Sovereign Debt and the Effects of Fiscal Austerity*

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Abstract

I study the impact of austerity programs implemented in the Eurozone since 2010. To do so I incorporate strategic sovereign default into a DSGE model where the government follows fiscal rules, which are estimated from data. I calibrate the model using data from Spain and estimate the size and impact of fiscal policy shocks associated with austerity policies. I then use the model to predict what would have happened to output, consumption, employment, sovereign debt levels and spreads if Spain had continued to follow the pre-2010 fiscal rule instead of switching to the austerity track. I find that, contrary to the expectations of policy makers at the time, austerity did not decrease sovereign spreads or debt-to–GDP ratios during 2010-2013. Furthermore it had a negative impact on employment and GDP. Nevertheless, the short run pain is related to a long run gain. The model predicts that as a consequence of austerity Spain is more likely to show lower levels of debt and spreads in the future.

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1 Introduction

The European debt crisis of 2010 triggered a debate on the potential effects of fiscal austerity. On the one hand, some economists claim that austerity is beneficial because it can increase creditworthiness and reduce sovereign spreads.[1] On the other, those against fiscal consolidation argue that it can worsen recessions and even become self-defeating or ineffective in reducing debt to GDP ratios and default risk.[2]

This policy debate started when most Eurozone countries were implementing fiscal austerity packages. Indeed, most of these policies were carried out after 2010, at the beginning of the European debt crisis. Hence, one way to contribute to this debate is to assess the ex post consequences of these policy measures. This paper aims to do so by taking one country, Spain, and asking: What was the impact of fiscal austerity from 2010 to 2014? In particular I focus on the effects on real variables (i.e., GDP, consumption, employment) and fiscal variables such as sovereign spreads and debt to GDP ratios.

To address this question, I propose a small open economy Dynamic Stochastic General Equilibrium (DSGE) model that incorporates the trade-off behind the debate. In this model, fiscal austerity can reduce debt and sovereign spreads, but it can also cause a deeper recession with higher unemployment that might in turn increase default risk and spreads. The model has three salient characteristics. First, in order to display a realistic fiscal policy it incorporates fiscal rules estimated using historical data up to 2007. These rules enter the model in a similar way to how a Taylor rule is incorporated into a nominal DSGE model. These rules are a key element to identify discretionary changes in fiscal policy aiming to reduce government spending. In other words, I use these rules to define fiscal austerity.

Second, motivated by high unemployment rates in some European countries, the model features downward nominal wage rigidity as in Schmitt-Grohé and Uribe (2016a). This nominal rigidity, coupled with a fixed exchange rate, generates a real rigidity that can cause unemployment in equilibrium. Third, it assumes that the government can strategically default on its debt

[1] "Sharp corrections are needed in countries that already face high and increasing risk premia on their debt. Failure to consolidate would not only raise the cost of borrowing for the government; it would also undermine macroeconomic stability with widespread economic costs." Corsetti (2010)

[2] See Corsetti (2012) for a summary of the discussion. Also see Cafiso and Cellini (2012), Cottarelli (2012), Gros (2011), Krugman (2015) and Wren-Lewis (2016).

as in Eaton and Gersovitz (1981) and Arellano (2008). To the best of my knowledge, this is the first paper to propose a model with these three characteristics jointly.

I calibrate the model to Spain, one of the countries that implemented important austerity packages after 2010. I then use it to assess the effects of austerity through a counterfactual exercise. I ask what would have happened to GDP, consumption, employment, sovereign spreads and debt to GDP ratios if, instead of implementing fiscal austerity after the second quarter of 2010, Spain had followed historical fiscal rules. I find that there was a significant impact on GDP, consumption and employment. Particularly, relative to the counterfactual, GDP, consumption and hours worked were 6% lower in 2014 as a consequence of austerity. Moreover, the results indicate that fiscal austerity did not decrease the debt to GDP ratio until the end of 2014 and actually slightly increased annual sovereign spreads (27 basis points higher on average after 2010Q2). As intended, austerity reduced government's debt level relative to the counterfactual . However, it also decreased GDP in similar proportions leaving the debt to GDP ratio unchanged in most of the period 2010-2014. This drop in GDP is associated with high fiscal multipliers generated by rigid nominal wages.

The reason why spreads increased is as follows. Since the model assumes that the government can strategically default, the increase in default risk and sovereign spreads is directly related with how austerity impacted the welfare associated with repaying the debt (or the value of repaying) and the welfare of not repaying (or the value of defaulting). The results indicate that austerity did not change the value of repaying even though it decreased debt levels. This is mainly because it worsened the recession and decreased consumption levels making debt repayment less attractive. Moreover, the value of defaulting increased with austerity. This result is mainly related to the assumption that the government is in financial autarky after default. Financial autarky implies that the government is forced to have a balanced budget and therefore the value of government spending equals taxes. Hence, lower government spending as a result of austerity entailed lower taxes causing higher consumption and welfare levels in default. With lower relative welfare from repaying debt, the government's default probability increased causing the sovereign spread to rise.

In turn, austerity seems to be effective in the long run. Model simulations indicate that Spain after the 2010-2014 austerity package is more likely to show lower future sovereign spreads and debt to GDP ratios compared to the counterfactual. The intuition behind this result is as follows. In the long run GDP levels start to converge back to steady state levels in both "versions" of Spain: with and without austerity. Nevertheless, the version of Spain with austerity in 2010-14 has a lower stock of debt and, as a result, it shows lower debt to GDP ratios and spreads.

Literature Review. This paper is related to three lines of research: (i) fiscal austerity, (ii) models with strategic sovereign default, and (iii) analysis of the Eurozone Crisis.

Regarding fiscal austerity analysis, this paper is most closely related to papers following a structural approach. In that line, House et al. (2017) pursue a similar exercise but without incorporating sovereign debt in their analysis. They find significant output costs as a consequence of austerity. Arellano and Bai (2016) and de Córdoba et al. (2017) use sovereign default models to analyze the Greek crisis. However, these models do not display unemployment in equilibrium. Moreover, de Córdoba et al. (2017) does not analyze the impact of austerity on sovereign spreads and Arellano and Bai (2016) does not use data on fiscal variables to discipline their calibration. Bianchi et al. (2016) is also directly related to this paper. They use a similar model to perform a normative analysis of fiscal policy. They show that wasteful expansionary fiscal policy might be desirable during recessions. Mendoza et al. (2014) analyzes how austerity through tax increases can restore fiscal solvency. However, the authors use a model without unemployment or default risk. Finally, Bi et al. (2013) study the macroeconomic impact of fiscal consolidations when the starting date of an austerity plan is unknown. They find that the composition, monetary policy stance and debt levels are important to determine the final impact.

The fiscal austerity literature has an older empirical branch starting with Giavazzi and Pagano (1990) and Alesina and Ardagna (2010). In these papers the authors use panels of austerity events to identify fiscal austerity shocks. Subsequent developments in this line of research are Alesina et al. (2012) who analyze medium term fiscal plans instead of fiscal policy shocks, and Guajardo et al. (2014) and Alesina et al. (2015) who follow a narrative approach as in Romer and Romer (2010). These papers generally find significant costs in terms of GDP growth, but the size of costs varies depending on the composition of austerity packages. In a similar spirit, Easterly et al. (2008) and Easterly and Servén (2003) remark that fiscal consolidation might have important supply side effects when it is highly focused on public investment. Following a different approach, this paper contributes to this branch of literature by computing the effects of fiscal consolidation on real GDP. Moreover, it also assesses the impact on default risk and sovereign spreads. More recently, Born et al. (2018) use a panel of developing and developed countries and show that the impact of austerity on spreads depends on the fiscal stress of the country. In particular, they show that when spreads and debt to GDP ratio are relatively high fiscal austerity leads to higher spreads. These results are consistent with my findings for the case of Spain.

The strategic default part of my model is taken from the sovereign default literature. In particular, I model default as in Eaton and Gersovitz (1981), Arellano (2008) and Mendoza and Yue (2012). I also adopt the technique for modeling long term debt from Hatchondo and Martinez (2009) and Chatterjee and Eyigungor (2012). Hatchondo et al. (2015) incorporate fiscal rules into a sovereign default model, but in the form of debt to GDP and sovereign spreads ceilings. They use their model to perform a different exercise. They assess the impact of debt and spreads ceilings on equilibrium sovereign spreads.

There are several papers that analyze the recent European crisis. This paper contributes to this literature by analyzing how fiscal policy after 2010 affected the severity of the crisis. Lane (2012) and Shambaugh (2012) provide a detailed description. Martin and Philippon (2014) use a structural DSGE model to assess the different factors that might have caused the crisis. They find that pre-crisis fiscal policy was an important ingredient. Like this paper, Schmitt-Grohé and Uribe (2016a) highlight the importance of downward nominal wage rigidity as a propagation factor in Europe.

Outline. The rest of the paper is organized as follows. Section 2 to 5 describe the model, section 6 highlights the key mechanisms, section 7 describes the calibration and 8 shows the results. Section 9 concludes.

2 Model

The model is in discrete time and describes an economy populated with four different agents: Households, Firms, International Creditors and a Government.

2.1 Household

There is a representative household that chooses consumption (C_t) and labor (H_t) plans to maximize a time separable utility,

$$E_t \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{H_t^{1+\frac{1}{\theta}}}{1+\frac{1}{\theta}} \right\} \tag{1}$$

where σ is the risk aversion coefficient, χ is a labor disutility parameter and θ denotes the Frisch elasticity. Consumption (C_t) is a composite of nontradable and tradable goods defined by the following Armington aggregator with elasticity of substitution μ and nontradables weight ω,

$$C_t = \mathcal{C}(C_{Nt}, C_{Tt}) = \left[\omega \left(C_{Nt}\right)^{\frac{\mu-1}{\mu}} + (1-\omega)\left(C_{Tt}\right)^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} \tag{2}$$

C_{Nt} and C_{Tt} denote nontradable and tradable consumption, respectively. The budget constraint that this agent faces is given by,

$$P_{Ct}C_t = W_t H_t + P_{Tt}\Pi_t - P_{Tt}T_t$$

Where W_t is the nominal wage, P_{Tt} and P_{Nt} represent tradable and nontradable prices. Further, Π_t are firm profits and T_t denotes lump sum taxes, both expressed in units of tradable goods. P_{Ct} is the consumer price level and is defined by,

$$P_{Ct} = \left[\omega^{\mu} P_{Nt}^{1-\mu} + (1-\omega)^{\mu} P_{Tt}^{1-\mu} \right]^{\frac{1}{1-\mu}}$$

The tradable good has a constant price $P_{Tt} = P^*$ and is the numeraire in this economy. I use lower cases to denote relative prices with respect to P_{Tt}, ie. $p_{Nt} = \frac{P_{Nt}}{P_{Tt}}$, $p_{Ct} = \frac{P_{Ct}}{P_{Tt}}$ and $w_t = \frac{W_t}{P_{Tt}}$. Therefore, the budget constraint and consumer price definition can be re-expressed as,

$$p_{Nt}C_{Nt} + C_{Tt} = w_t H_t + \Pi_t - T_t \tag{3}$$

$$p_{Ct} = \left[\omega^{\mu} p_{Nt}^{1-\mu} + (1-\omega)^{\mu}\right]^{\frac{1}{1-\mu}} \tag{4}$$

2.2 Firms

There are two firms that employ labor to produce nontradable and tradable goods. They use the following production technologies,

$$Y_{Nt} = A_{Nt}(H_{Nt}^{d})^{\alpha_N} \tag{5}$$

$$Y_{Tt} = A_{Tt}(H_{Tt}^{d})^{\alpha_T} \tag{6}$$

Y_{Nt} and Y_{Tt} are the production levels in every sector. Productivity levels are denoted by A_{Nt} and A_{Tt}, and labor demand in each sector is represented by H_{Nt}^{d} and H_{Tt}^{d}. I assume that productivity follow AR(1) processes,

$$log(A_{Nt}) = \rho_N log(A_{Nt-1}) + \sigma_N \epsilon_{Nt}^{A} \tag{7}$$

$$log(A_{Tt}) = \rho_T log(A_{Tt-1}) + \sigma_T \epsilon_{Tt}^{A} \tag{8}$$

Firms hire labor and maximize the following profit functions,

$$\Pi_{Tt} = A_{Tt}(H_{Tt}^{d})^{\alpha_T} - w_t H_{Tt}^{d} \tag{9}$$

$$\Pi_{Nt} = p_{Nt}A_{Nt}(H_{Nt}^{d})^{\alpha_N} - w_t H_{Nt}^{d} \tag{10}$$

2.3 Labor Market

As in Schmitt-Grohé and Uribe (2016a), I introduce downward nominal wage rigidity in the labor market. In particular, I assume that nominal wages at time t cannot be lower than a proportion, γ, of the wage level at $t-1$.

$$w_t \geq \gamma w_{t-1} \tag{11}$$

Constraint (11) implies that this model can display unemployment whenever the constraint binds.

