The Employment Cost of Sovereign Default*

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May 12, 2017

First version: October 2016
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Abstract

This paper analyzes the interaction between government default decisions and labor market outcomes in an environment with persistent unemployment and financial frictions. Sovereign risk impairs bank intermediation through balance sheet effects, worsening the conditions for firms to pre-finance wages and vacancies. This generates a new type of endogenous domestic default cost – the employment cost of default. The persistence of unemployment produces serial defaults and rationalizes high debt-to-GDP ratios. In the dynamic strategic game between the government and the private sector, anticipation effects allow the study of debt crises in addition to outright default episodes. Introducing employment subsidies and bank regulations affect the government's ability to commit to debt repayment.

Keywords: Sovereign Default, Search and Matching, Financial Frictions
JEL: E24, E44, E62, F34, F41

*I thank Morten Ravn, Patrick Kehoe, Vincent Sterk, Jan Eeckhout, Mariacristina DeNardi, Marco Bassetto, Mark Wright, Jeff Campbell, Wei Cui, Ralph Luetticke, Victor Rios-Rull, Jing Zhang, Carlo Galli, Thomas Drechsel and Thibaut Lamadon for helpful comments and discussions.

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1 Introduction

The recent European debt crisis was characterized by high government indebtedness and rising bond spreads in Portugal and Spain and a sovereign default in Greece. In all three countries, the crisis was accompanied by high levels of unemployment. Firm-level evidence documents that sovereign risk depresses job vacancies via bank lending, suggesting a link between a government's debt policies and labor market outcomes.[1]

Such employment effects make debt and default crises costly for an economy.[2] This cost channel can address the difficulty faced by the literature in rationalizing plausible debt levels and default frequencies in sovereign debt models with limited commitment. These models usually rely on exogenous costs that cannot affect both features separately: a more severe default punishment increases debt ratios but decreases default frequencies. The persistence of unemployment can disentangle the two. Unemployment effects also offer a theory of endogenous costs of debt crises and help evaluate debt policies during and in anticipation of default. Yet frictional unemployment as a source of default cost has not received attention in the sovereign default literature.

In this paper, I introduce labor market frictions à la Diamond, Mortensen and Pissarides and frictional financial markets into a default model in the tradition of Eaton and Gersovitz (1981). In the model, firms hire workers subject to matching frictions and borrow from bank intermediaries to pre-finance wages and vacancies. Government debt shows up on banks' balance sheets and facilitates lending to firms. The government understands that its tax, debt and default decisions affect labor market outcomes during and in anticipation of default due to the forward-looking behavior of the private sector. The model therefore features a dynamic strategic game between the government and private agents.

The main theoretical contribution is that the model endogenously creates an employment cost of sovereign default. When sovereign bond prices fall due to rising default risk the bankers' supply of loans to firms falls. Firms post fewer vacancies and fire workers, increasing unemployment. Fixed output sharing prevents the wage from fully adjusting to changes in credit conditions which amplifies the increase in unemployment. Workers face the uninsurable idiosyncratic income risk of becoming unemployed. The rise in unemployment creates an endogenous cost of default and, importantly, cost of default risk. Higher unemployment reduces production and contributes to the recession. This is consistent with evidence showing that a declining labor input significantly contributed to GDP drops during the European debt crisis (Wright (2014)).

The combination of endogenous default costs and anticipation effects allows me to conduct

[1]Domestic banks with a higher exposure to sovereign risk on their balance sheets cut loans to the private sector more aggressively during the crisis and firm-level evidence suggests that this loan contraction depressed job creation, see Acharya, Eisert, Eufinger, and Hirsch (2015) and Bentolila, Jansen, Jiménez, and Ruano (2015).

[2]A long tradition of papers look at frictional labor markets and the transmission properties to the real economy, e.g. Diamond (1982b), Diamond (1982a), Mortensen (1982a), Mortensen (1982b), Pissarides (1979), Pissarides (1985), Mortensen and Pissarides (1994), Merz (1995), Andolfatto (1996), Shimer (2005).

three distinct exercises. First, I use a calibrated version of the model to look at actual default episodes and contrast them with debt crises – periods of elevated bond spreads that do not lead to default. Second, I address three quantitative challenges faced by standard models of sovereign default where the cost of default is exogenous: the model generates plausible debt-to-GDP ratios at realistic default probabilities, serial defaults (Reinhart (2010)) and the occurrence of default after growth periods. Third, I consider how different labor market policies and bank regulations change the government's ability to credibly borrow and repay debt.

The forward-looking vacancy-posting behavior of firms is crucial for the model to be able to match the empirically observed decline in employment that accompanies increases in bond spreads before an actual default event (Yeyati and Panizza (2011)). Firms cut vacancy postings when they anticipate default not only because job vacancies become more expensive but also because the expected job separation rate rises. With a static labor market the latter effect would be absent.

Both the persistence and asymmetry of the employment cost of default are central to the model's quantitative ability to explain three empirical regularities standard default models have difficulty in replicating. First, high debt-to-GDP ratios are sustained because persistent unemployment creates an additional disincentive to default and so increases average indebtedness. Defaulting entails prolonged costs because new matches take time to form. Lowering the labor market frictions decreases equilibrium indebtedness to the point where the government is not able to borrow at all. The asymmetry of the employment cost, which increases more than proportionally with employment and productivity, is required to address the problem of simultaneously generating plausible default frequencies and high debt levels (Aguiar, Chatterjee, Cole, and Stangebye (2016)). With high productivity it allows the government to borrow extensively and cheaply but also makes default optimal after sudden productivity reversals and so increase default frequencies. Second, in addition to using default as insurance mechanism in bad times, the government may default after several periods of growth. Asymmetric default costs and the role of government debt to facilitate lending in the private sector create an incentive for the government to take on large amounts of debt in good times. However, at high debt levels even small productivity drops can then trigger default, which is in line with the finding that 38 percent of the historical default events occurred when output was above trend (Tomz and Wright (2013)). Third, the combination of a higher default probability in high unemployment states and persistently high unemployment after default is responsible for the model's ability to generate clustered default events – situations where one default follows shortly after another.

Finally, I consider counterfactual labor market policies in the form of wage and employment subsidies that alleviate the employment cost of default if they circumvent the financing constraints of firms. Furthermore, financial market regulations in the form of higher capital requirements for bankers limit layoffs and the rise in unemployment during default. Since the capability of sovereign debt to facilitate lending is reduced by tighter bank regulations, which enforce a lower debt exposure of domestic banks, the government's ability to commit to debt repayment and thus indebtedness increases.

