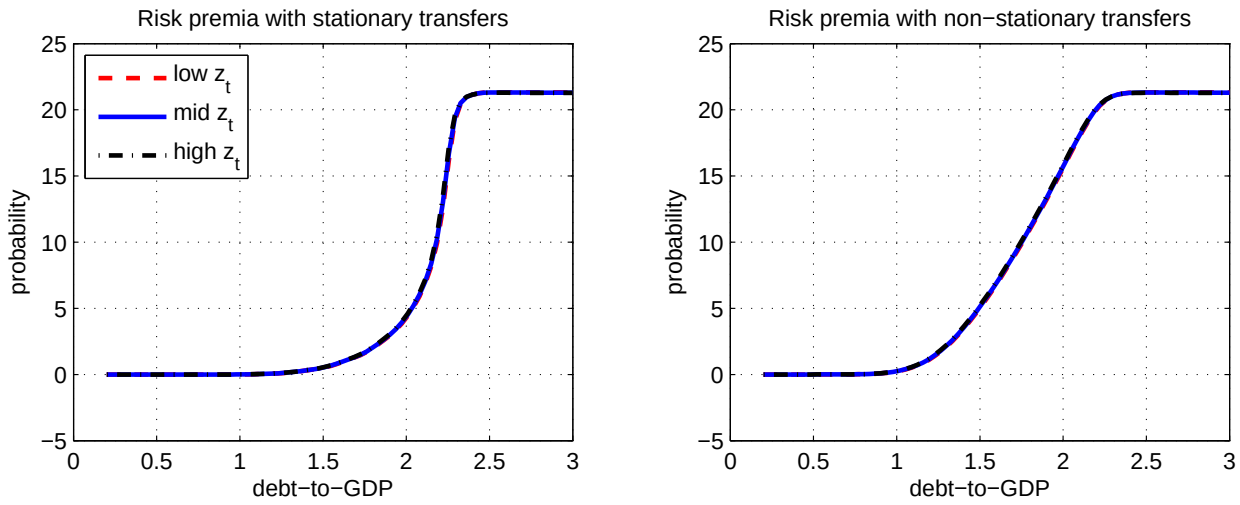

Figure 6: Risk premia when calibrating to Greek data: baseline case

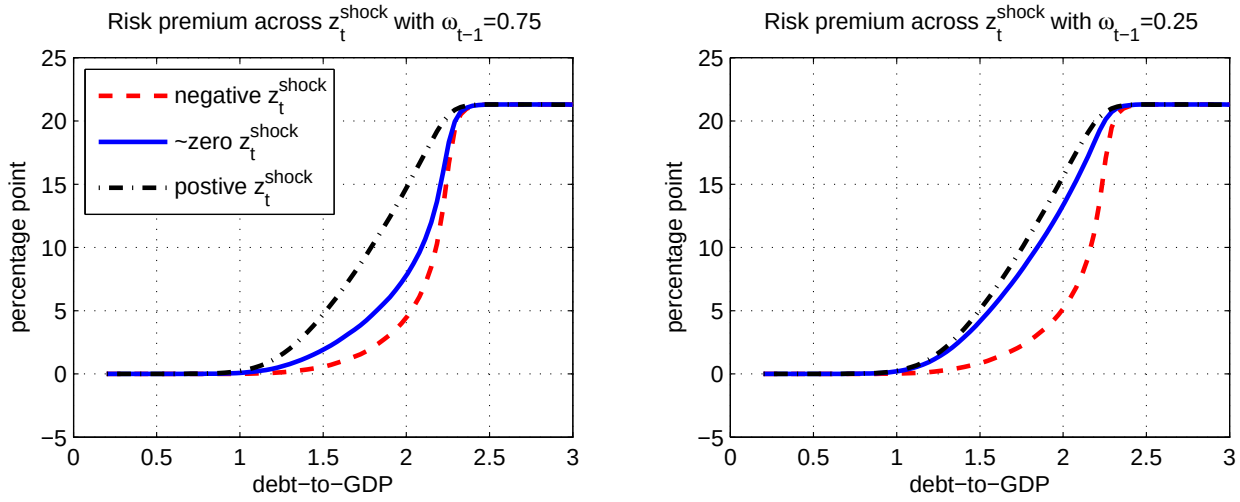

Figure 7: Risk premia when calibrating to Greek data: the case with signal extraction