2.4 Government

I assume the government is benevolent and has different policy instruments: government consumption G_t, lump sum net taxes T_t, and the decision of defaulting on its debt d_t.

For simplicity, I assume government consumption is allocated to tradables and nontradables in fixed proportions. In other words, I assume G_t is given by,

$$G_t = min\left\{\frac{G_{Nt}}{\phi_g}, \frac{G_{Tt}}{1-\phi_g}\right\} \tag{12}$$

where ϕ_g is the percentage of G_t that is allocated to nontradables. As a result, the government consumption price (relative to tradable goods) is given by,

$$p_{Gt} = \phi_g p_{Nt} + (1-\phi_g) \tag{13}$$

Moreover, the government issues long term debt to finance deficits. As in Chatterjee and Eyigungor (2012) and Hatchondo and Martinez (2009), the government can issue bonds with a geometrically decaying coupon δ. In particular, a bond issued at time t promises a stream of coupon payments $\delta(1-\delta)^{i-1}$ in periods $t+i$ for $i \geq 1$. Hence, the government budget constraint is given by,

$$p_{Gt}G_t + (1-d_t)\delta B_t = T_t + (1-d_t)q_t\left[B_{t+1} - (1-\delta)B_t\right] \tag{14}$$

where B_t is the face value of debt, q_t is the price of debt that international creditors are willing to pay, δB_t represents the coupon payments the government needs to pay at time t, and $B_{t+1} - (1-\delta)B_t$ is the amount of debt units issued (if $B_{t+1} \geq (1-\delta)B_t$) or purchased (if $B_{t+1} < (1-\delta)B_t$). Further, d_t represents the default decision, $d_t = 1$ if the country decides to default and $d_t = 0$ otherwise. Debt issuance and coupon payments are multiplied by $(1-d_t)$ because they only happen when the country is not in default.

2.5 International Creditors

As it is usual in the sovereign default literature, international creditors are deep pocket. They have a time separable linear utility function given by,

$$\sum_{t=0}^{\infty} \tilde{\beta}^t \left[C_t^* - \nu_t q_t B_{t+1}\right]$$

where ν_t is a liquidity shock that acts as an exogenous shock to the price of debt as in Krishnamurthy and Vissing-Jorgensen (2012). No arbitrage implies the following pricing equation,

$$q_t = \frac{\tilde{\beta}}{1+\nu_t} E_t \left\{ (1-d_{t+1}) \underbrace{(\delta + (1-\delta)q_{t+1})}_{\text{payoff if repay}} + d_{t+1} \underbrace{q_{t+1}^D}_{\text{price in default}} \right\} \tag{15}$$

As expressed in equation (15), q_t is the discounted expected payoff flow at $t+1$. Future payments depend on the default decision d_{t+1}. Hence, if government does not default ($d_{t+1} = 0$) creditors receive a coupon payment δ and the market value of outstanding debt $(1-\delta)q_{t+1}$. On the other hand, if government defaults creditors receive a defaulted bond with price q_{t+1}^D. The price of a defaulted bond is given by,

$$q_t^D = \frac{\tilde{\beta}}{1+\nu_t} E_t \left\{ \phi \left[(1-\tilde{d}_{t+1}) \underbrace{(\delta + (1-\delta) q_{t+1})(1-\psi) R^*}_{\substack{\text{payoff if return} \\ \text{and repay}}} + \tilde{d}_{t+1} \underbrace{q_{t+1}^D R^*}_{\substack{\text{payoff if return} \\ \text{and default}}} \right] + (1-\phi) \underbrace{q_{t+1}^D R^*}_{\text{no return}} \right\} \tag{16}$$

A country in default faces an exogenous probability ϕ to have the chance of regaining access to international capital markets. If it happens to have that chance the government has to decide whether to start repaying the outstanding debt or not. The repaying decision is represented by the endogenous variable $\tilde{d}_t$ that equals zero if there is repayment and one otherwise. As noted in equation (16), if the government has access to capital markets and decides to start repaying, the government receives the usual repayment with a face value haircut ψ, $(\delta+(1-\delta)q_{t+1})(1-\psi)R^*$.[3] Moreover, the international creditor keeps the same defaulted bond if the country can not regain access to capital markets or is able to return but decides not to start repaying. In other words, the repayment in those cases is given by $q_{t+1}^D R^*$. Note that both repayments in equation (16) incorporate accrued interests on defaulted debt. In particular, we assume the the stock of defaulted debt is updated by the risk free interest rate R^*.

In both price equations (15) and (16) the liquidity premium shock is given by $\nu_t = e^{m_t + \frac{\sigma_m^2}{2(1-\rho_m^2)}} - 1$, where m_t is a random variable that follows an AR(1) process in logs,

$$m_t = \rho_m m_{t-1} + \sigma_m \epsilon_t^m$$

where ϵ_t^m is a standard normally distributed shock.

3 Implementable Equilibrium

Given $B_0, A_{N0}, A_{T0}, m_0, G_0$, a sequence of fiscal policy variables $\{G_t, T_t, B_{t+1}, d_t, \tilde{d}_t\}_{t=0}^{\infty}$ and a shocks sequence $\{A_{N,t+1}, A_{T,t+1}, m_{t+1}\}_{t=0}^{\infty}$, an equilibrium is a set of prices $\{w_t, p_{Nt}, p_{Ct}, q_t\}_{t=0}^{\infty}$

[3]The exogenous haircut assumption is made for simplicity but it is common practice in quantitative sovereign default models. For models with endogenous haircuts see: Benjamin and Wright (2013) and Yue (2010)

and allocations $\{H_{Nt}, H_{Tt}, H_t^s, C_{Nt}, C_{Tt}\}$ such that,

1. Household maximizes utility (1) subject to (3)

2. Firms maximize profits (9) and (10)

3. Markets clear

$$G_{Nt} + C_{Nt} = Y_{Nt} \tag{17}$$

$$C_{Tt} + G_{Nt} + \delta B_t = Y_{Tt} + q_t \left[B_{t+1} - (1-\delta)B_t\right] \tag{18}$$

$$(w_t - \gamma w_{t-1})(H_t^s - H_{Nt}^d - H_{Tt}^d) = 0 \tag{19}$$

$$w_t \geq \gamma w_{t-1} \tag{20}$$

4. q_t satisfies (15)

Note that market clearing in labor markets (equations (19) and (20)) is not standard because of downward nominal wage rigidity. In particular, labor demand $H_{Nt}^d + H_{Tt}^d$ determines the equilibrium total working hours. If the nominal wage rigidity constraint is slack $w_t > \gamma w_{t-1}$ labor demand equals supply (H_t^s) and there is no unemployment. In turn, if the constraint binds total hours equal $H_{Nt}^d + H_{Tt}^d$ and there is positive unemployment as $H_t^s > H_{Nt}^d + H_{Tt}^d$.

4 Government Policy

The government has access to three different instruments when it has access to capital markets: a sovereign default decision d_t that affects the price of debt q_t, government consumption G_t, and net taxes T_t. The interaction of these three instruments determines the evolution of the face value of debt B_t through the government budget constraint.

I assume that the government follows fiscal rules to determine G_t and T_t. These fiscal rules describe fiscal policy in normal times and are calibrated using fiscal data before the Great Recession.

The rules determine a primary deficit $p_G G_t - T_t$. This deficit together with debt repayments are the financial needs that the government has to cover by issuing new debt. The government might decide to default on its debt because of two different reasons. First, it might default because financial needs are too high and as result the government is not able to get sufficient credit from the markets. This happens when the financial needs are higher than the peak of the debt Laffer Curve, that is when,

$$p_{Gt}G_t - T_t + \delta B_t > \max_{B_{t+1}} \{q_t(B_{t+1})\,[B_{t+1} - (1-\delta)B_t]\} \tag{21}$$

where the right hand side of (21) represents the maximum amount the government could get from international markets (the peak of the debt Laffer curve).

Second, I also assume that the government can strategically choose to default even when the government is able to get the necessary funds to repay the debt. This default decision is modeled as in typical sovereign default models à la Eaton and Gersovitz (1981). Hence, every period the government decides whether to repay the debt and keep having access to international debt markets, or to default and stay in autarky for a random number of periods bearing productivity costs.

4.1 Fiscal Rules

Following Blanchard and Perotti (2002), I assume that (detrended) government spending G_t evolves according to the following fiscal rule,

$$log(G_t) = \rho_G log(G_{t-1}) + \rho_{GY} log(Y_{t-1}) + \rho_{GB}\frac{B_{t-1}}{Y_{t-1}} + \sigma_G \epsilon_t^G \tag{22}$$

where ϵ_t^G is a standard normally distributed fiscal shock, Y_{t-1} is lagged detrended output and $\frac{B_{t-1}}{Y_{t-1}}$ is the lagged debt to GDP ratio. This fiscal rule includes lagged GDP and debt to GDP in order to allow for systematic changes in fiscal policy as a respond to changes in fundamentals. Hence, for instance, the government might systematically react to low GDP by increasing government spending. The implicit assumption in this rule is that the government can only react to changes in GDP or debt to GDP ratios with a lag of one quarter.

Moreover, following Bi (2012), net taxes are defined by the following fiscal rule with parameters t^* and γ_T

$$\frac{T_t}{Y_t} = t^* + \gamma_T \left(\frac{B_t}{4Y_t} \right) \tag{23}$$

where Y_t is GDP and B_t is the stock of sovereign debt, both variables are expressed in units of tradable goods.[4] As shown in figure 1, there is positive relationship between net taxes and debt levels in most of Eurozone countries with a sufficiently long series of Debt to GDP ratios. The exception seems to be Netherlands that does not show a statistically significant relationship.

The rule implies that higher debt levels imply higher debt repayments and, hence, more financial needs. According to the rule, the government decides to rise taxes to face those needs.

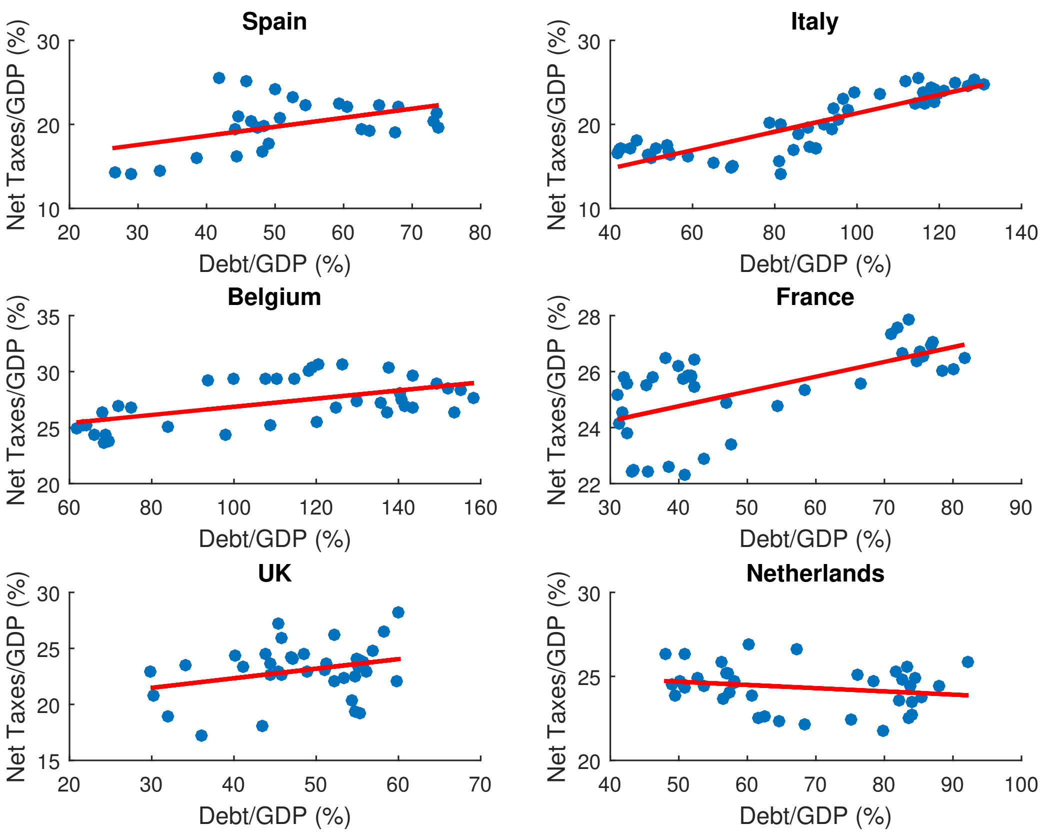
4.2 Default Decision

Conditional on having repayment capacity, the Government decides whether to repay or default in order to maximize Household's welfare. This welfare maximization is constrained by the implementable equilibrium conditions defined in section 3 and the fiscal rules defined in section 4.1. As it is usual in the sovereign default literature I focus on a Markov Perfect Equilibrium. This equilibrium definition implies that the default decision depends on a set of states $\mathbf{S}$, ie. $d = \Phi(\mathbf{S})$. The relevant set of states is given by $\mathbf{S} \equiv \{\mathbf{S_1}, \mathbf{S_2}\}$, where $\mathbf{S_1} \equiv \{B, w_{-1}\}$ and $\mathbf{S_2} \equiv \{A_N, A_T, G, m\}$. $\mathbf{S_1}$ is composed by the two endogenous states in the economy, the face value of debt and the lagged wage level. Further, $\mathbf{S_2}$ groups the exogenous variables that hit the economy and follow stochastic processes described in section 2.