Relation to literature. This paper is related to the literature on sovereign debt as well as the vast literature on financial frictions, labor frictions and the interaction between the two. Following the original default framework of Eaton and Gersovitz (1981), recent papers study the quantitative dynamics of sovereign defaults. Arellano (2008) and Aguiar and Gopinath (2006) analyze sovereign default and business cycle properties in emerging economies. Several studies have extended the framework[3] finding that the presence of reputational costs in the form of exclusion from financial markets cannot explain the high debt levels seen in the data.[4] In particular, they conclude that the presence of domestic costs of default is necessary to reconcile high indebtedness with low default frequencies. I propose a new type of domestic default cost by studying the effects of sovereign default on the labor market through the banking system.

Mendoza and Yue (2012) and Perez (2015) also endogenize default costs in an optimal sovereign default framework. Mendoza and Yue (2012) assume that default impairs the import of intermediate goods, which have to be substituted by domestic goods. Since domestic goods are imperfect substitutes, productivity declines. In contrast, I do not impose constraints that are absent in repayment. This is important for generating expectations effects on unemployment before default. As the role of imports does not feature in my model, I regard the proposed employment cost of default as complementary to trade exclusion costs. Perez (2015) assumes that default hurts the balance sheets of heterogeneous bank-firm entities which results in a misallocation of investment, with production taking place in less productive firms. My work incorporates a similar negative effect on banks' balance sheets. However, it includes a labor margin that contributes to output declines.

The balance sheet mechanism of default has been explored theoretically by Gennaioli, Martin, and Rossi (2014), Basu (2009), Mengus (2014) and Sosa-Padilla (2012). Bocola (2016) contrasts it with a risk effect when bankers perceive the private sector as riskier. My work differs significantly from his work because I endogenize the government's default decision. In recent work, Niemann and Pichler (2016) include the role of debt as collateral in a quantitative default setting.

The modeling of the banking sector in this paper builds on the literature on financial intermediation dating back to Bernanke and Gertler (1989), Kiyotaki and Moore (1997), and Bernanke, Gertler, and Gilchrist (1999) and is closest to Gertler and Karadi (2011).

[3]Extensions focus on e.g. longer debt maturities (Chatterjee and Eyigungor (2012), Hatchondo and Martinez (2009), Arellano and Ramanarayanan (2012)), debt renegotiations (Yue (2010), Benjamin and Wright (2013) and D'Erasmo (2008)), political uncertainty (Cuadra and Sapriza (2008)), inflation and devaluations (Du and Schreger (2015), Na, Schmitt-Grohe, Uribe, and Yue (2015). The handbook chapter by Aguiar, Chatterjee, Cole, and Stangebye (2016) provides an overview.

[4]Bulow and Rogoff (1989) show that without direct sanctions, no debt can be sustained in equilibrium by reputational mechanisms alone if countries are allowed to save after default. This result motivated subsequent research to offset it. Aguiar and Amador (2014) survey recent advances in the literature.

More recent work includes Mendoza (2010), Gertler and Kiyotaki (2010), and Gilchrist and Zakrajšek (2012). The presence of this friction coupled with banks' exposure to public debt allows government bonds to facilitate private lending. Falling debt prices hurt the banking sector.

The matching frictions in the labor market follow Pissarides (1985) and a large subsequent literature, see e.g. Rogerson, Shimer, and Wright (2005) for a survey. As a solution to the Shimer (2005) puzzle – that the standard framework is unable to generate enough volatility in labor market tightness relative to productivity – wage rigidity and the interaction of financial and labor market frictions have gained attention. Kehoe, Midrigan, and Pastorino (2015) and Garín (2015) offer explanations for more wage rigidity relative to the standard DMP model, despite determining the wage by period-by-period Nash bargaining.[5] Fixed output sharing captures those amplification mechanisms, while leaving them unmodeled, in this work.

2 Stylized facts

This section summarizes the empirical regularities during debt and default crises that my model seeks to replicate. I provide evidence that default risk is associated with higher unemployment and worse credit conditions.

Labor markets. Sovereign bond spreads negatively co-move with labor market tightness and are positively correlated with unemployment. Figure 1 plots the sovereign bond spreads of Portugal, Spain, Greece and Iceland over German 10 year bonds together with labor market tightness (the ratio of job vacancies to the unemployment rate) during the recent crisis. Figure 2 shows the time series for the quarterly, non-seasonally adjusted unemployment rate alongside sovereign bond spreads for the same set of countries. These countries were confronted with serious fiscal problems that led to sharp increases in their bond spreads. Iceland was categorized as "near default" between 2007 and 2010 by Reinhart (2010) and Greece underwent a haircut on government bonds in 2012. Sovereign spreads are negatively correlated with labor market tightness and positively correlated with the unemployment rate, as documented in Table 1. The correlations are statistically significant.

Labor is an important determinant of the decline in output that occurs during debt and default crises.[6] Wright (2014) points out that the two main determinants of lower GDP growth during the recent debt crisis in Europe were labor on the one hand and productivity on the other hand. I provide a similar decomposition of GDP growth, based on the Conference Board Total Economy Database, in Table 5 in the Appendix.

[5] Other work concerned with financial and labor market frictions includes e.g. Wasmer and Weil (2004), Boz, Durdu, and Li (2015), Petrosky-Nadeau (2014), Schoefer (2015), Chugh (2013) and Zanetti (2015).

[6] Empirical work on the output loss of default includes for example Borensztein and Panizza (2009), Sturzenegger and Zettelmeyer (2006), Yeyati and Panizza (2011).

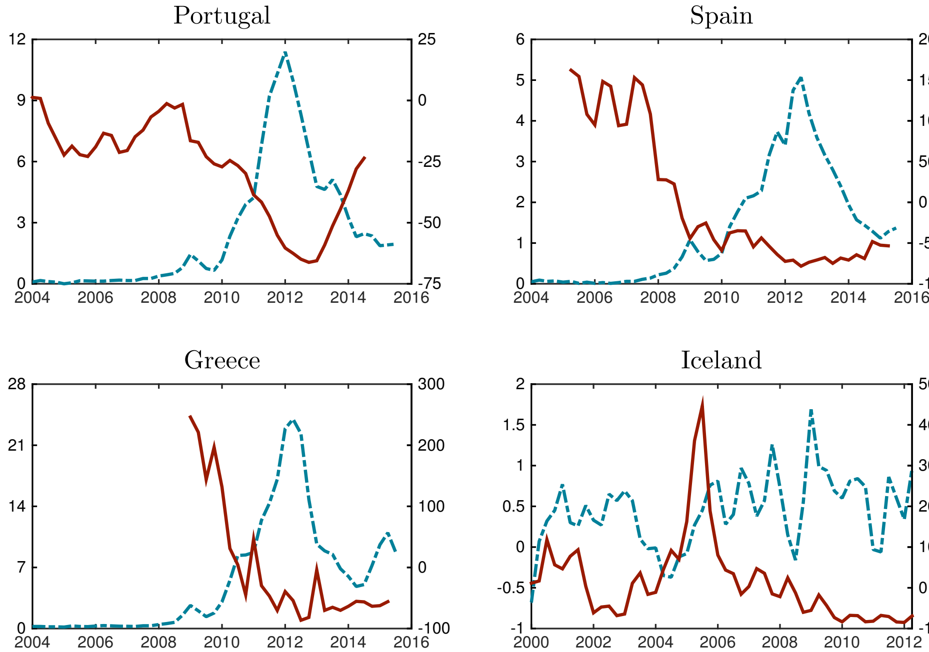

Figure 1: Sovereign spread and labor market tightness: Annualized interest rate spread over 10 year German bonds in percent (dashed blue line, left axis). Labor market tightness in percent deviation from the mean of the considered time period (solid red line, right axis).