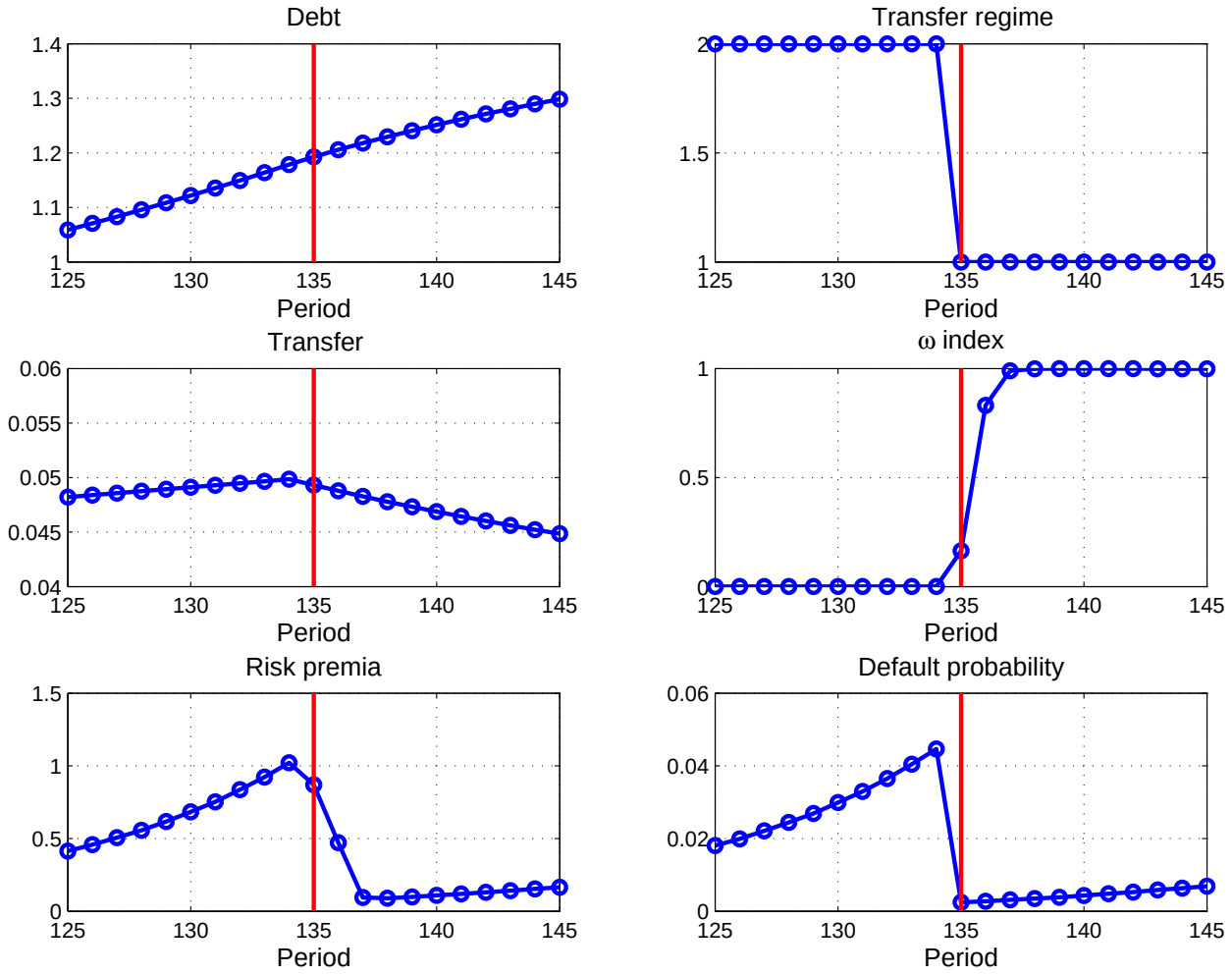

Figure 8: Simulation in the model with signal extraction: standard deviation for transfer shock is 0.8 per cent of the steady-state level. Transfer regime switches at the period of 135.