Let $\mathcal{V}(\mathbf{S})$ be the government's value function before making the repayment/default decision. Also, let $\mathcal{V}^R(\mathbf{S})$ and $\mathcal{V}^D(\mathbf{S})$ be the value functions after deciding to repay and default, respectively. Define $C(\mathbf{S}), H(\mathbf{S}), Y(\mathbf{S}), p_G(\mathbf{S}), w(\mathbf{S})$ as consumption, hours, total product, price of government consumption and wage rate consistent with the implementable equilibrium. Hence, for a given price function $q(\mathbf{S_1'}, \mathbf{S_2})$ where $\mathbf{S_1'} \equiv \left\{B', w'_{-1}\right\}$ the value functions satisfy,

[4] Bi (2012) finds a positive relationship between debt levels and taxes. I find that this relationship still applies when using net taxes (Tax Income minus Transfers)

Figure 1: Tax Rules in Eurozone



Notes. Annual data up to 2007, starting points are around 1970 (they vary depending on each country). Net Taxes are total tax income minus transfers. Debt is defined as general government gross financial liabilities (see Appendix A.2 for data sources).

$$\mathcal{V}(\mathbf{S}) = \max_{d\in\{0,1\}} \Big\{ (1-d)\,\mathcal{V}^R(\mathbf{S}) + d\mathcal{V}^D\Big(B, w_{-1}, A_N, A_T, (1-d_g)G, m\Big)\Big\} \tag{24}$$

$$st.$$

$$d = 1 \quad \text{if} \quad p_G(\mathbf{S})G(\mathbf{S}) - T(\mathbf{S}) + \delta B > \max_{B'} \left\{ q(\mathbf{S_1'}, \mathbf{S_2}) \left[B' - (1-\delta)B\right]\right\}$$

$\mathcal{V}(\mathbf{S})$ summarizes the default/repayment decision. Every period the government compares the value of repaying $\mathcal{V}^R$ with the value of defaulting $\mathcal{V}^D$ and acts accordingly. Notice that the value of defaulting has one parameter (d_g) modifying one of its arguments. These two parameters highlight two different things that happen at the default event. in particular, we assume there is a drop (of d_g percent) in government consumption, where d_g is calibrated to match the average drop in G in historic default episodes. This change in G is a one time event and only happens at the default episode. The constraint in (24) highlights the fact that the government decides whether to default or not only when it has repayment capacity. If that is not the case, the government automatically defaults.

The value of repayment $\mathcal{V}^R(\mathbf{S})$ satisfies,

$$\mathcal{V}^R(\mathbf{S}) = u\left(C(\mathbf{S}), H(\mathbf{S})\right) + \beta E\left\{\mathcal{V}(\mathbf{S'})|\mathbf{S}\right\} \tag{25}$$

$$st.$$

$$p_G(\mathbf{S})G + \delta B = T(\mathbf{S}) + q(\mathbf{S_1'}, \mathbf{S_2})\left[B' - (1-\delta)B\right]$$

$$T(\mathbf{S}) = t^* Y(\mathbf{S}) + \frac{\gamma_T}{4}B$$

$$w'_{-1} = w(\mathbf{S})$$

$$log(G') = (1-\rho_G)log(\bar{G}) + \rho_G log(G) + \rho_{GY}\left[log(Y(\mathbf{S})) - log(\bar{Y})\right] + \sigma_G \epsilon^G$$

$$+ \text{ Equilibrium Conditions}$$

The value of repayment consists of an instantaneous utility $u\left(C(\mathbf{S}), H(\mathbf{S})\right)$ and a discounted continuation value $E\left\{\mathcal{V}(\mathbf{S'})|\mathbf{S}\right\}$. The first constraint in (25) is the government budget constraint and the second describes the net tax rule. These two conditions determine the law of motion for the debt face value B. The third constraint describes the law of motion for lagged wages w_{-1}, it simply states that future lagged wages are equal to wages today. The forth constraint shows the fiscal rule for government spending G, and the fifth line highlights the fact that private allocations are consistent with the implementable equilibrium.

The value in default $\mathcal{V}^D(\mathbf{S})$ is given by,

$$\mathcal{V}^D(\mathbf{S}) = u\left(C(\mathbf{S_1}, \tilde{\mathbf{S}}_\mathbf{2}), H(\mathbf{S_1}, \tilde{\mathbf{S}}_\mathbf{2})\right) + \beta E\left\{\phi \max\left\{\mathcal{V}^D(\mathbf{S}'), \mathcal{V}^R((1-\psi)B', w'_{-1}, \mathbf{S}'_\mathbf{2})\right\} + (1-\phi)\,\mathcal{V}^D(\mathbf{S}')|\mathbf{S}\right\} \tag{26}$$

$st.$

$T(\mathbf{S_1}, \tilde{\mathbf{S}}_\mathbf{2}) = p_G(\mathbf{S_1}, \tilde{\mathbf{S}}_\mathbf{2})G$

$B' = BR^*$

$w'_{-1} = w(\mathbf{S_1}, \tilde{\mathbf{S}}_\mathbf{2})$

$log(G') = (1-\rho_G)log(\bar{G}) + \rho_G log(G) + \rho_{GY}\left[log(Y(\mathbf{S})) - log(\bar{Y})\right] + \sigma_G \epsilon^G$

$+$ Equilibrium Conditions

$\mathcal{V}^D(\mathbf{S})$ consists of an instantaneous utility level plus a continuation value. In this case, the continuation value includes an exogenous probability of coming back to international capital markets, ϕ. The first constraint in (26) is the government budget constraint, where the value of government spending equals net taxes. The second highlights the assumption that, once in default, the stock of debt that the government owes is updated by the international risk free rate $R^* = 1/\tilde{\beta}$. The third constraint is the law of motion for wages, and the forth represents the government spending fiscal rule. Hence, this model assumes that once in default, the government follows the government spending fiscal rules and adjusts net taxes in order to keep a balanced budget.

Moreover, $\tilde{\mathbf{S}}_2 \equiv \left\{\tilde{A}_N, \tilde{A}_T, G, m\right\}$ in (26) is a modified state vector that includes exogenous productivity costs of default.[5] In particular, I follow Chatterjee and Eyigungor (2012) and

[5]This is a typical assumption in sovereign default models. Mendoza and Yue (2012) provide a microfoundation

assume the following productivity levels in default,

$$\tilde{A}_N = A_N - max\left\{0, d_0 A_N + d_1 A_N^2\right\}$$
$$\tilde{A}_T = A_T - max\left\{0, d_0 A_T + d_1 A_T^2\right\}$$

As it is usual in the sovereign default literature, productivity costs are convex. This is key assumption to generate more incentives to default when the economy is facing low productivity levels, and therefore low GDP.

The government has also more incentives to default when sovereign debt is high. High debt generates high net taxes through the tax rule and, therefore, low consumption. In turn, low consumption means that there is a high marginal utility for consuming, which implies high utility gains from defaulting and reducing taxes.

The lagged nominal wage level affects the default decision as well. Particularly, lower lagged nominal wages imply lower costs of default. Lower lagged wages implies that the downward nominal wage rigidity is less likely to bind in case of default. That implies that the expected increase in unemployment after default is lower and, therefore, defaulting becomes more attractive.

A higher liquidity shock is related with higher default probabilities as it increases the cost of issuing debt. Finally, the effect of government spending on spreads is ambiguous a priori. I will come back to the effects of austerity on spreads in section 8, but bear in mind that a drop in G has opposite effects on spreads because it reduces debt levels on one hand, but on the other it might affect private equilibrium allocations in a negative way, reducing consumption levels and nominal wages.

5 Recursive Equilibrium

The recursive Markov Perfect Equilibrium incorporates the optimal default decision of the government subject to the implementable equilibrium defined in section 3.

for this assumption. They claim that during financial autarky firms are not able to import certain intermediate goods, generating lower levels of productivity.

A Markov Perfect Equilibrium is a set of value functions $\mathcal{V}(\mathbf{S}), \mathcal{V}^R(\mathbf{S}), \mathcal{V}^D(\mathbf{S})$, a default decision $d = \Phi(\mathbf{S})$, a decision of defaulting when the country is in default and has the chance to regaining access $\tilde{d} = \tilde{\Phi}(\mathbf{S})$ and price schedules $q(\mathbf{S_1'}, \mathbf{S_2})$ and $q^D(\mathbf{S_1'}, \mathbf{S_2})$ such that,

1. Given the price schedule $q(\mathbf{S_1'}, \mathbf{S_2})$, the value functions solve problems (24), (25) and (26)

2. Given the default decision, the price schedules satisfy the following equation

$$q(\mathbf{S_1'}, \mathbf{S_2}) = \frac{\tilde{\beta}}{1+\nu_t} E\left\{m' \left\{(1-\Phi(\mathbf{S'}))\left(\delta + (1-\delta) q(\mathbf{S_1''}, \mathbf{S_2'})\right) + \Phi(\mathbf{S'}) q^D(\mathbf{S_1''}, \mathbf{S_2'})\right\} |\mathbf{S_1'}, \mathbf{S_2}\right\} \tag{27}$$

$$\begin{aligned} q^D(\mathbf{S_1'}, \mathbf{S_2}) =& \frac{\tilde{\beta}}{1+\nu_t} E_t\{\phi \left[(1-\tilde{\Phi}(\mathbf{S'}))\left(\delta + (1-\delta) q(\mathbf{S_1''}, \mathbf{S_2'})\right) + \tilde{\Phi}(\mathbf{S'}) q^D(\mathbf{S_1''}, \mathbf{S_2'}) R^*\right] \\ &+ (1-\phi) q^D(\mathbf{S_1''}, \mathbf{S_2'}) R^* |\mathbf{S_1'}, \mathbf{S_2}\} \end{aligned} \tag{28}$$

3. The default decisions solve problems (24) and (26)

6 Analysis

The model described in the previous sections is rich enough to display non-linear responses to fiscal policy. As a consequence, the effect of changes in government expenditure depends on what part of the state space the economy is located. In this section I describe the mechanisms behind the fiscal policy impact. In particular, I explain the main mechanism that determines the size and sign of fiscal multipliers

What is the impact of a decrease in government consumption in this model ? To provide some intuition consider the following equation that comes from Household first order conditions with respect to consumption of nontradables C_{Nt} and tradables C_{Tt},

$$
\begin{aligned}
p_{Nt} &= \frac{\omega}{1-\omega}\left(\frac{C_{Tt}}{C_{Nt}}\right)^{1/\mu} \\
\downarrow p_{Nt} &= \frac{\omega}{1-\omega}\left(\frac{C_{Tt}}{Y_{Nt} - \downarrow G_{Nt}}\right)^{1/\mu}
\end{aligned} \tag{29}
$$

where the second line in (29) plugs in the market clearing in nontradable goods market. Equation (29) implies that, for a given level of C_{Tt} and nontradables output Y_{Nt}, the impact of a drop in government spending on nontradables G_{Nt} is a reduction in the relative price of nontradables p_{Nt}.[6] The drop in p_{Nt} has an effect on the labor market. In particular, consider the labor demand for tradables and nontradables that come from maximizing (9) and (10), respectively.