Unemployment is high during debt crises, independently of the realization of a default ex-post. Whether one looks at an actual default event in Greece, a near-default episode in Iceland or the debt crises in Portugal and Spain, there are strong correlations between spreads and labor market variables. Yeyati and Panizza (2011) look at a wider range of historical default events and conclude that defaults usually occur after quarters with increasing or stable unemployment.

Credit markets. As pointed out by Bocola (2016) and Perez (2015), domestic banks' balance sheets include a large amount of sovereign debt and deteriorate in default, causing the financial sector distress. Borensztein and Panizza (2009) provide evidence that the probability of a banking crisis conditional on default is 14 percent, an 11 percentage point increase compared to its unconditional probability.

Acharya, Eisert, Eufinger, and Hirsch (2015) document that European banks with higher sovereign risk exposure on their balance sheets cut loans by more than banks with lower sovereign risk exposure, which led to a reduction in the lending volume by 66 and 45 percent in Spain and Portugal, respectively, over the period from 2008 to 2013. They also present firm-level evidence that this loan contraction depressed job creation.

Finally, when sovereign spreads rise private borrowing becomes more expensive and falls in quantity (Gilchrist and Mojon (2014) and Adelino and Ferreira (2016)). A number of

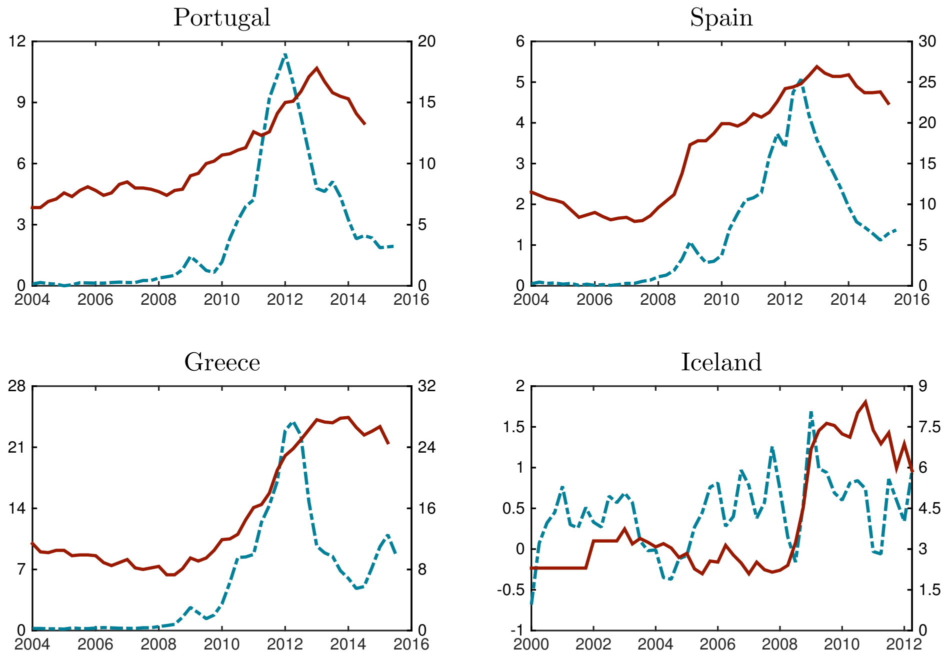

Figure 2: Sovereign spreads and unemployment rate. Interest rate spread over German bonds (dashed blue line, left axis). Seasonally adjusted quarterly unemployment rate (solid red line, right axis).

papers have further documented the co-movement of sovereign and private spreads.[7]

To sum up, there is ample evidence that in times of higher sovereign risk the borrowing conditions in financial markets deteriorate and unemployment tends to be higher. Given this evidence, I present a model designed to incorporate the co-movement of sovereign spreads with labor market tightness, unemployment and the amount and price of banks' lending to firms during debt crises and defaults.

3 Model

This section outlines a small open economy model populated by five different agents. Workers are either employed and consume their after-tax wage or unemployed and consume unemployment benefits. Heterogeneous firms post vacancies to attract workers and produce output. Domestic financial families consist of depositors who buy government debt and give funds to other families and bankers who provide loans to existing and entering firms. Lenders with deep pockets buy government debt and own firms. A government taxes workers and may default on the sovereign debt it issues to depositors and lenders.

[7] See for example Arellano, Atkeson, and Wright (2015), Klein and Stellner (2014), Bai and Wei (2012), Avino and Cotter (2014) and Bedendo and Colla (2015).

Country	$\rho(spr, \theta)$	p-value	$\rho(spr, u)$	p-value	Time period
Portugal	-0.5957	0.0000	0.7880	0.0000	1998Q1-2014Q3
Spain	-0.7325	0.0000	0.8151	0.0000	2005Q2-2015Q2
Greece	-0.5946	0.0014	0.7360	0.0000	2009Q1-2015Q2
Iceland	-0.3342	0.0091	0.3383	0.0082	2000Q1-2014Q3

Table 1: Sovereign spreads: Correlation with labor market tightness and unemployment rate.

Time is discrete and infinite $t = 0, 1, 2, ...$ First, aggregate productivity z_t is realized. It is assumed to follow an AR(1) process in logs:

$$\log(z_{t+1}) = \rho \log(z_t) + \sigma_\epsilon \epsilon_{t+1} \tag{1}$$

Second, government debt is issued to international investors and depositors in the bond market. Third, firms receive within-period lending from bankers in the loan market. Fourth, unemployed workers and firms meet in the labor market.

3.1 Preferences and technology

Workers. There is a continuum of mass 1 of infinitely-lived and risk-averse workers. In each period t, a share $(1 - u_t)$ of workers is employed, earns a wage w_t, pays lump-sum taxes τ_t and consumes their after-tax income $c_t = w_t - \tau_t$. The remaining share u_t is unemployed and consumes unemployment transfers $c_t = T$.[8] Each worker maximizes the discounted stream of lifetime utility from consumption

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \mathbf{u}(c_s) \tag{2}$$

where preferences exhibit constant relative risk aversion, $\mathbf{u}(c) = \frac{c^{1-\sigma}}{1-\sigma}$.