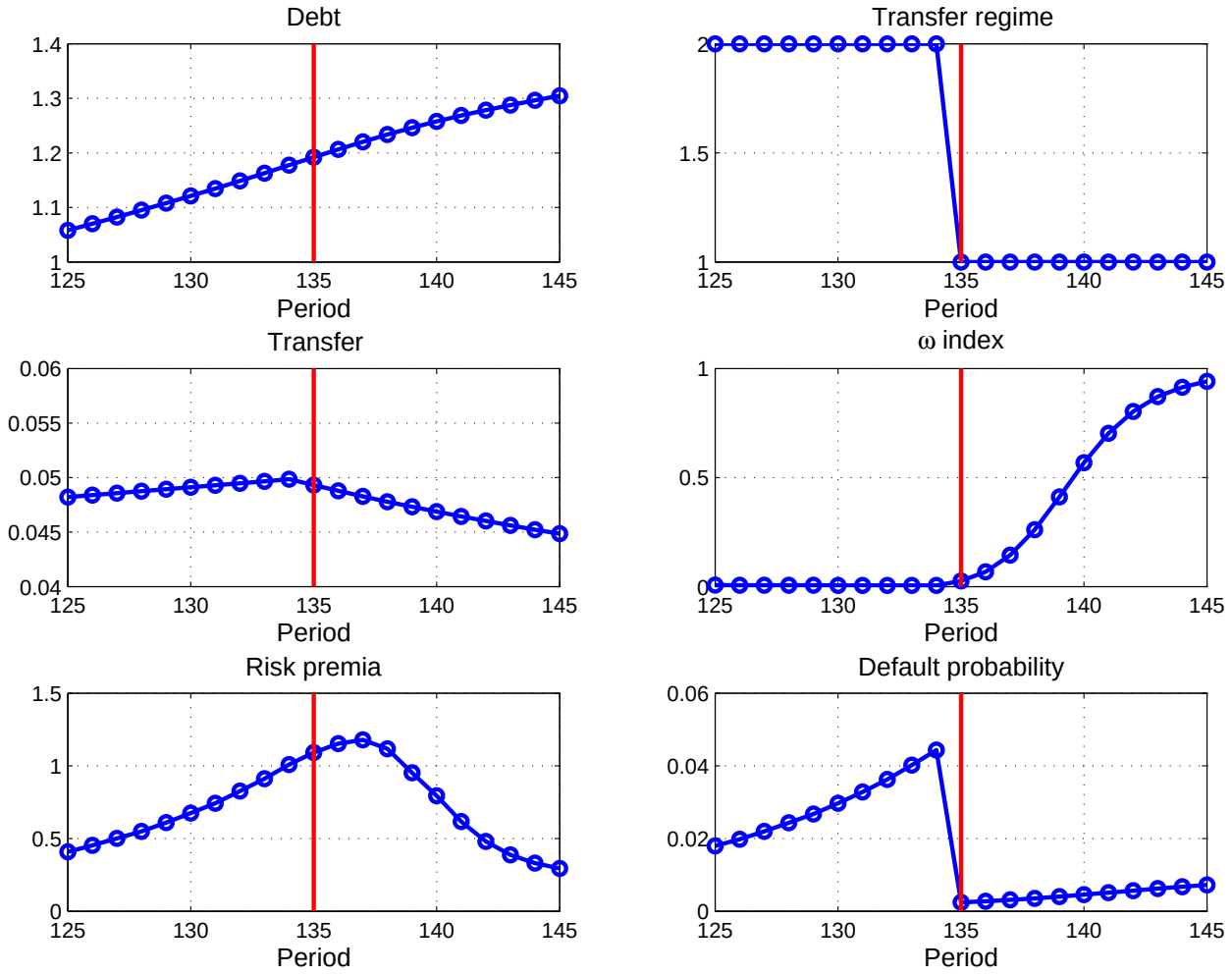

Figure 9: Simulation in the model with signal extraction: standard deviation for transfer shock is 1.6 per cent of the steady-state level. Transfer regime switches at the period of 135.