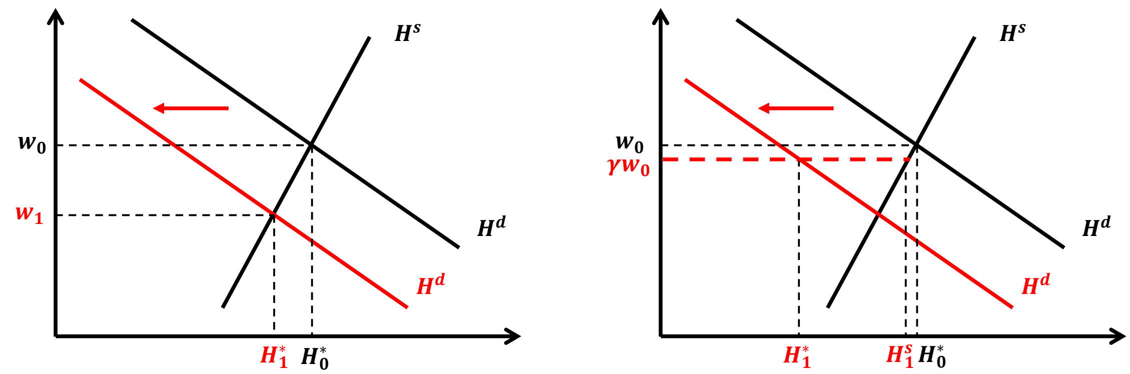
$$
H^d_{Tt} = \left(\frac{\alpha_T A_{Tt}}{w_t}\right)^{\frac{1}{1-\alpha_T}} \tag{30}
$$

$$
\downarrow H^d_{Nt} = \left(\frac{\downarrow p_{Nt}\alpha_N A_{Nt}}{w_t}\right)^{\frac{1}{1-\alpha_N}} \tag{31}
$$

Equation (31) shows that a drop in p_N generates a fall in the nontradable sector labor demand. This fall in labor demand generates a drop in total GDP. However, the magnitude of the final impact on GDP will depend on the downward nominal wage rigidity constraint. If the constraint does not bind the total effect is mitigated by a drop in wages. Lower wages increase labor demand and reduce the initial drop in H_{Nt}. However, this second effect is not present when the constraint binds. Hence, since wages fall little GDP drops more as a result.

[6] Here I focus on a change in G_N instead of G because, as I will detail in the calibration section, most of government consumption is spent on nontradables.

Figure 2: Occasionally Binding Constraint and Fiscal Multipliers



(a) Non-binding constraint

(b) Binding constraint

The two different cases are depicted in figure 2. Panel (a) shows the case in which wages fall reducing the total impact on quantities. On the other hand, panel (b) illustrates the case in which the downward nominal wage constraint binds and wages can fall only up to γw_0. In this second case the impact of the fiscal shock is much more important. As wages can not adjust, labor demand ends up being lower than supply resulting in positive unemployment levels ($H_1^s > H_1^*$).

The previous analysis shows that fiscal multipliers can be highly non linear and state dependent. But how big can they be with reasonable parameter values ? Table 1 shows the impact multipliers for different changes in government consumption (in direction and magnitude). The Impact multiplier is defined as,

$$\mu_G = \frac{\Delta GDP_t}{\Delta G_t} = \frac{\bar{p}_N \Delta Y_{Nt} + \Delta Y_{Tt}}{\Delta G_t} \tag{32}$$

where $\bar{p}_N$ is the steady state relative price of nontradable to tradable goods, ΔGDP_t and ΔG_t represent the change in real GDP and government spending. The columns in Table 1 compute μ_G for ΔG's of different magnitudes, assuming an initial point in which the constraint does not bind. The rows compute the multiplier at different points of the state space. Particularly, I analyze the change in multipliers for different amounts of debt and productivity levels in both sectors. In the case of productivity in the tradable and nontradable sectors, "High" and "Low" represent levels four standard deviations above and below the steady state value. When I change debt levels, "High" and "Low" denote debt levels 20% above and below the steady state.

Table 1: Impact Multipliers and Fundamentals

States	$\downarrow 5\%\ \bar{G}$	$\downarrow 1\%\ \bar{G}$	$\downarrow 0.1\%\ \bar{G}$
Steady State	3.11	2.32	-0.13
Nontradables productivity A_N			
High	3.03	2.11	-0.06
Low	3.19	2.53	-0.22
Tradables productivity A_T			
High	3.15	2.40	-0.21
Low	3.07	2.23	-0.06
Debt level B			
High	3.05	2.05	-0.10
Low	3.17	2.58	-0.17

Notes. The table shows impact multipliers when government spending changes by different amounts (as percentage of steady state government spending). These different cases are shown in different columns. The rows imply different parts of the state space. The first row shows multipliers at the steady state. The rest of the columns compute the multipliers for different levels of productivity and debt levels. High and low productivity levels (in tradable and nontradable sectors) means four standard deviations above and below the mean. High and low debt cases correspond to debt levels 20% above and below the steady state, respectively.

Table 1 shows that the multipliers are close to zero when government spending decreases by a small amount so that the constraint does not bind (column 3). In theses cases government spending affects GDP through two channels: wealth effects and reallocation of labor across sectors. Wealth effects affect GDP through changes in labor supply: a lower G brings about lower taxes T which in turn increase demand for leisure, shifting labor supply leftwards. In addition, since most of G is devoted to nontradable goods, a lower G decreases relative demand for nontradable goods shifting labor to the tradable sector. The total effect of this reallocation on GDP depends on the relative labor productivity of each sector. If the nontradables labor productivity is higher than that of tradables, this shift decreases GDP and viceversa. In general, Table **??** shows that multipliers are negative when the constraint does not bind. This means that a drop in government spending can increase GDP.

As presented in Table 1, multipliers are much higher when the constraint binds. Hence, output contracts more when there is a drop in G. They are between 2 and 3.2 when the reduction in G is large enough (column 1 and 2). These values are higher than the ones found in the empirical literature on average. However, they are in line with fiscal multipliers in recessions that are found using regime switching VARs.[7] Note that the value of multipliers when the constraint binds changes for different points in the state space. This is due to the fact that the initial impact of G on p_N varies across the state space. From equation (29) one can see that the effect of G on p_N is higher when tradables consumption C_T is relatively high and nontradables output Y_N low. This explains why the multiplier is higher when tradables productivity A_T is high and nontradables productivity A_N is low. Moreover, a high level of debt is associated with high debt repayments, high exports of tradable goods and lower tradable consumption C_T, implying a lower multiplier.

7 Calibration

I calibrate the model using data from Spain, one of the countries with most important austerity programs in Europe. Standard parameters are set using common values in the literature. The rest of the parameters are chosen to match a set of moments. Table 3 shows the chosen values.

Risk aversion σ, the Frisch elasticity θ, and output labor elasticities α_N and α_T are calibrated to standard values. Household's discount factor β is 0.9, a low value but in line with the sovereign default literature. The labor disutility parameter χ is set to get a steady state labor equal to one. In addition, the elasticity of substitution between tradables and nontradables μ comes from Stockman and Tesar (1995) and corresponds to a sample of industrialized countries. The weight of nontradables (ω) is used to match the share of nontradables value added on total GDP in

[7]See for example Auerbach and Gorodnichenko (2012), Nicoletta Batini and Melina (2012) and Owyang et al. (2013).

steady state.[8]

Regarding the government sector, fiscal rules are estimated using data before the financial crisis. In particular, I use data from 1980 to 2007. Table 2 shows the estimation results. Columns (1)-(2) present the coefficients for the government spending rule. The first column includes lagged GDP as a control whereas the second uses the lagged debt to GDP ratio. Both columns show that government spending is persistent with an AR(1) coefficient of 0.98. Moreover, lagged GDP and debt are economically insignificant: a quarterly drop in real GDP of 1% generates a fall in government spending of 0.09% and an increase in debt to GDP of one percentage point is associated with a decrease in government spending of 0.02%. For that reason, I assume that G_t follows a simple AR(1) process when I solve the model.

Table 2 column (3) shows the estimation of the net tax rule. The coefficient that relates the tax rate with debt levels is statistically significant and equal to 0.13. Mainly as a robustness check, the table also displays estimation results using data for the period 1995-2007, that is, only considering the period after Spain joined the European Union. As shown in columns (4)-(6), results do not change significantly for the government spending fiscal rule. However, the tax rule coefficient changes from 0.13 to 0.22 (see columns 3 and 6). I solve the model using 0.13, however the main results of the paper do not change if I use 0.22 instead.

The proportion of government expenditure that is devoted to nontradables ϕ_g is difficult to calibrate given the lack of detailed data. I set this parameter equal to the non-tradables share of GDP (78%). I calibrate the drop in G in a default event (d_g) to match the reduction in government spending in historical default episodes. These episodes are taken from Schmitt-Grohé and Uribe (2016b) and correspond to developing countries.

The coupon rate is set to match a 6 year average debt maturity [9]. International creditor's discount factor is such that the annual risk free rate is 4%. The default haircut ψ is taken from Cruces and Trebesch (2013) and refers to the average haircut after debt restructurings involving face value reductions (65%). The probability of returning to markets ϕ matches the average exclusion time computed by Cruces and Trebesch (2013). I am using the average exclusion time

[8] Data from Instituto Nacional de Estadìsticas (INAE) for the period 1997Q1-2014Q2. The tradable sector refers to Agriculture and Industry, whereas the nontradable part of the economy includes Construction and Services.

[9] Data from the Spanish Treasury, see http://www.tesoro.es/sites/default/files/estadisticas/02I.pdf

related to restructurings with haircuts higher than 30%.

I estimate the downward nominal wage rigidity parameter γ, the productivity costs of default parameters d_0 and d_1 and the shock processes by fitting the moments listed in table 4. The Simulated Method of Moments estimation aims to match the standards deviation of wages, average spreads, and average and standard deviation of debt to GDP ratio. In addition I match the standard deviation and serial correlation of spreads, tradable and non-tradable output.

In order to get the model implied estimates I simulate the model 10,000 times and compute the moments for windows of time in which the government is not in default.[10] The moments in table 4 are the median values of all windows. The distance between the data and model implied moments is weighted by the data Bootstrap standard errors of each moment. Therefore, moments that are not precisely estimated with real data receive a lower weight in the calibration.

Model Fit. The model does a decent job fitting the selected moments as table 4 shows. Following Bocola and Dovis (2016), I check the model fit by comparing the relationship between

[10] I only consider windows with more than 30 observations. Also, I exclude from the analysis the first 30 observations after a default event.

Table 2: Estimated Fiscal Rules

Variables	**Data 1980-2007**			**Data 1995-2007**		
	$log(G_t)$	$log(G_t)$	T_t/GDP_t	$log(G_t)$	$log(G_t)$	T_t/GDP_t
	(1)	(2)	(3)	(4)	(5)	(6)
$log(G_{t-1})$	0.98***	0.98***		0.96***	1.00***	
	(0.02)	(0.02)		(0.03)	(0.04)	
$log(GDP_{t-1})$	0.09***			0.05		
	(0.02)			(0.05)		
$Debt_{t-1}/GDP_{t-1}$		-0.02**			-0.06**	
		(0.01)			(0.03)	
$Debt_t/GDP_t$			0.13***			0.22***
			(0.02)			(0.03)
Observations	111	111	112	59	59	60
R-squared	0.974	0.971	0.236	0.933	0.937	0.43

Notes. Standard errors in parentheses, $***p < 0.01$, $**p < 0.05$, $*p < 0.1$.
Data from OECD economic outlook No. 99.

Table 3: Calibration

Description	Parameter	Value	Target
Panel A: Household, Firms and Labor Market			
Discount Factor	β	0.9	Standard
Risk Aversion	σ	2	Standard
Frisch Elasticity	θ	1	Standard
Labor disutility	χ	1.52	Steady State Labor $\bar{H} = 1$
Elast. of substitution	μ	0.74	Stockman and Tesar (1995)
Nontradables weight	ω	0.80	SS Nontradables Output Share = 78%
Labor elasticity	α_N,α_T	2/3	Standard
Downward wage rigidity	γ	$0.99^{1/4}$	Moments in table 4
Panel B: Government			
Steady State G	$\bar{G}$	0.24	Steady State G/Y = 21%
G rule AR(1)	ρ_G	0.976	Fiscal Rule Estimation
G rule SD	σ_G	0.96%	Fiscal Rule Estimation
Net Tax rule parameter	t^*	0.16	Fiscal Rule Estimation
Net Tax rule parameter	γ_T	0.13	Fiscal Rule Estimation
Bond coupon rate	δ	1/24	Avg maturity = 6 yrs
Nontradables share G	ϕ_g	0.78	nontradables GDP share
Drop of G in default	d_g	0.95	Figure 4(a)
Panel C: Int'l Creditors and Default			
Int creditors Disc Factor	$\tilde{\beta}$	0.99	Annual risk free rate = 4%
Default Haircut	ψ	0.65	Cruces and Trebesch (2013)
Prob. of reentry	ϕ	0.04	Cruces and Trebesch (2013)
Default Prod Cost	d_0	-0.39	Moments in table 4
Default Prod Cost	d_1	0.47	Moments in table 4
Panel D: Shock Processes			
Tradables Prod AR(1)	ρ_{AT}	0.98	Moments in table 4
Nontradables Prod AR(1)	ρ_{AN}	0.95	Moments in table 4
Liq Premium AR(1)	ρ_m	0.44	Moments in table 4
Tradables Prod SD	σ_{AT}	1.17%	Moments in table 4
Nontradables Prod SD	σ_{AN}	0.93%	Moments in table 4
Liq Premium SD	σ_m	2.54%	Moments in table 4

fundamentals and spreads. Figure 3 shows the model implied relationships and the data points for Spain in the period 1995-2014. The black solid line is a fitted fourth degree polynomial using model simulated data. The blue data points correspond to data before 2012, whereas the red ones refer to quarters after that year. Figure 3 shows a good fit with the data if we only consider data points before 2012. We can see there is a strong nonlinear relationship between GDP, debt to GDP ratios and spreads (see panels a and b) if we focus on the blue dots. In the case if the relationship between debt to GDP and sovereign spreads, the model implied regression cannot fit the data points after 2012 simply because spreads dropped even debt to GDP ratios were the highest in the sample. The reason of this drop in spreads after 2012 may be related to the European Central Bank implementation of Outright Monetary Transactions (OMT) program. This program was launched by the European Central Bank (ECB) in 2012, and basically allowed the ECB to buy sovereign bonds in order to keep sovereign spreads low. The program has not been used so far, but its announcement might have had important effects on international creditors risk aversion. This is incorporated in the model as an external factor affecting sovereign spreads and is captured by the liquidity premium shock.