Workers live by themselves and cannot save.[9] The employed face the risk of becoming unemployed because their job can be destroyed or because they are fired. The unemployed workers can find a new job with time-varying probability that is determined by the labor market. The government is able to borrow and save and wants to insure workers against their unemployment and wage risk.

Firms. There is an endogenous measure H of firms. A firm is a job. Firms that are matched with a worker have a constant returns to scale production technology and the

[8] In this work, transfers T are assumed to be fixed. Balke and Ravn (2016) study how the government trades off intratemporal wedges when it chooses the level of unemployment transfers in each period.

[9] The absence of savings is standard in the sovereign default literature to create an intertemporal insurance motive of the government on behalf of the private sector.

output of a firm is equal to aggregate productivity z_t. In each period, there is a distribution of heterogeneous firms $G(k_i)$ due to idiosyncratic operational cost shocks $k_{i,t} \in [\underline{k}, \overline{k}]$ that are iid over time. Firms can create vacancies v_t at a unit cost a. If vacancies are matched with an unemployed worker, production starts in the following period.

Two types of financial frictions constrain a firm. First, firms face a pre-financing constraint and so borrow to pay for vacancies and wages before production takes place.[10] Borrowing takes the form of within-period loans from bankers at rate R_t. Firms cannot default on loans. Since vacancies are sold to foreign investors before matching takes place, loans are riskless and always paid back at the end of the period. With an aggregate unemployment level u_t, the total loan demand of firms L_t^f is given by

$$L_t^f = w_t(1 - u_t) + av_t. \tag{3}$$

Second, firms are unable to issue equity. The flow profit of a matched firm of type i in period t therefore needs to be non-negative:

$$z_t - R_t w_t - k_{i,t} \geq 0 \tag{4}$$

If condition (4) is violated, firm i fires the worker, receives zero payoff and exits.

Labor market. The labor market is characterized by matching frictions in the tradition of Diamond, Mortensen and Pissarides. The matching technology is assumed to be Cobb-Douglas,

$$M(u_t, v_t) = \min(\mu u_t^{\psi} v_t^{1-\psi}, v_t, u_t) \tag{5}$$

where μ is the match efficiency. The number of matches cannot exceed the number of unemployed workers or posted vacancies. Labor market tightness $\theta(u_t, v_t) = v_t/u_t$, defined as the ratio of vacancies to unemployment, determines the probability of a match. Let $\lambda_f(\theta(u_t, v_t))$ be the probability of filling a vacancy and $\lambda_w(\theta(u_t, v_t))$ the probability that an unemployed worker finds a job. Matches are separated exogenously at destruction rate ξ or endogenously because firms fire a share s_t of workers.

Wages are determined by a wage function that implements fixed output sharing

$$w_t = z_t - \omega \tag{6}$$

The wage function links the wage to aggregate productivity such that firms make a constant expected profit at a zero loan interest rate. The wage is volatile due to its co-movement with productivity and so is not fixed.[11] However, it does not fully adjust to financial conditions.

[10] This assumption is similar to the working capital requirements in Christiano and Eichenbaum (1992) and Neumeyer and Perri (2005).

[11] Shimer (2005) pointed out that, with fully flexible wages, the employment responses to productivity

This has important implications for situations in which firms face bad credit conditions but need to pre-finance wages and vacancies. In times of high loan rates, it prevents firms and workers from agreeing to a lower wage to avoid separation. As wages cannot fully downward adjust, firms fire workers despite the fact that there would be a positive surplus for the firms and workers of continued employment. This amplifies match destruction.

Financial families. There is a continuum of identical financial families. Financial families consist of two types of family members: depositors and bankers. Depositors decide on consumption or saving and bankers intermediate funds between depositors and firms. However, bankers cannot manage the deposits of their own family members. At each point in time, there is a measure $(1-f)$ of depositors and a measure f of bankers. With probability $(1-\phi)$ bankers become depositors and are replaced by other depositors who become bankers, keeping the relative shares of both types constant. The setup follows Gertler and Karadi (2011) and is described in detail in Appendix A.2.

Depositors choose consumption c_t^f, buy government bonds b_{t+1} at price q_t and make within-period deposits X_t to bankers from other families to maximize their family's discounted utility stream:

$$\mathcal{G}_t = \max \quad \mathbb{E}_t \sum_{s=t}^{\infty} \left(\tfrac{1}{1+r}\right)^{s-t} c_s^f \tag{7}$$

$$\text{s.t.} \quad c_s^f = d_s\left(b_s - q_s b_{s+1}\right) + R_{x,s} X_s - X_s + \pi_s \tag{8}$$

They are risk-neutral and discount future utility with $1/(1+r)$, where r is the risk-free interest rate. Holding government bonds is risky because the government may not repay ($d_t = 0$) and cannot exceed aggregate bond issuance $b_{t+1} \leq B_{t+1}$. Deposits earn the non-contingent gross return $R_{x,t}$. Depositors receive net payments π_t from the bankers who are part of their family. In return for receiving dividends, they endow new bankers in their family with start-up transfers, described below. One can show that if $q_t = \mathbb{E}_t\left(\frac{d_{t+1}}{1+r}\right)$, risk-neutral depositors buy any given share $\gamma \in [0,1]$ of aggregate bonds, $b_t = \gamma B_t$.[12]

Bankers intermediate between depositors and firms. A banker j, who starts a period with wealth $W_{j,t}$, obtains deposits $X_{j,t}$ and makes loans $L_{j,t}$ to firms in order to maximize

shocks tend to be small in the standard matching model. A large literature has since tried to solve the Shimer puzzle, namely the inability of the standard model to generate enough volatility in labor market tightness relative to labor productivity. In recent work Kehoe, Midrigan, and Pastorino (2015) show that one way of rationalizing much bigger responses of employment in models with household-owed firms is to include on-the-job human capital accumulation. Garín (2015) includes credit shocks to the collateral requirement of firms which creates a smaller volatility of wages.

[12]This follows from the first oder condition of the depositor's maximization problem with respect to bond holdings.

expected terminal wealth $P_{j,t}$.

$$P_{j,t} = \max \quad \mathbb{E}_t \sum_{s=t}^{\infty} (1-\phi)\phi^{s-t} \left(\tfrac{1}{1+r}\right)^{s-t} W_{j,s+1} \tag{9}$$

$$\text{s.t.} \quad W_{j,s+1} = (R_s - R_{x,s})L_{j,s} + R_{x,s}W_{j,s} \tag{10}$$

$$P_{j,s} \geq \lambda L_{j,s} \tag{11}$$

When banker j becomes a depositor, the accumulated equity is part of the family's profits. The growth in equity given by (10) depends on the difference between the return on loans R_t and the interest rate on deposits $R_{x,t}$ as well as the amount of lending $L_{j,t}$. The incentive constraint (11) limits the banker's ability to borrow. It is motivated by a moral hazard problem between bankers and depositors. In each period, bankers can choose to divert their assets, in which case depositors can recover a share $(1-\lambda)$ but cannot enforce the repayment of the remaining share λ that is kept by the banker.