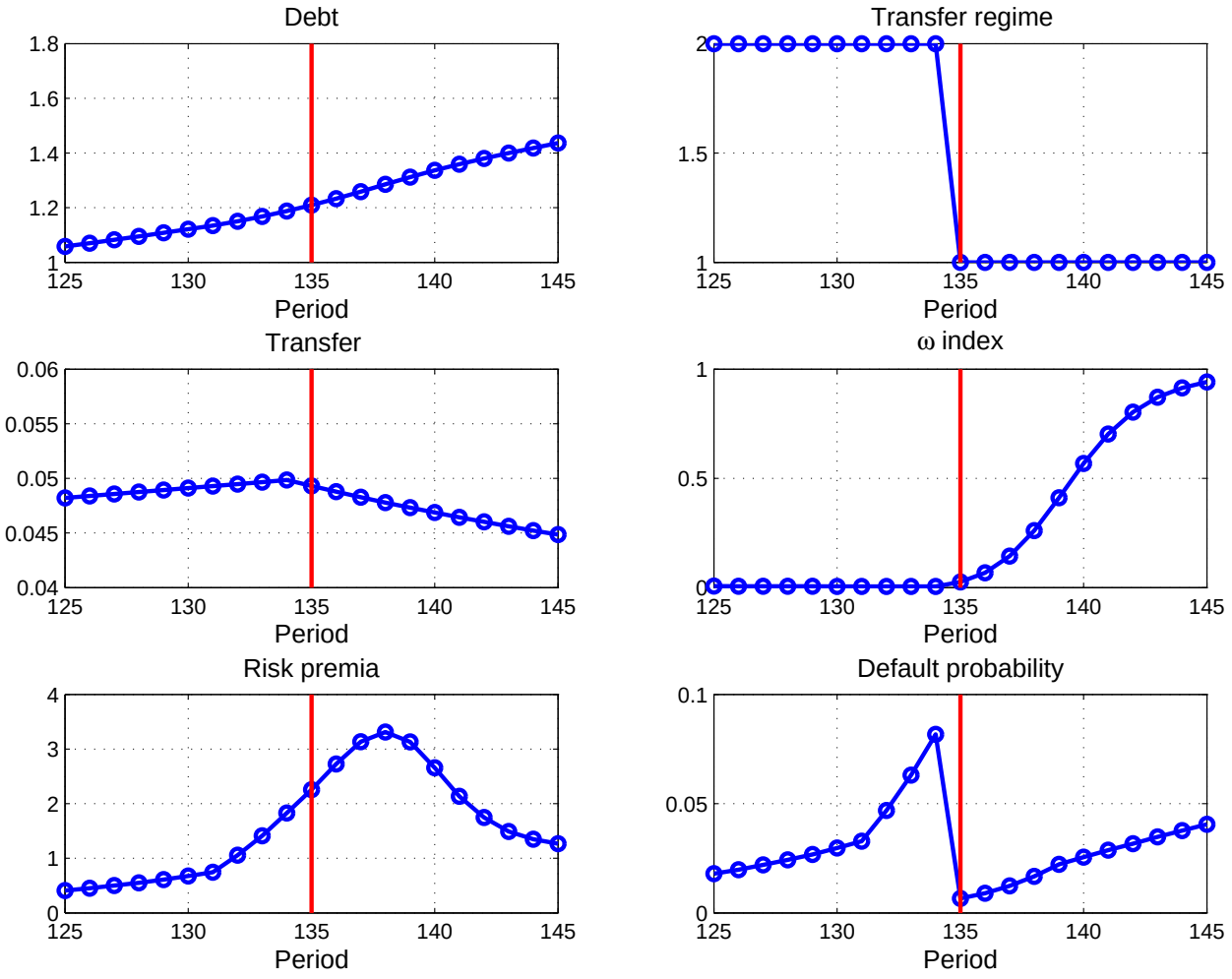

Figure 10: Simulation in the model with signal extraction: standard deviation for transfer shock is 1.6 per cent of the steady-state level. Transfer regime switches at the period of 135, and negative productivity shocks of 2 standard deviations occur from period of 133 to 140.