Table 4: Model Fit

Target	**Model**	**Data**	**Data Description**
Average Spread	1.94%	1.17%	10 yr bond spread 1995Q1-2014Q4
Serial Corr spread	0.90	0.98	10 yr bond spread 1995Q1-2014Q4
SD spread	3.6%	1.5%	10 yr bond spread 1995Q1-2014Q4
Average Debt/GDP	64%	55%	Debt to GDP 1995-2015
Std Dev Debt/GDP	16%	14%	Debt to GDP 1995-2015
Serial Corr $\log(Y_N)$	0.93	0.99	Const and Serv V. Added 1995Q1-2014Q4
SD $\log(Y_N)$	4.2%	7.2%	Const and Serv V. Added 1995Q1-2014Q4
AR(1) coefficient $\log(Y_T)$	0.92	0.98	Agr and Ind V. Added 1997Q1-2014Q4
SD $\log(Y_T)$	7.9%	5%	Agr and Ind V. Added 1995Q1-2014Q4
SD $\Delta \log(W)$	0.6%	0.7%	Nominal Wages 2000Q2-2014Q4

Notes. Spreads and Debt to GDP ratios come from the OECD. Data on tradables and nontradables value added are from the Spanish National Statistics Institute (INE). See Appendix A.2 for a detailed description of data.

I am also including a third panel (c) to check the relationship between government spending and spreads. As will be clear in the results section, the relationship between G and spreads is strongly state dependent and can be positive or negative depending on the effects of G on the value of staying in markets and the value of defaulting. For that reason the model predicts a very weak relationship between the two variables. In line with the model, the data for Spain do not show a clear relationship either.

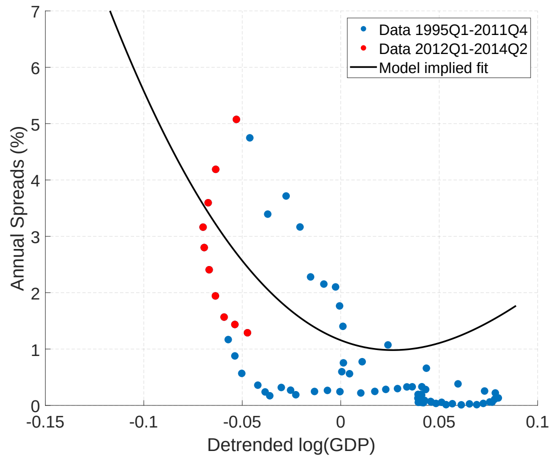
Figure 4 panel (a) presents the result of the calibration of the exogenous drop in government spending in default (d_g). This figure shows the evolution of government spending before, during and after default. The paths are expressed in percentage deviations with respect to real government spending four years before the default episode. The blue line is computed using model simulated data, the black line corresponds to the average path computed using real data from historical default episodes, whereas the grey shaded area shows a data-implied two standard deviation confidence interval. As shown in the figure, the two government spending series are similar and the model implied path (dashed blue) is within the data confidence interval. The government spending levels before and after the default event are closely matched.

I also use this type of exercise to check whether the parameters of the productivity cost of default (d_0 and d_1), which are calibrated using data on spreads, are sensible in terms of GDP costs during default. To do so I compare the evolution of GDP during historical default episodes with the model-implied average path. This exercise is shown in 4 panel (b). The figure depicts similar data and model implied paths, suggesting that calibrated productivity costs are reasonable.

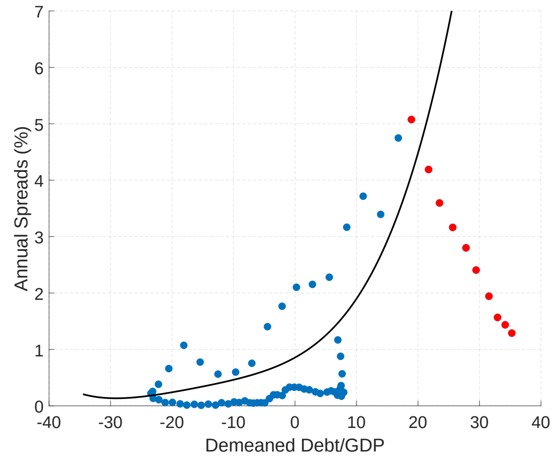
8 Results

In this section I use the model to quantify the effects of fiscal austerity in Spain. I define austerity as the negative government spending shocks ϵ_t^G that hit the economy after the second quarter of 2010. The exercise simply consists of running a counterfactual and test what would have happened if these negative shocks on G were absent after 2010-Q2. I follow two steps to perform the exercise. First, I recover the realization of shocks such that model implied paths for tradable output (Y_T), nontradable output (Y_N), sovereign spreads, debt to GDP ratios and

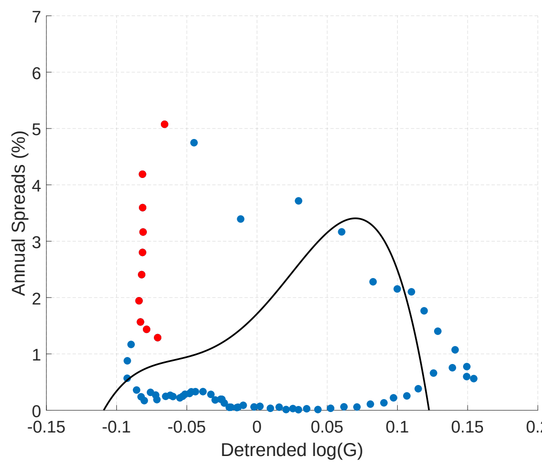
Figure 3: Spreads and Fundamentals



(a) GDP



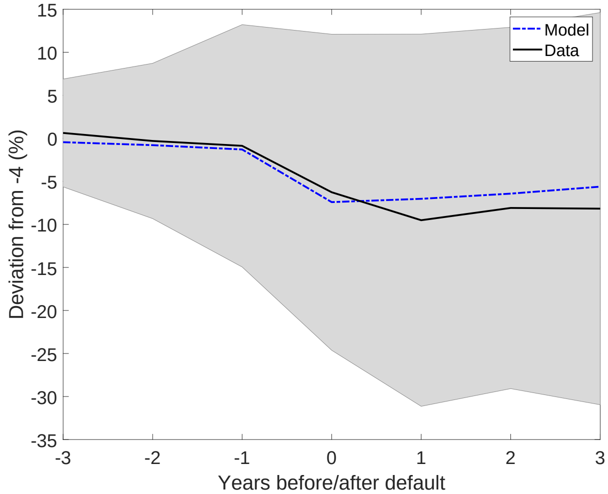
(b) Debt/GDP



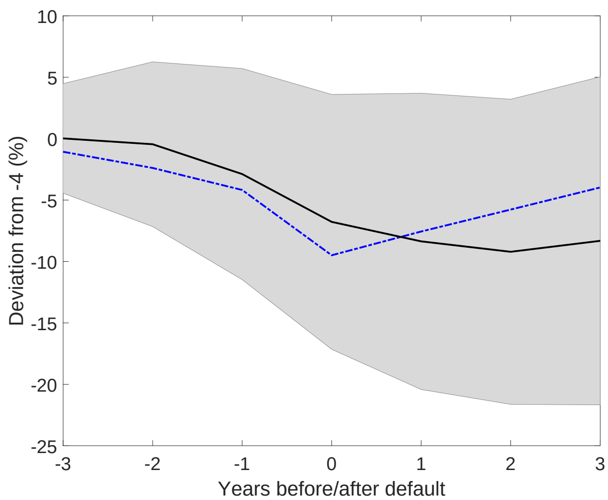
(c) Government Consumption

Notes. The figures show the relationship between spreads and (a) GDP, (b) demeaned debt to GDP ratio, and (c) Government Consumption. The solid line is estimated by fitting a fourth degree polynomial to model implied data (simulation of 10,000 periods). The dots highlight true data points for Spain (1995Q1-2014Q2). Blue dots are observations before 2012, red dots highlight post 2012 data points.

Figure 4: Default events: model vs data



(a) Government Consumption



(b) GDP

Notes. Figures show the evolution of Government Consumption (Panel a) and GDP (Panel b) in typical default episodes. Units are percentage deviation with respect to four years before the default event. Black lines represent data averages, the grey shaded area correspond to 2 standard deviations interval around the data implied average, and blue lines come from model simulations. Data series are average paths for recent default episodes taken from Schmitt-Grohé and Uribe (2016b). Data on GDP and government consumption come from World Bank's World Development Indicators. Model implied series come from 10,000 simulations from the calibrated model.

government spending (G) best fit the empirical paths. Second, I run a counterfactual without austerity shocks, and compare implied paths of endogenous variables.

Getting Filtered Shocks. As noted in section 7, the model does a good job matching relevant moments for Spain. As it is usually done in the DSGE literature, I can use this structure to extract the model implied shocks that hit the economy during and after the last financial crisis. To do so I employ a Particle Filter as in Fernandez-Villaverde and Rubio-Ramirez (2007). Consider the following state space representation,

$$\boldsymbol{S_t} = f\left(\boldsymbol{S_{t-1}}, \boldsymbol{\epsilon_t}\right) \tag{33}$$

$$\boldsymbol{Y_t} = g\left(\boldsymbol{S_t}\right) + \boldsymbol{\eta_t} \tag{34}$$

Equation (33) is the state equation, where $f(.)$ is a nonlinear function of the state variables in the previous period $\boldsymbol{S_t}$, and $\boldsymbol{\epsilon_t}$ is a vector of structural shocks. Moreover, equation (34) represents the measurement equation where $g(.)$ is a nonlinear function of the states, and $\boldsymbol{\eta_t}$ is a vector of measurement errors.

The observables I use to perform the filtering exercise are: tradable output (Y_T), nontradable output (Y_N), government consumption (G), debt to GDP ratio and sovereign spreads (s). The data correspond to the period 1997Q1-2014Q2. I calibrate the measurement error variances setting them equal to 10% of the variance of each data series.[11] Three of the four structural shock processes are unobserved: the liquidity premium shock and both productivity shocks. Government expenditure shocks are directly observed from data.

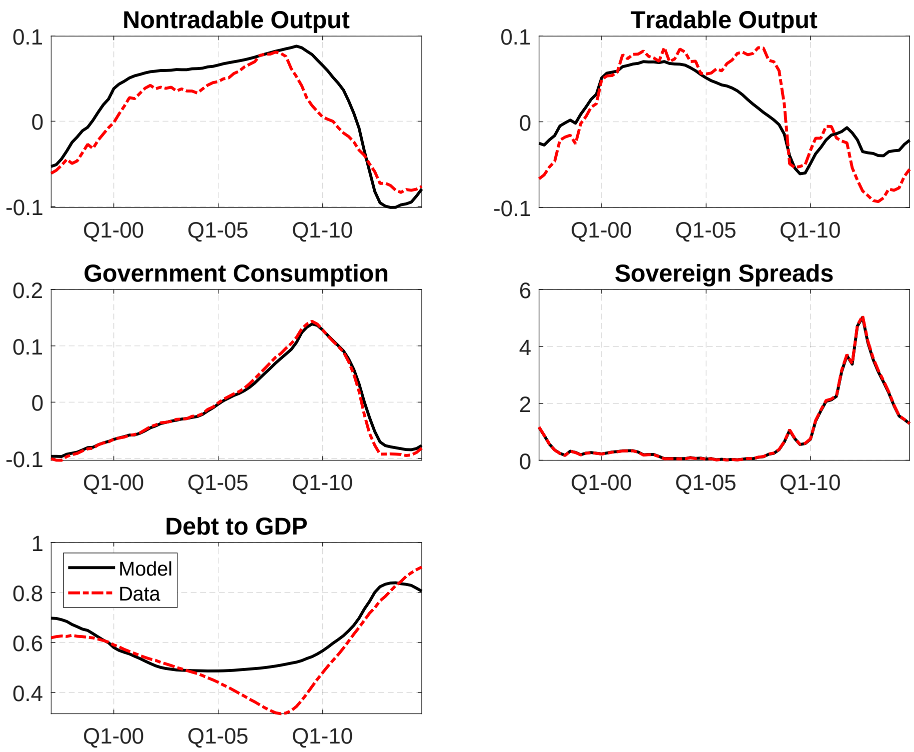
Note that the productivity shocks computed in this exercise should be interpreted as any private sector shock affecting firms marginal costs. The list of factors that might affect marginal costs includes productivity levels, but also financial costs and any shock affecting capital stock levels. I will refer to them in this section as "fundamental shocks".