The bankers' problem can be easily characterized if there exists an arbitrage opportunity due to market imperfections that renders loans profitable, $R_t \geq R_{x,t}$. First, it is optimal for bankers to build up net worth until they become depositors which makes the incentive constraint is binding, $\lambda L_{j,t} = P_{j,t}$. Second, the value of a banker and the loan supply of each banker is linear in net worth.

Accordingly, aggregate loan supply and wealth accumulation can be expressed as functions of aggregate wealth W_t:

$$L_t^b = \chi_t W_t \tag{12}$$

$$W_t = \phi \left[(R_{t-1} - 1)L_{t-1}^b + W_{t-1} \right] + \kappa + \gamma q_t B_{t+1} \tag{13}$$

where χ_t in the aggregate loan supply equation (12) is endogenous and time-varying. The evolution of aggregate wealth (13) captures one term for the existing wealth of surviving bankers, $W_{e,t} = \phi \left[(R_{t-1} - 1)L_{t-1}^b + W_{t-1} \right]$, and another term for the endowment of new bankers, $W_{n,t} = \kappa + \gamma q_t B_{t+1}$, comprising a constant component κ and an amount equal to the domestic bond holdings $\gamma q_t B_{t+1}$.

Investors. There is a continuum of investors who are risk-neutral. Some investors buy government bonds to break even in expectation. The marginal investor is foreign and determines the price of government debt to satisfy

$$q_t = \mathbb{E}_t \left(\frac{d_{t+1}}{1+r} \right) \tag{14}$$

where $d_{t+1} \in \{0, 1\}$ is the government's default decision in the following period. Other investors own firms. They receive the profits, bear the risk of destruction and discount future profits at rate $1/(1+r)$. However, they cannot provide the within-period loans which has to go through intermediate banks.

Government. In each period, the government chooses non-contingent one-period bonds B_{t+1}, lump-sum taxes τ_t paid by employed workers, and default or repayment of inherited debt $d_t \in \{0,1\}$. The government is utilitarian and maximizes social welfare,

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \left[(1-u_s)\mathbf{u}(c_s) + u_s \mathbf{u}(T)\right] \tag{15}$$

where it weights each worker's utility equally, regardless of their employment status or consumption level. When the government defaults ($d_t = 0$) it cannot issue new debt in the same period ($B_{t+1} = 0$). It is further constrained by the government budget constraint

$$u_t T = (1-u_t)\tau_t + d_t[q_t B_{t+1} - B_t] \tag{16}$$

The government understands how its policy affects the private sector and is constrained by private sector implementability conditions. These involve the response of the private sector to current policy changes that pin down the unemployment rate u_t and the law of motion for aggregate employment which determines future unemployment rates and the evolution of bankers' net worth. Section 3.2 describes these constraints in detail. The government further understands the pricing schedule that is dictated by foreign investors who need to break even in expectation according to equation (14).

Importantly, the government cannot commit to any future default, debt or tax policy. I restrict attention to Markovian policies that depend on aggregate productivity, outstanding debt, initial employment and equity of continuing bankers summarized by the aggregate state $\Omega_t = (z_t, B_t, N_t, W_{e,t})$. Beginning-of-period employment level N_t and unemployment rate u_t relate to each other by accounting for firing s_t such that $u_t = 1-(1-s_t)N_t$. Markov-perfect equilibria allow a recursive representation of the workers', firms', bankers' and government's problems (see Appendix A.3). A Markov government policy $\mathcal{D}$ maps the state into the policy instruments $\mathcal{D} : \Omega_t \to (B_{t+1}, \tau_t, d_t)$. Henceforth, I will drop time subscripts to denote current period's states and choices and use " ' " to indicate next period's states and choices.

Timing. The timing of the model, illustrated in Figure 3, is as follows. In each period, the aggregate productivity state z is realized first and the current state is given by $\Omega = (z, B, N, W_e)$. Next, the government chooses its default d, tax τ and debt B' policy. This decision pins down the debt level B' in next period's state. Depositors make deposits X and endow new bankers with funds, leading to the aggregate net worth of bankers W. Firms face idiosyncratic cost shocks k_i. Then the loan market clears and determines loans L^b, firing s and vacancies v. Wages w are paid before production of output $z(1-s)N$ and consumption c take place. Loans are repaid and bankers become depositors and vice versa, establishing existing banker's net worth W_e'. At the end of the period, a share ξ of active jobs is destroyed and new matches M are formed. The tuple (s, ξ, M) determines the next period's initial employment state N'.

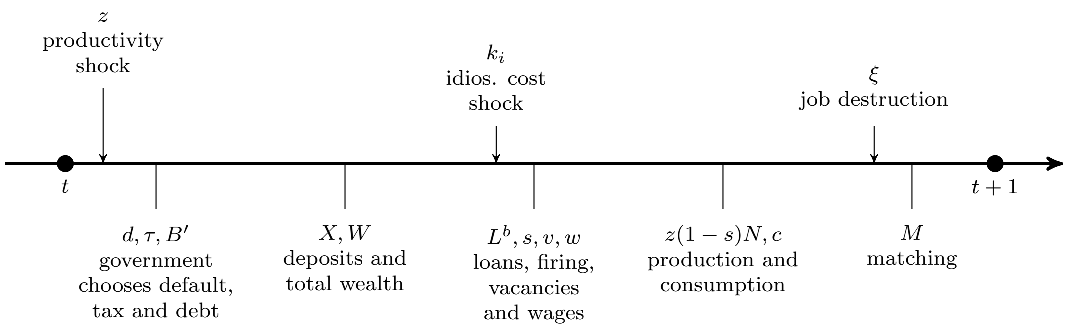

Figure 3: Timing of the model.

3.2 Equilibrium

I concentrate on Markov-perfect equilibria that can be characterized as follows. In each period, the government moves first by choosing current period policies. Its choices are constrained to depend only on the value of the current period's state – productivity, government debt and the aggregate initial employment and existing wealth levels.[13] After the government has moved, the private agents choose their current period actions. Since the private sector consists of small agents, private agents take future private and government policies and aggregate laws of motion as given. The government, however, correctly anticipates how future policy will depend on current policy through its effect on the state of the economy. I postulate a current government policy as a given debt issuance, taxation and default decision $\delta = (B', \tau, d)$ and a constant future government policy as a mapping from the aggregate state to borrowing, tax rates and default $\mathcal{D} : \Omega \to (B', \tau, d)$

I represent the Markov-perfect equilibrium in recursive form in two parts. First, given the aggregate state Ω and the current and future government policies δ and $\mathcal{D}$, I compute the equilibria in the private sector associated with these government policies. I check for multiple equilibria and focus on the one with the highest employment level.[14] Second, I characterize the economic behavior implied by the best one-period deviation to construct optimal equilibrium policies on the part of the government (fixed-point problem). I will now discuss these steps in detail.