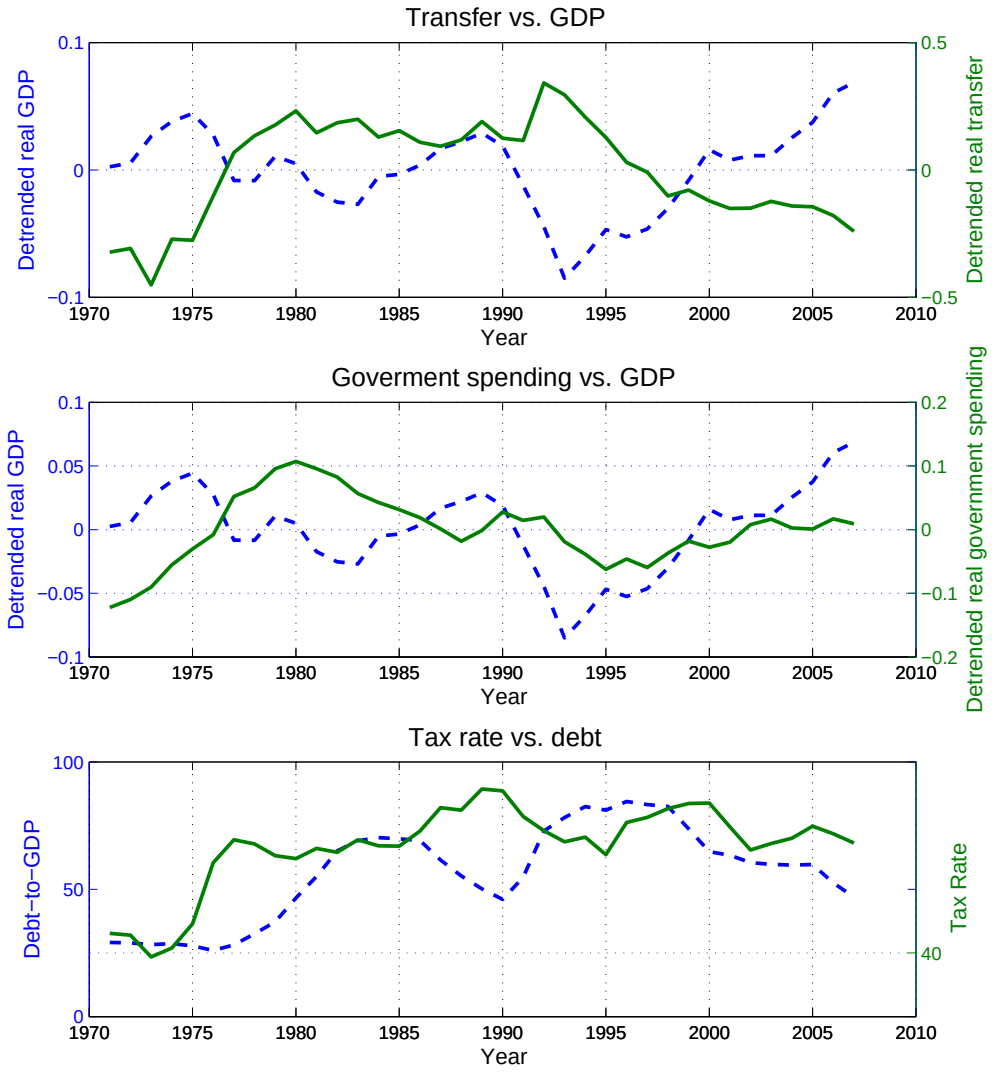

Figure 11: Swedish fiscal data: dashed lines are measured on the left axis, and solid lines are measured on the right axis. GDP, transfers, and government spending are detrended.