Figure 5 presents the data series and the filtered variables implied by the model. The figure

[11] Since government spending is directly observed from data and spreads are affected by a exogenous shock, I set the measurement error variance of these two series to only 1% of sample variance. I use 10,000 particles for the results.

shows that the model can actually replicate the recent evolution of macro variables in Spain. Indeed, even though I am including measurement errors, the true series are close to the model implied ones.

Figure 5: Filtered Series and Data



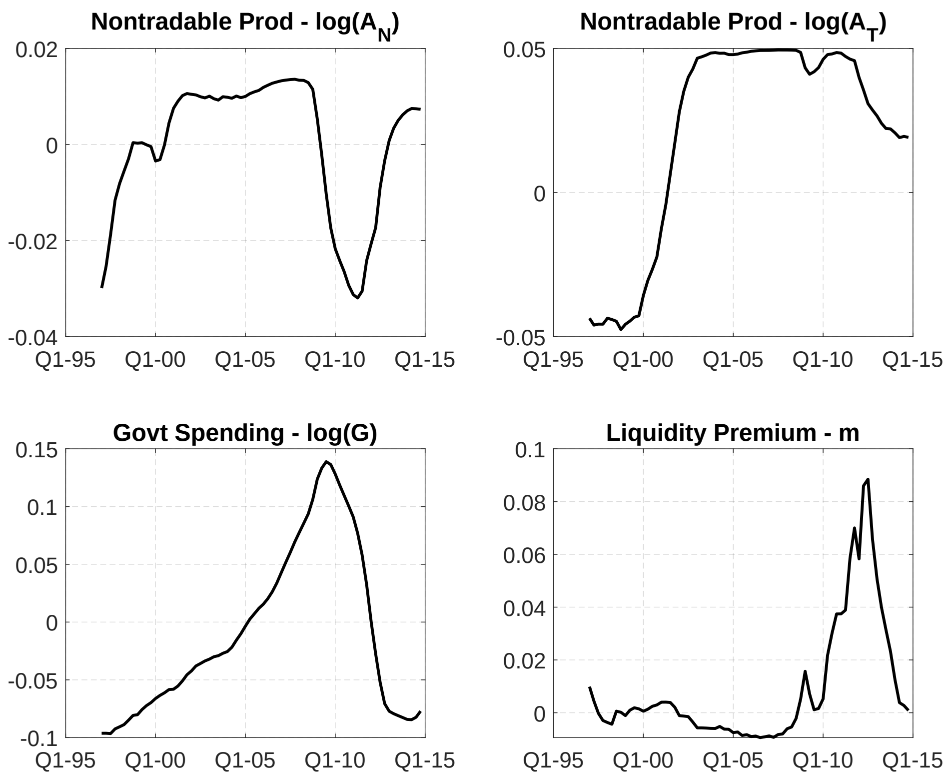
Notes. This figure shows the data employed in the filtering exercise. Red dashed lines are data series, solid black lines are filtered series from the model. Government consumption, tradable and nontradable output are log detrended values. Spreads are annual and expressed in percentages.

Figure 6 shows the filtered exogenous states computed by the filter: nontradable and tradable productivity, government spending and liquidity premium. The model suggests that the most important driver of the financial crisis has to do with fundamentals in the nontradable sector. In turn, the tradable sector productivity level is above its mean most of the sample.[12] The

[12]One key driver of the Spanish crisis has to do with the banking sector and credit availability. These factors are not explicitly modeled, but their effects on firms marginal costs are included in the private sector fundamentals

European debt crisis that started in 2011 showed a drop in productivity in nontradables. In the debt crisis the government reduced government spending quickly. From 2011Q3 to 2013Q1 detrended government spending dropped by 12%. Liquidity premium shows an upward trend at the beginning of the debt crisis. Interestingly, it starts falling from 2012, year in which the Outright Monetary Transactions (OMT) program was announced. This evolution of the liquidity premium shock shows that spreads were also affected by external factors. [13]

Figure 6: Filtered Shocks



Notes. This figure shows the filtered shock processes computed using the Particle Filter. The solid black line is the mean value, the grey bars highlight Eurozone recessions.

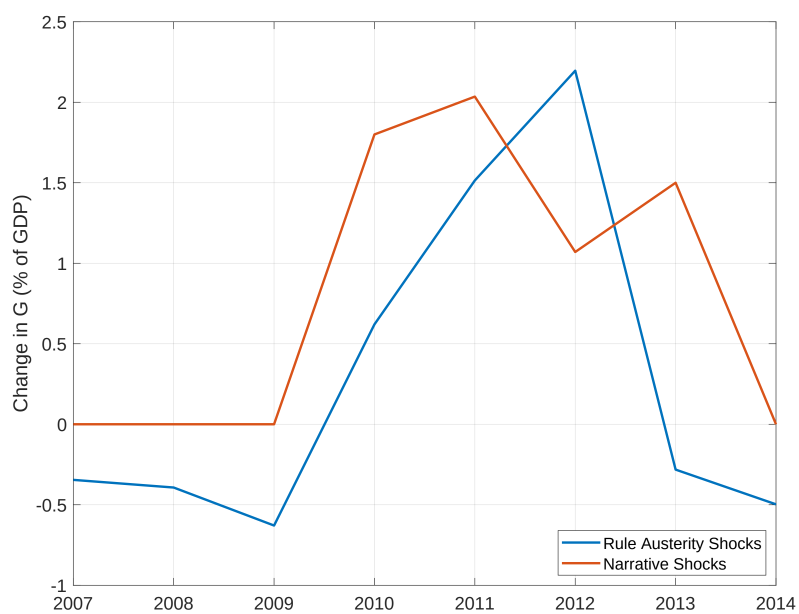
Quantifying the Effects of Austerity. Having a calibrated model allows me to run a

A_N and A_T.

[13] Bocola and Dovis (2016) assess the importance of fundamentals in the last European debt crisis.

counterfactual exercise to isolate the impact of fiscal austerity measures. I define austerity using the government spending fiscal rule (22) in the model. In particular, I interpret the shocks ϵ_t^g as unexpected discretionary fiscal austerity measures. One way to check whether this interpretation is reasonable is to compare the fiscal rule shocks with other measures of fiscal austerity. In this line, figure 7 compares the fiscal austerity shocks with narrative measures of austerity from Alesina et al. (2015). The correlation between these two measures of austerity is 0.66 indicating a strong association between deviations from the rule and austerity announcements in the period of analysis.

Figure 7: Austerity Shocks



Notes. Narrative shocks are government spending unexpected shocks. Model based austerity shocks are computed taking annual averages of $[exp\left(-\sigma_G \epsilon^g\right) - 1] \frac{G_{ss}}{Y_{ss}}$ *where* $\frac{G_{ss}}{Y_{ss}}$ *is the steady state government spending to GDP ratio.*

The counterfactual exercise to quantify the impact of austerity consists of simulating the model using the filtered shocks but setting the austerity shocks to zero after the second quarter of 2010, time in which the main austerity measures were announced.[14] In particular, if

[14]The announced measures included cuts in public wages and public investment, reductions in public health

$\boldsymbol{\epsilon^g} \equiv \left\{\epsilon^g_{97Q1}, \epsilon^g_{97Q2}, ..., \epsilon^g_{14Q2}\right\}$ is the vector of filtered G shocks from 1997Q1 to 2014Q2, the counterfactual "no austerity" sequence of shocks is $\tilde{\boldsymbol{\epsilon}}^{\boldsymbol{g}} \equiv \left\{\epsilon^g_{97Q1}, \epsilon^g_{97Q2}, ...\epsilon^g_{10Q2}, 0, 0, .., 0\right\}$. Hence, instead of causing a sharp contraction in G, the government follows the fiscal rule with a slow convergence toward the steady state levels of government spending.

Figure 8 presents the counterfactual paths for government consumption, GDP, consumption and hours worked. Under the counterfactual, G slowly converges to steady state levels instead of dropping steeply from the second half of 2010. Relative to this counterfactual, figure 8 shows that there is an important drop in real GDP. In particular, as a consequence of austerity measures real GDP is 6% lower during by the end of 2014. This implies an annual growth rate 0.43% lower from 2010Q2. Actually, there is a similar impact on private consumption levels. This drop in economic activity is explained by a drop in hours worked due to the downward nominal wage rigidity in the labor market.

Figure 9 shows the impact of austerity on sovereign spreads and debt to GDP levels. The results indicate that austerity was not effective in reducing debt to GDP levels until the last quarters of 2014. In fact, there is not a significant change in the path of this variable during the implementation of the austerity package in 2010-2013. Interestingly, sovereign spreads increased slightly as a consequence of austerity. Notice that this result has to do with the fact that austerity did not increase the value of staying in markets, whereas it increased the value of defaulting.

The result that spreads increased might be surprising given that the main objective of implementing fiscal consolidation is to reduce debt levels. However, a steep reduction in government spending has other effects in real variables that might have changed spreads. In particular, the total impact depends on what happens with the value of repaying $\mathcal{V}^R(\mathbf{S})$ and the value of default $\mathcal{V}^D(\mathbf{S})$. These two value functions depend on the state vector $\mathbf{S}$. Indeed, three of the six state variables change with austerity: sovereign debt (B), lagged wages (w_{-1}) and government spending (G). Therefore, there are three different channels through which austerity impacts the value functions and, hence, sovereign spreads. Figure 10 shows the impact of each channel taken separately. In this figure I start from the counterfactual scenario (black line, no austerity) and

related expenses. See https://www.ft.com/content/91ca42de-5d9e-11df-b4fc-00144feab49a plug each channel individually to check its sign.

The red line in figure 10 represents the effect of austerity through debt. Spreads fall because of this channel. The intuition is that austerity measures reduce the stock of debt that needs to be repaid, which increases the value of staying in markets. For a given a value of defaulting, this ends up reducing default risk.

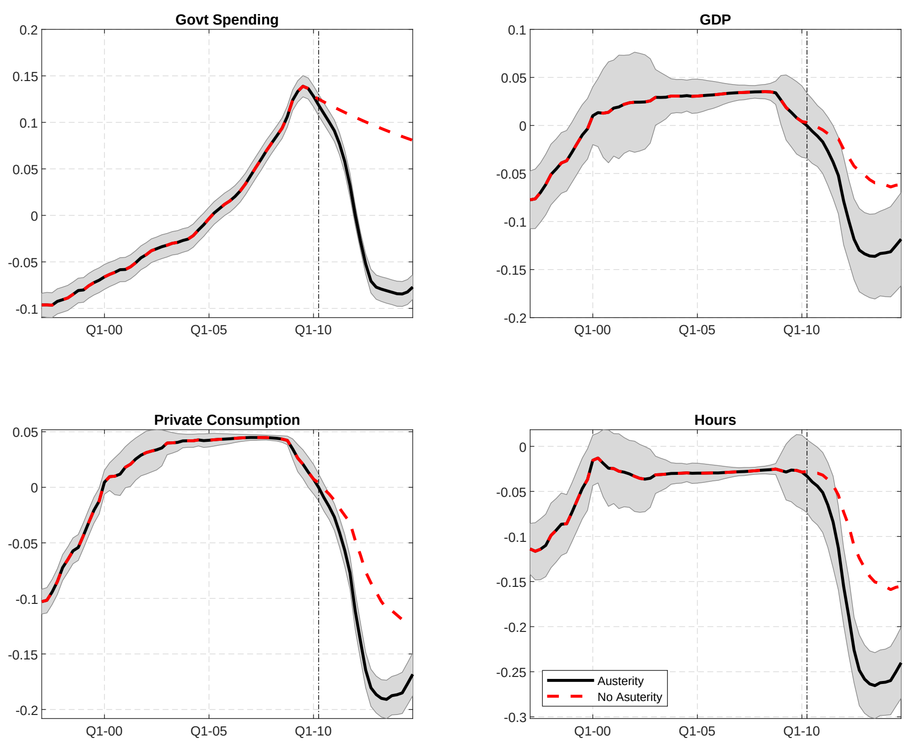
The second channel happens through the other endogenous state, lagged wages. Lower government spending might decrease the future expected path of wages, which increases both the value in markets and the value for defaulting. The reason is that lower (lagged) wages implies that the downward nominal wage rigidity is less likely to bind in the future. The increase in the value for defaulting through this channel is more important than that of the value in markets. This is because lagged wages are an important determinant of the cost of defaulting. A default event generates a big drop in productivity, which generates big increases in unemployment if lagged wages are high. Overall, this lagged wage channel is quantitatively not important as spreads barely moves trough this channel.