First, consider a government policy $\mathcal{D} : \Omega \to (B', \tau, d)$ such that the state in the following period is given by $\Omega' = (z', B', N', W'_e)$.

Definition 1 *Given state Ω, current government policy δ and future government policy $\mathcal{D}$, a **private sector equilibrium** $\mathcal{P}$ is defined as*

- *policies s, v, X, b' and L^b*
- *value functions $\mathcal{J}$, $\mathcal{V}$, $\mathcal{E}$, $\mathcal{U}$, P and $\mathcal{G}$*

[13]Alternative equilibrium concepts include for example sustainable equilibria that can depend on the entire previous history of shocks (Chari and Kehoe (1990)).

[14]In Balke (2016), I focus on the possibility of multiple equilibria in this step and study its implications for bond pricing and expectation-driven debt crises.

- *prices* R, R_x, q *and* w
- *laws of motion* N' *and* W'_e

which are functions of $(\Omega, \delta, \mathcal{D})$*, such that*

1. *policies are optimal, i.e. endogenous separation* s *satisfies the non-negative profit condition (4), vacancies* v *satisfy free entry* ($\mathcal{V} \leq 0$)*, and deposits* X*, bond holdings* b' *and loans* L^b *solve (7) - (11);*
2. *value functions solve Bellman equations, i.e.* $\mathcal{J}$ *maximizes profits (58) subject to the pre-financing constraint,* $\mathcal{V}$ *is the value of an open vacancy (59),* $\mathcal{E}$ *and* $\mathcal{U}$ *solve the workers' Bellman equations (56)-(57), and* P *and* $\mathcal{G}$ *solve the problem of banker families (60)-(64);*
3. *the loan rate* R *clears the loan market,* R_x *clears the deposit market, the debt price* q *lets lenders break even in expectation (14) and the wage* w *is set as a function of output (6);*
4. *wealth evolves according to (13) and the law of motion of aggregate employment is consistent with matching technology and separation:* $N' = (1-\xi)(1-s)N + M(1-(1-s)N, v)$.

In a private sector equilibrium, the private sector faces an arbitrary policy $\delta = (B', \tau, d)$ in the current period, after which government policy reverts to the constant policy mapping $\mathcal{D}$. However, in a Markov-perfect equilibrium the government lacks commitment and therefore neither can commit to a constant policy mapping nor abstain from making the best decision for the current period. In order to define a policy equilibrium I therefore need to consider the best possible current deviations of a government in a subsequent step.

Second, I can determine a time-consistent policy equilibrium. Turning to the determination of $\mathcal{D}$, let δ^* be the most preferred policy of the incumbent government, which gives the highest value to the workers given that its successors will revert to policy $\mathcal{D}$.[15] By construction the indirect utilities $\mathcal{E}$ and $\mathcal{U}$ can be used to express the attained social welfare so that δ^* solves

$$\mathcal{W}(\Omega, \mathcal{D}) = \max_{d \in \{0,1\}} d\mathcal{W}^{rep}(\Omega, \mathcal{D}) + (1-d)\mathcal{W}^{def}(\Omega, \mathcal{D}) \tag{17}$$

$$\mathcal{W}^{rep}(\Omega, \mathcal{D}) = \max_{\tau, B'} N\mathcal{E}(\Omega, \delta, \mathcal{D}) + (1-N)\mathcal{U}(\Omega, \delta, \mathcal{D}) \tag{18}$$

$$\mathcal{W}^{def}(\Omega, \mathcal{D}) = \max_{\tau, B'} N\mathcal{E}(\Omega, \delta, \mathcal{D}) + (1-N)\mathcal{U}(\Omega, \delta, \mathcal{D}) \tag{19}$$

$$\text{s.t. } [1-(1-s)N]T = (1-s)N\tau + d(qB' - B) \tag{20}$$

$$(\mathcal{E}, \mathcal{U}, s) \text{ is a private sector equilibrium } \mathcal{P} \tag{21}$$

[15] In general, there may be more than one solution to δ^*. In the numerical computation I verify that $\mathcal{W}^{rep}$ is single-peaked.

Note that δ^* is the best one-time deviation given that in the future $\mathcal{D}$ is chosen forever and achieves the social value $\mathcal{W}$. The government chooses whether to default or repay d according to which it either receives the value of repayment $\mathcal{W}^{rep}$ or default $\mathcal{W}^{def}$. Choices are constrained by the government budget requirement and the implementability conditions that are summarized by the fact that $(\mathcal{E}, \mathcal{U}, s)$ must be a private sector equilibrium.

Definition 2 *A **time-consistent policy equilibrium** is a government policy $\mathcal{D}$ and a private sector equilibrium $\mathcal{P}$ such that*

1. *$\mathcal{P}$ is the private sector equilibrium associated with δ^* and $\mathcal{D}$*
2. *$\mathcal{D}$ is the most preferred one-time deviation, $\delta^* = \mathcal{D}$*

A solution to the overall policy problem is therefore a fixed point. This definition of equilibrium amounts to subgame perfection or time consistency of equilibrium. By varying the policy currently under consideration, the government takes into account the equilibrium response of all future variables.

4 Model analysis

4.1 Loan market clearing

This section describes the loan market equilibrium and the joint determination of endogenous separation s, job vacancies v and the loan price R. The loan market clears when the price of loans R equalizes aggregate loan supply L^b and demand L^f:

$$\chi W = w(1-s)N + av \tag{22}$$

Loan supply in (22) follows from (12) and is a linear function of aggregate net worth if the incentive constraint binds. The ratio of assets to equity χ is increasing in R and time-varying, however, it does not depend on firm specifics (see Appendix A.2). Therefore, aggregate loan supply L^b is increasing in the loan rate. Net worth W reflects the existing wealth W_e of the continuing bankers and new wealth W_n of new bankers. The first order condition of the depositors impose on the within-period deposit return to satisfy:

$$R_x = 1 \tag{23}$$

Bankers only operate if $R \geq R_x = 1$.

Loan demand in (22) follows from (3) together with $(1-u) = (1-s)N$. The total loan demand by new and incumbent firms is given by the sum of funds they require to pre-finance wages and vacancies and depends on the separation of matches s and the entry of vacant firms v.