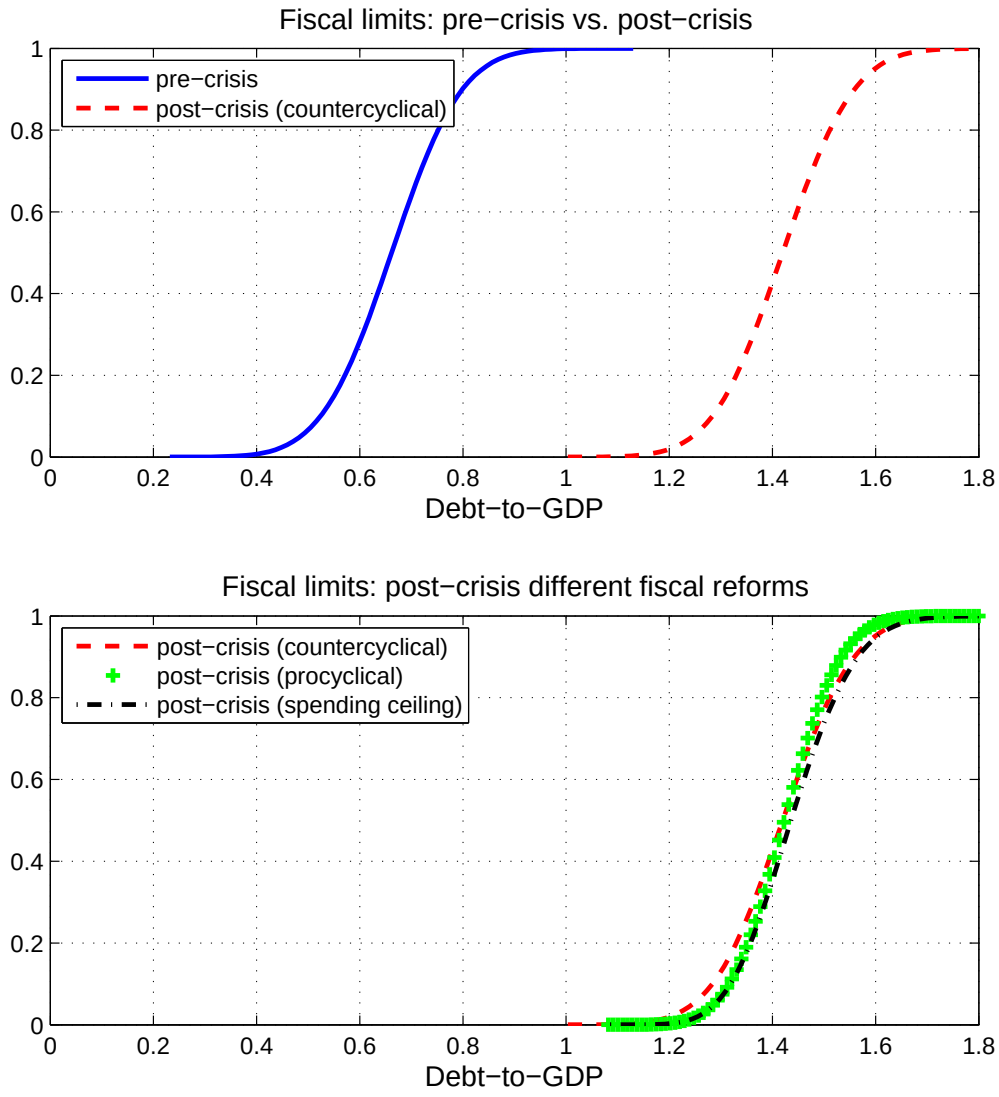

Figure 12: Estimated CDF for fiscal limits under alternative fiscal policies when calibrating to Swedish data. Top panel compares the pre-crisis case to the post-crisis case with countercyclical government spending. Bottom panel compares three post-crisis cases: countercyclical government spending, expenditure ceiling, and procyclical government spending.