The last effect has to do with the direct impact of government spending on consumption levels and hours worked, and therefore on the instantaneous utility level $u(C, H)$. The channel is depicted in green in figure 10. A lower G reduces the value of repaying $\mathcal{V}^R(\mathbf{S})$ and increases the value of default $\mathcal{V}^D(\mathbf{S})$. It lowers $\mathcal{V}^R(\mathbf{S})$ because a drop in G reduces output and consumption due to high fiscal multipliers. Lower consumption implies a lower instantaneous utility and hence a lower value of repaying. On the other hand, a lower G increases $\mathcal{V}^D(\mathbf{S})$ because, in financial autarky, a lower G is effectively a lower tax level T.[15] This lower tax level allows consumption in default to be higher, and hence it increases the value of default. As we can see in figure 10, this last channel seems to be the most important one during the 2010-2014 period.

Long Run Effects. The results discussed so far show that austerity was not effective to reduce spreads and debt to GDP levels in the short run, during the period 2010-2014. However, it is also interesting to analyze the long run consequences of this policy. As it is typical in macroeconomic models, nominal frictions such as the downward nominal wage rigidity tend to be less important in the long run. Hence, it might be the case that the austerity package

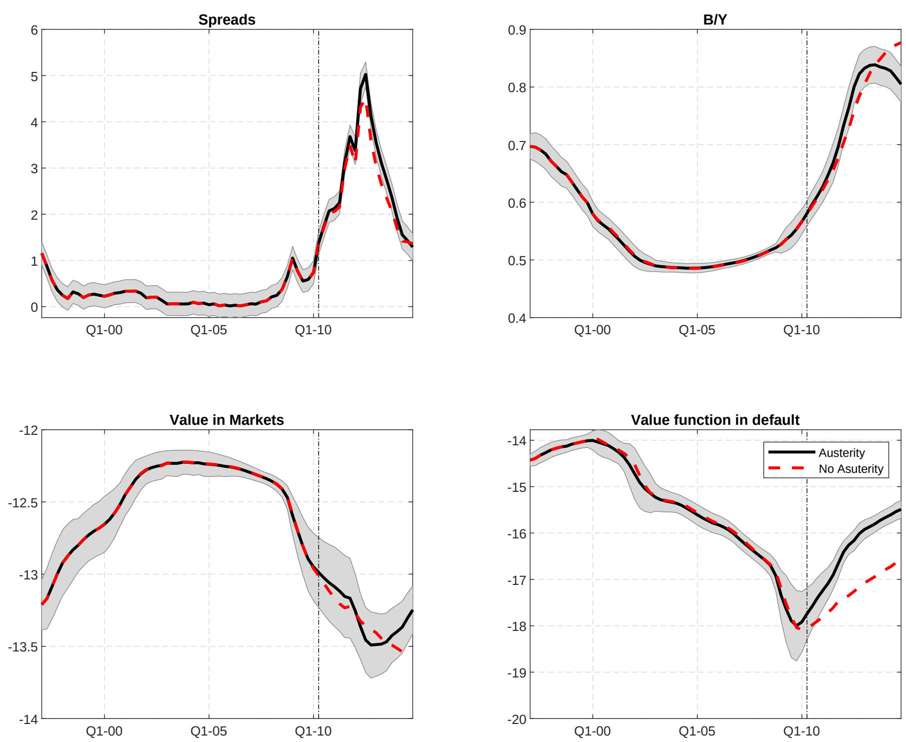
[15] Remember that the government budget constraint in autarky is simply $p_G G = T$.

Figure 8: Effects of Fiscal Austerity



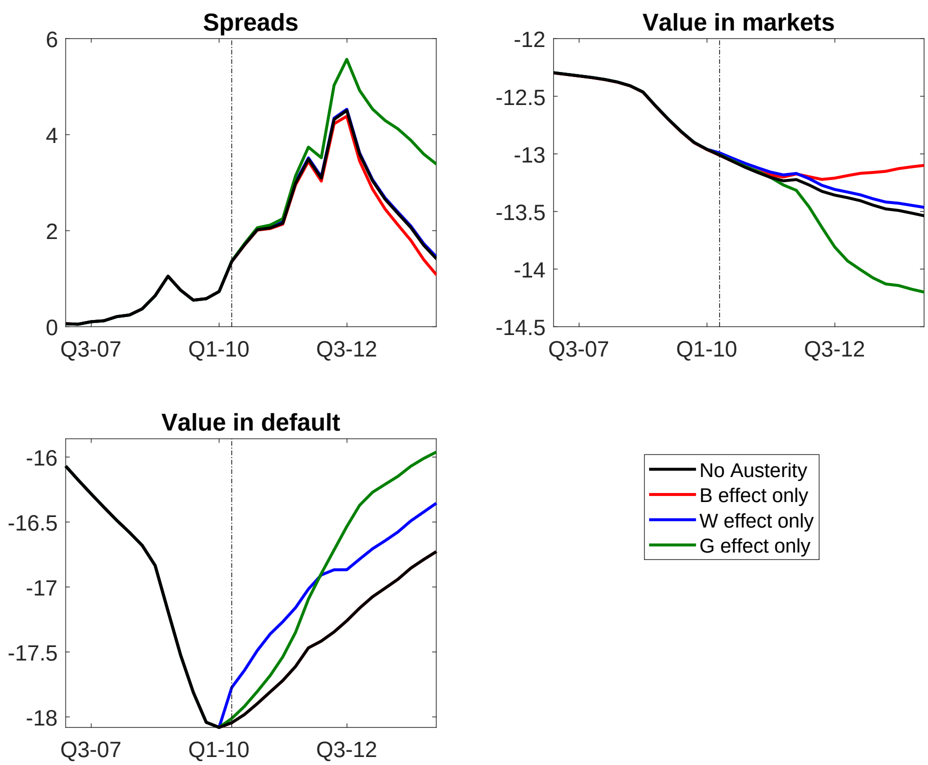
Notes. Black line shows filtered variables with austerity shocks after 2010Q2. The shaded are highlights two standard deviation intervals around the austerity case. Red line depicts a counterfactual exercise where austerity shocks are set to zero after 2010Q2.

Figure 9: Effects of Fiscal Austerity



Notes. Black line shows filtered variables with austerity shocks after 2010Q2. The shaded are highlights two standard deviation intervals around the austerity case. Red line depicts a counterfactual exercise where austerity shocks are set to zero after 2010Q2.

Figure 10: Decomposing Impact on Spreads



Notes. Black line represents the counterfactual scenario without austerity measures after 2010-Q2. Color lines show the impact of austerity through three different channels: reduction in debt levels (red), lower wages (blue) and direct impact on consumption, hours and instantaneous utility level $u(C,H)$(green) implemented in Spain had the intended consequences in the long run.

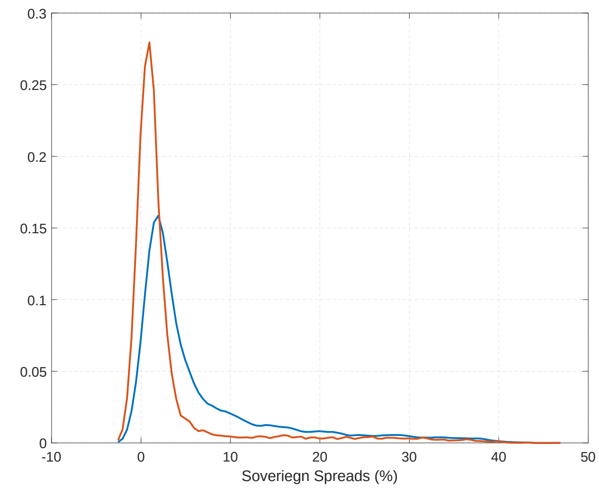
To check for that possibility I simulate the two economies forward, the one with the austerity package in 2010-2014 and the one without, in order to analyze the distribution of future sovereign spreads and debt to GDP ratios. In particular, I start from the last period of my sample (2014Q4) and I simulate 10,000 times each of the two economies 10 years forward. Figure 11 shows the distribution of future sovereign spreads and debt to GDP ratios. The figure shows that after austerity spreads tend to be lower: the mode of the distribution after austerity is 1 percent whereas it is 2 percent without austerity. Similarly, the distribution of debt to GDP ratios seems to be more favorable after the austerity package. The mode after austerity is around 65 percent and 90 percent in the no-austerity scenario.

Figure 12 provides the intuition behind the result. The figures show the median simulated paths of real GDP and stock of debt for the two versions of Spain. As shown in the figure, by the end of the simulation real GDP levels seem to be similar for both Spain with and without austerity in 2010-2014. However, the economy with austerity has a lower stock of debt during the simulation, implying a lower average spread and debt to GDP ratio with respect the economy without austerity.

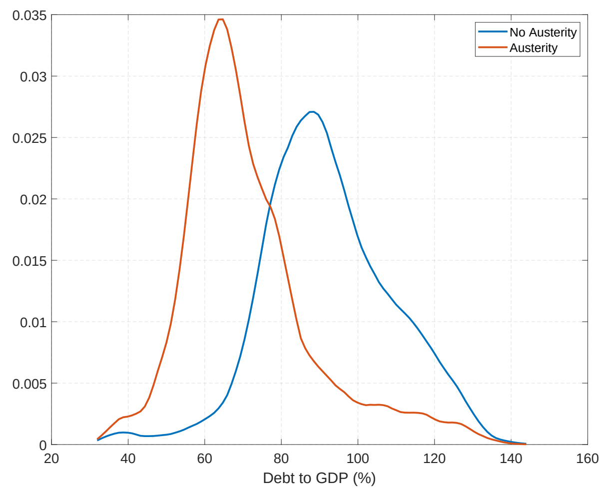
Wages and Employment. One concern regarding the results from this section might be that I am overstating the importance of downward nominal wage rigidity and, as a result, the model generates an excessive drop in hours worked after 2008. This is a reasonable concern given the fact that I do not use employment to calibrate the model or extract model implied structural shocks.

Figure 13 compares data and model implied series for hours and nominal wages. As shown in panel (a), the fall in nominal wages in the data and the model is similar. This suggests that the downward nominal wage rigidity parameter is appropriate. Panel (b) shows the annual percentage change in hours worked from 2005 to 2014. The two series are of course different but both of them show important drops in hours after 2008. Particularly, the model shows an average annual drop in hours of 3.2% after 2008, whereas the data details an average decrease of 2.6%.

Figure 11: Long run effecrs: spreads and debt histograms



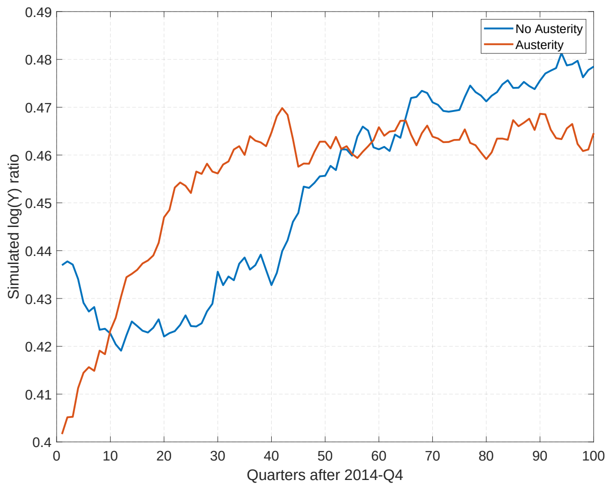
(a) Sovereign Spreads (annual %)



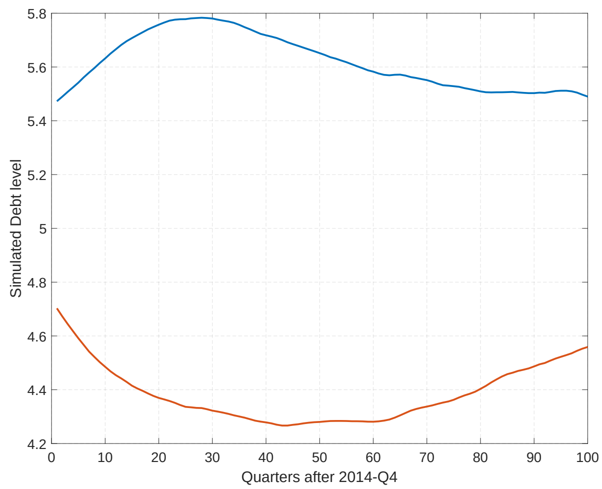
(b) Debt to GDP ratios (%)

Notes. Fitted distributions (Epanechnikov kernel) of simulated sovereign spreads and debt to GDP levels after 2014, with and without austerity package. Data come from 10,000 simulations of 10 years.