To determine the endogenous separation of matches s, let $\hat{k}$ be the operational cost level above which flow profits are negative, given productivity z, wages w and interest rate R. In other words, a firm with operational costs at the cut-off value $\hat{k} = z - Rw$ makes zero period profits. Due to the no-equity issuance constraint (4), firms with idiosyncratic operational costs exceeding this threshold, $k_i > \hat{k}$, need to exit. The share of separations s is therefore determined by the measure of firms with operational costs higher than $\hat{k}$:

$$s = 1 - G(\hat{k}) \tag{24}$$

Given productivity z and wage w, a firm with the highest cost $\overline{k}$ makes zero profits at the loan rate:

$$R^{exit} = \frac{z - \overline{k}}{w}. \tag{25}$$

Once the loan rate exceeds R^{exit} firms violate the non-negative profit condition. Hence, the loan rate R^{exit} describes a threshold, below which all existing firms can continue to operate and endogenous separation is zero, $s = 0$, but above which a positive share of firms exits, $s > 0$. In particular, the higher the loan rate the more firms need to exit such that loan demand is decreasing in the loan rate.

Turning to the pre-financing of vacancy postings v, consider the value of a firm with operational costs k_i, given the aggregate state Ω and an equilibrium government policy $\mathcal{D}$:

$$\mathcal{J}^i(k_i, \Omega, \mathcal{D}) = \begin{cases} z - Rw - k_i + \frac{1}{1+r}\mathbb{E}_{z,k}\{(1-\xi)\mathcal{J}^i(k_i', \Omega', \mathcal{D})\} & \text{if } z - Rw - k_i \geq 0 \\ 0 & \text{if } z - Rw - k_i < 0 \end{cases} \tag{26}$$

Expected profits of a previously matched firm before the realization of types can be expressed recursively as

$$\mathcal{J}(\Omega, \mathcal{D}) = (1-s)\left(z - Rw - \mathbb{E}_k\{k | k \leq \hat{k}\} + \frac{1}{1+r}\mathbb{E}_z\{(1-\xi)\mathcal{J}(\Omega', \mathcal{D})\}\right) \tag{27}$$

where $(1-s)$ is the probability of meeting the profit condition. Given $\mathcal{J}(\Omega, \mathcal{D})$ the value of a vacancy can be expresses as:

$$\mathcal{V}(\Omega, \mathcal{D}) = -Ra + \lambda_f(1 - (1-s)N, v)\frac{1}{1+r}\mathbb{E}_z\{\mathcal{J}(\Omega', \mathcal{D})\} \tag{28}$$

Free entry requires that vacancies are posted until the value of a vacancy is equal to zero, $\mathcal{V} = 0$, and there is no vacancy posting if $\mathcal{V} < 0$. Fewer vacancies are posted when they are expensive and so vacancies are decreasing in the within-period interest rate.

Let R^{post} be the cut-off loan rate above which vacancies fall to zero, even if the vacancy

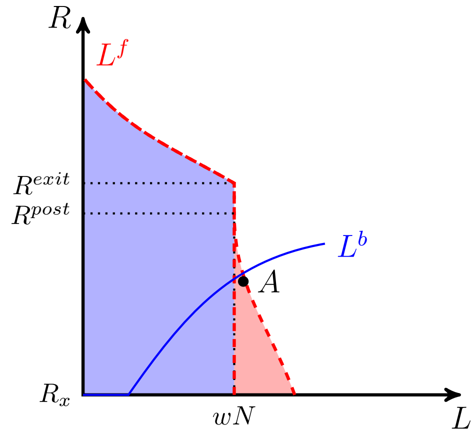

Figure 4: Loan market equilibrium: Point A. Supply L^b (blue solid line) and demand L^f (red dashed line) with loan rate R. Above R^{post} vacancies fall to zero (v=0). Below R^{exit} all existing firms continue (s=0).

was filled with certainty, $\lambda_f = 1$:

$$R^{post} = \frac{1}{a(1+r)} \mathbb{E}_z\{\mathcal{J}(\Omega', \mathcal{D})\} \tag{29}$$

Then no vacancies are posted above the threshold R^{post} because a vacancy costs more than it is worth in expectation, $v = 0$. Below the threshold R^{post} more vacancies are posted as the interest rate R decreases, $v > 0$.

In equilibrium s, v and R must jointly solve non-negative firm profits, free entry, and loan market clearing:

$$s = 1 - G(z - Rw) \tag{30}$$

$$Ra \geq \lambda_f(1-(1-s)N, v)\frac{1}{1+r}\mathbb{E}_z\{\mathcal{J}(\Omega', \mathcal{D})\} \quad (v = 0 \text{ if } >) \tag{31}$$

$$\chi W = w(1-s)N + av \tag{32}$$

Figure 4 illustrates the loan market equilibrium. Loan supply (blue solid line) is increasing in the loan rate R. Loan demand (red dashed line) comprises demand for wages and entry costs and is decreasing in the loan rate. Below R^{exit} all incumbent firms continue to operate and their loan demand is invariant with the loan rate, while the loan demand decreases above this threshold because more and more firms exit as R increases. Above R^{post} no vacancies are posted but with decreasing R vacancies become cheaper and increase. The equilibrium return R is located where aggregate loan demand L^f crosses loan supply L^b, point A. Free entry binds ($\mathcal{V} = 0$) and no firing takes place ($s = 0$) because the loan rate lies below R^{post} and R^{exit}.

Firing and firm destruction determine the total probability of separation in equilibrium. While exogenous destruction takes place at the end of each period, firing may become neces-

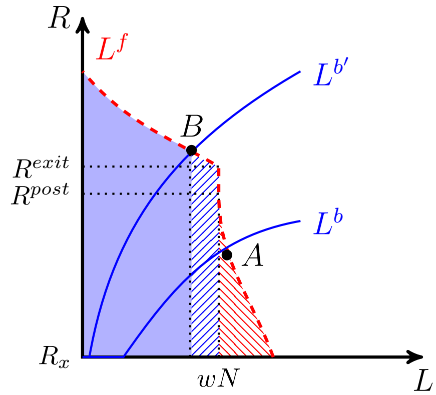

Figure 5: Employment cost of sovereign default: Fewer vacancies (red northeast hatched area) and separation of matches (blue northwest hatched area) due to default or lower debt prices. Fewer loans and higher loan rates in equilibrium B.

sary after productivity realizes and the government sets its current policy at the beginning of a period. This timing makes the government's current debt and default policy have an immediate effect on current firing.

4.2 Transmission of default risk

This section describes how default risk transmits to the labor market and the main trade-off the government faces when making its debt-default decision. The government is concerned about the fact that government bonds aid loan creation, which is needed for the functioning of the labor market.

The complementarity between the public and private sector stems from the fact that the bankers' optimal loan supply depends positively on their assets, which are partially formed by government debt. The labor market is disrupted by either less government debt issuance or lower debt prices.