Figure 12: Long run effecrs: Median Simulation Paths



(a) Real GDP

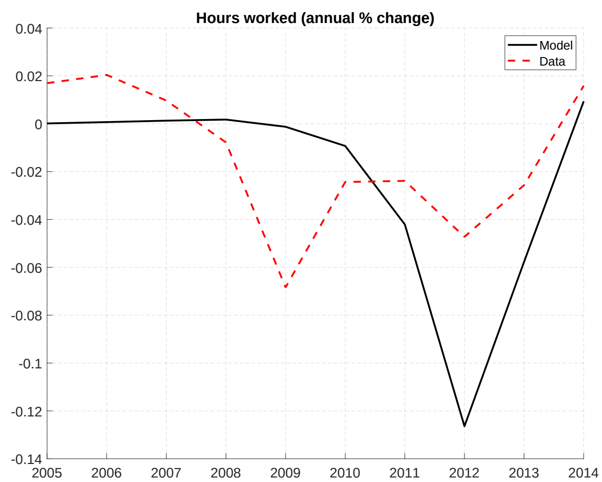


(b) Stock of Debt

Notes. Both figures show the median simulation path for real GDP and the stock of debt for the economy with and without austerity in the past, both expressed in tradable good units. Simulations are for 10 years after 2014-Q4.

Figure 13: Wages and Hours Worked

(a) Nominal Wages



(b) Hours

Notes. Black lines are model implied series, dashed blue lines indicate data. Panel (a) shows nominal wages series. Data implied nominal wages are linearly detrended to be consistent with the fact that the series used in the particle smoother are also detrended. Panel (b) shows data and model implied annual percentage change in hours worked. Real data on hours come from OECD economic outlook Number 99.

9 Conclusions

I proposed a small open economy model with strategic sovereign default to analyze the effects of fiscal austerity in Spain. The results indicate that austerity had an important impact on output, consumption and employment. Moreover, austerity was not effective in reducing debt to GDP ratios and did not decrease sovereign spreads in the short run. However, the intended effects seem to emerge in the long run. According to the model, Spain is more likely to enjoy lower spreads and debt to GDP levels as a result of the austerity packages implemented in the past.

This paper contributes to the general discussion about the effects of austerity measures in different ways. First, it proposes a model with a novel feature: the combination of realistic fiscal policy with strategic sovereign default. This model allows me to run counterfactuals and analyze implications of different policies. Second, it highlights the importance of labor market frictions as an important propagation mechanism. Wage rigidity not only affects the size of fiscal multipliers, but also shapes the short run impact on sovereign spreads. Third, it emphasizes the fact that the effect of austerity measures is strongly state dependent. In fact, in some situations it might actually increase default risk instead of reducing it.

A Appendix

A.1 Implementable Equilibrium Equations

$$(H_t^s)^\theta (C_t)^\sigma = \frac{w_t}{p_{Ct}} \tag{35}$$

$$p_{Ct} = \left[\omega^\mu p_{Nt}^{1-\mu} + (1-\omega)^\mu\right]^{\frac{1}{1-\mu}} \tag{36}$$

$$p_{Nt} = \frac{\omega}{1-\omega}\left(\frac{C_{Tt}}{C_{Nt}}\right)^{1/\mu} \tag{37}$$

$$\alpha_T A_{Tt}(H_{Tt}^d)^{\alpha_T-1} = w_t \tag{38}$$

$$\alpha_N p_{Nt} A_{Nt}(H_{Nt}^d)^{\alpha_N-1} = w_t \tag{39}$$

$$Y_{Nt} = A_{Nt}(H_{Nt}^d)^{\alpha_N} \tag{40}$$

$$Y_{Tt} = A_{Tt}(H_{Tt}^d)^{\alpha_T} \tag{41}$$

$$G_{Nt} + C_{Nt} = Y_{Nt} \tag{42}$$

$$C_{Tt} + G_{Nt} + \delta B_t = Y_{Tt} + q_t\left[B_{t+1} - (1-\delta)B_t\right] \tag{43}$$

$$(w_t - \gamma w_{t-1})(H_t^s - H_{Nt}^d - H_{Tt}^d) = 0 \tag{44}$$

$$w_t \geq \gamma w_{t-1}$$

A.2 Data

- **Value added in nontradable and tradable sectors** come from the Spanish Statistical Office (INE). I define the nontradable sector as Construction and Services, the rest of the economy (Industry and Agriculture) is considered as tradable. Data were linearly detrended.[16]

- **Government spending** G is defined as government consumption and investment. Data from from the OECD Economic Outlook Number 99 (2016).[17] These data are annual, but I interpolate them to quarterly frequency using Chow and Lin (1971) method.

- **Net taxes** T are defined as taxes and social security contributions minus social security benefits paid by the general government. Data from from the OECD Economic Outlook Number 99 (2016).

- **Public debt** B and **sovereign spreads** also come from OECD Economic Outlook Number 99 (2016). Debt corresponds to general government gross financial liabilities. Spreads are defined as the difference of 10 year bond yields with respect to a 10 year German bond.

- **Sovereign debt average maturity** data come from the Spanish Treasury.[18]

[16]See: `http://www.ine.es/jaxiT3/Tabla.htm?t=9148&L=0`
[17]See `http://stats.oecd.org/index.aspx?DataSetCode=EO`
[18]See `http://www.tesoro.es/sites/default/files/estadisticas/02I.pdf`

A.3 Solution Method

I solve the model using global numerical methods. I use linear interpolation and Gauss Hermite to compute expectations. The steps for the numerical solution are the following

Step 0 (a). Define grids for endogenous and exogenous states. Set an initial guess for value functions $\mathcal{V}^R_{(0)}(\mathbf{S})$ and $\mathcal{V}^D_{(0)}(\mathbf{S})$ and prices of debt $q_{(0)}$ and $q^D_{(0)}$.

Step 0 (b). Compute private equilibrium allocations for each one of the grid points defined in the previous step. There are two different cases, one when the economy has access to markets and another when the economy is in default. In this second case, incorporate the productivity costs associated with default. In particular compute consumption $C(\mathbf{S}, d)$,hours $H(\mathbf{S}, d)$, price of government spending $p_G(\mathbf{S}, d)$ and output $Y(\mathbf{S}, d)$. These allocations are a function of the states $\mathbf{S}$ and the default decision d ($d = 1$ if default, $d = 0$ otherwise).

Step 1. Update the value functions using the private sector allocations, price schedule and value functions from previous step. Hence, for iteration i the updated value function are computed by,

1. Define the value before deciding whether to default or not as,

$$\mathcal{V}_{(i-1)}(\mathbf{S}) = \left\{\mathcal{V}^R_{(i-1)}(\mathbf{S}); \mathcal{V}^D_{(i-1)}\Big(B, w_{-1}, A_N, A_T, (1-d_g)G, m\Big)\right\} \tag{45}$$

2. Update value of repaying

$$\mathcal{V}^R_{(i)}(\mathbf{S}) = u\left(C(\mathbf{S}, 0), H(\mathbf{S}, 0)\right) + \beta E\left\{\mathcal{V}_{(i-1)}(\mathbf{S}')|\mathbf{S}\right\} \tag{46}$$

where the low of motion of the endogenous states is given by,

$$p_G(\mathbf{S}, 0)G + \delta B = t^* Y(\mathbf{S}, 0) + \frac{\gamma_T}{4}B + q_{(i-1)}(\mathbf{S_1'}, \mathbf{S_2})\left[B' - (1-\delta)B\right]$$
$$w'_{-1} = w(\mathbf{S}, 0)$$

where $\mathbf{S_1} = \{B, w_{-1}\}$ and $\mathbf{S_2} = \{A_N, A_T, G, m\}$. When getting B' from its law of motion, get the value of B' is on the left side of the debt Laffer curve. This is done to rule out one possible source of multiplicity.

3. Value of defaulting

$$\mathcal{V}^D_{(i)}(\mathbf{S}) = u\left(C(\mathbf{S},1), H(\mathbf{S},1)\right) + \beta E\left\{\phi max\left\{\mathcal{V}_{(i-1)}(\mathbf{S}'), \mathcal{V}^D_{(i-1)}(\mathbf{S}')\right\} + (1-\phi)\,\mathcal{V}^D_{(i-1)}(\mathbf{S}')|\mathbf{S}\right\} \tag{47}$$

Where the budget constraint of the government and law of motion of endogenous states are,

$$T(\mathbf{S},1) = p_G(\mathbf{S},1)G$$
$$B' = BR^*$$
$$w'_{-1} = w(\mathbf{S},1)$$

Step 2. With the updated value functions from the previous step redefine the default decisions (while in markets or right after reentering from default),

$$d(\mathbf{S}) = \begin{cases} 1 & \mathcal{V}^D_{(i)}(\mathbf{S}) \geq \mathcal{V}^R_{(i)}(\mathbf{S}) \\ 0 & \mathcal{V}^D_{(i)}(\mathbf{S}) < \mathcal{V}^R_{(i)}(\mathbf{S}) \end{cases}$$

$$\tilde{d}(\mathbf{S}) = \begin{cases} 1 & \mathcal{V}^D_{(i)}(\mathbf{S}) \geq \mathcal{V}^R_{(i)}(\tilde{\mathbf{S}}) \\ 0 & \mathcal{V}^D_{(i)}(\mathbf{S}) < \mathcal{V}^R_{(i)}(\tilde{\mathbf{S}}) \end{cases}$$

where $\tilde{\mathbf{S}}$ incorporates the face value haircut. That is, it replaces B for $(1-\psi)B$. Then update the prices of debt using the following expression,

$$\tilde{q}(\mathbf{S}) = \frac{\tilde{\beta}}{1+\nu} E\left\{(1-d(\mathbf{S}'))\left(\delta + (1-\delta)q(\mathbf{S}')_{(i-1)}\right) + d(\mathbf{S}')q^D(\mathbf{S}')_{(i-1)}|\mathbf{S}\right\}$$

$$\tilde{q}^D(\mathbf{S}) = \frac{\tilde{\beta}}{1+\nu} E\left\{\left\{(1-\tilde{d}(\mathbf{S}'))\left(\delta + (1-\delta)q(\mathbf{S}')_{(i-1)}\right) + d(\mathbf{S}')q^D(\mathbf{S}')_{(i-1)}\right\} |\mathbf{S}\right\}$$

$$\tilde{q}^D(\mathbf{S}) = \frac{\tilde{\beta}}{1+\nu} E\{\phi\left[(1-\tilde{d}(\mathbf{S}'))\left(\delta + (1-\delta)q(\mathbf{S}')_{(i-1)}\right) + \tilde{d}(\mathbf{S}')q^D(\mathbf{S}')_{(i-1)}R^*\right] + (1-\phi)q^D(\mathbf{S}')_{(i-1)}R^*|\mathbf{S}\}$$

Step 3. compute distances $r^q = \left|\left|\tilde{q}(\mathbf{S}) - q(\mathbf{S})_{(i-1)}\right|\right|$, $r^{qD} = \left|\left|\tilde{q}^D(\mathbf{S}) - q^D(\mathbf{S})_{(i-1)}\right|\right|$, $r^R = \left|\left|\mathcal{V}^R_{(i)}(\mathbf{S}) - \mathcal{V}^R_{(i-1)}(\mathbf{S})\right|\right|$ and $r^D = \left|\left|\mathcal{V}^D_{(i)}(\mathbf{S}) - \mathcal{V}^D_{(i-1)}(\mathbf{S})\right|\right|$. Check if they are lower than a tolerance value, if not, update prices and value functions and go to step 1 (set $i = i+1$). When updating the price function use a dampening parameter θ, such that

$$q(\mathbf{S})_{(i)} = \theta\tilde{q}(\mathbf{S}) + (1-\theta)q(\mathbf{S})_{(i-1)}$$

$$q^D(\mathbf{S})_{(i)} = \theta\tilde{q}^D(\mathbf{S}) + (1-\theta)q^D(\mathbf{S})_{(i-1)}$$

Details. I stop the algorithm when $r^q < 10^{-3}$ and $r^R, r^D < 10^{-5}$. The dampening parameter is set to $\theta = 0.1$. The number of points in the grid is 25 for B, 17 for w_{-1}, and 5 for each exogenous state. Grids limits are determine as follows. Minimum debt is $0.6\bar{B}$ and maximum $1.7\bar{B}$, where $\bar{B}$ is set to match a steady state debt to GDP ratio of 55%. Minimum and maximum lagged wages are respectively $0.6\bar{w}$ and $1.4\bar{w}$, where $\bar{w}$ is the steady state wage. Limits for productivity levels and liquidity premium grids are set to 5 standard deviations below and above the mean. Given the important variation in government spending during the period of analysis, I set the grid for government spending 15 standard deviations below and above the mean. I am using Gauss Hermite to compute integrals, with five nodes for each exogenous state.

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