To understand the transmission of default risk to the labor market, it is helpful to recall the two key equations for bond pricing and loan supply:

$$q = \mathbb{E}\left(\frac{d'}{1+r}\right) \tag{33}$$

$$L^b = \chi\left[W_e + \kappa + \gamma q B'\right] \tag{34}$$

The first links default risk to the debt price. The second implies that loan supply depends positively on the value and amount of sovereign debt. If default becomes more likely or the repayment probability decreases, the debt price q decreases as can be seen in (33). By (34) lower bond prices shrink the new bankers' equity and thus the total wealth of banks. It follows that the aggregate loan supply in the economy shrinks at each possible loan rate.

Figure 5 illustrates this scenario and shows how higher default probabilities cause unemployment to rise because they suppress loan supply and lead to higher within-period interest rates. The loan supply curve L^b shifts left to $L^{b'}$ (solid blue lines), moving the equilibrium from point A to point B for the same loan demand L^f (dashed red line). The market clearing interest rate increases. Since the associated loan rate is higher than the two threshold levels R^{post} and R^{exit}, the value of a vacancy is negative resulting in zero vacancies ($v = 0$) and some firms make negative profits leading to their exit ($s > 0$). Some pre-existing jobs are destroyed (blue northeast hatched area) and no new vacancies are posted (red northwest hatched area). This increases unemployment and constitutes the employment cost of sovereign default and default risk.

The main mechanism comprises that default or higher default risk decreases loan supply which in turn increases the equilibrium loan rate. Higher borrowing rates mean higher gross wage costs for a firm and lower incentives to post vacancies. More drastically, if the sovereign debt policy pushes the interest rate above R^{post} and R^{exit}, it depresses job vacancies and destroys jobs, which results in an increase in unemployment.

The wage setting is important for this outcome. If wages could be renegotiated and adjusted downwards in response to high loan rates, endogenous separation may be prevented. In this case most labor market dynamics would stem from vacancy posting instead of firing and the unemployment response would be smaller. Here, once the firm makes negative profits it exits although the bilateral bargaining set between the worker and the firm may be non-empty. The wage setting therefore creates inefficiencies.

The co-movement of sovereign spreads and loan rates means that the prospect of default alone dries up lending and hurts the labor market, independently of whether default takes place or not ex-post. This anticipation effect is important for the timing of labor market adjustments around default events but also enables the model to capture debt crises.

When the government is confronted with a low productivity shock, it trades the cost of increasing taxes to raise enough revenue for debt repayment off against the cost of compromising the loan generation function of its debt. In the first case, the government sacrifices utility of the employed who are left with lower after-tax income. In the latter case, the government sacrifices some employed workers' jobs through separation and reduces the unemployed workers' probability of finding a job. In equilibrium, defaulting becomes optimal when the utility costs from the tax burden on the employed outweigh the utility costs from higher unemployment.

5 Quantitative evaluation

5.1 Calibration strategy

The model is solved numerically and using calibration techniques. One period corresponds to a quarter. To give insights into the model predictions for the recent European debt crisis, the model is calibrated to match Portugal's labor market. I use estimates from other studies whenever possible and calibrate the remaining parameters using indirect inference targeting

Parameter	Description	Source/Target
Calibrated		
$r = 0.01$	Risk-free interest rate	Arellano (2008)
$\sigma = 2.00$	Relative risk aversion	Eichenbaum et al. (1988)
$\psi = 0.40$	Matching parameter	Merz (1995)
$\rho = 0.88$	Persistence parameter	Arellano and Bai (2014)
$\sigma_\epsilon = 0.03$	Standard deviation	Arellano and Bai (2014)
$\phi = 0.00$	Survival of bankers	Static banking
$k_i = 0.00$	Operational cost	Lottery
Estimated		
$\beta = 0.96$	Discount factor	Default probability 3%
$T = 0.30$	Benefit	Replacement rate 50%
$\kappa = 0.60$	Initial wealth	Firing 6%
$\lambda = 0.93$	Enforcement cost	Loan rate 12%
$\mu = 0.04$	Match efficiency	Unemployment 7%
$\xi = 0.03$	Exogenous separation	Inflow rate $0.4 - 1.1\%$
$\omega = 0.25$	Wage parameter	Non-negative surplus
$a = 0.04$	Vacancy costs	Cost-wage ratio 4.5%

Table 2: Calibration strategy: Quarterly. Calibrated parameters are set using outside estimates. Estimated parameter values are found by matching a set of targets using indirect inference.

a set of moments discussed further below. Table 2 summarizes the resulting parameters and targets. The exact implementation of the model and how it currently differs from the previous section is described in the following. Appendix A.4 summarizes the computational strategy.

Workers. The CRRA parameter $\sigma > 0$ determines the intertemporal elasticity of substitution of consumption. I assume $\sigma = 2$ which is in line with a large amount of empirical evidence using either household data or aggregate data, see e.g. Attanasio and Weber (1995) or Eichenbaum, Hansen, and Singleton (1988).

The discount factor β is estimated by indirect inference. The main target for β is the default probability which I set equal to 3 percent annually.[16] This frequency is consistent with historical default rates in Greece and a standard value in the default literature, see e.g. Arellano (2008). In conjunction with other parameters, I calibrate β to be 0.96, showing that domestic workers are impatient relative to the risk-free interest rate, which is calibrated to 4 percent annually, $r = 0.01$. Assuming a low value of unemployment, I adopt a transfer

[16]Because of the non-linearity of the moments in the parameters, there is no exact one-to-one mapping from targets to parameters individually. However, some targets are more important for some parameters than others and this is the logic of the discussion.

level $T = 0.3$ to target an average benefit replacement rate of 50 percent.[17]

Depositors and bankers. Bankers stay in business for only one period, $\phi = 0$. Since the domestic share of debt holdings is indeterminate, I report key moments of the model with a varying domestic debt share γ between 10 and 90 percent. High domestic debt reflects the high exposure of European banks to government debt.

The constant start-up wealth of bankers κ is estimated by targeting an average increase in the unemployment rate in default of six percentage points. This is in line with the steep hikes observed in Southern Europe during the last crisis. The estimate of κ is 0.60. Finally, I choose the enforcement cost parameter $\lambda = 0.93$ by targeting a maximum quarterly loan rate of 12 percent.

Firms. I follow Silva and Toledo (2009) and assume that vacancy posting costs correspond to 4.5 percent of quarterly wages. Given this target, I find an estimate of the vacancy posting cost of $a = 0.04$. Wages are set as in (6). The share parameter ω ensures that workers and firms, facing the risk-free loan rate but zero operational costs, make a surplus at the lowest possible productivity level $\underline{z}$, i.e. the wage lies within the bargaining set. This yields $\omega = 0.25$.

In the current version of the computational part, I abstract from idiosyncratic operational costs, $k_i = 0$. Instead I assume that the participation constraint always puts an upper limit on the deposits and that there is a maximum leverage of the banks. This implies that the upper loan rate also serves as firing and vacancy threshold. Homogeneous firms enter a lottery over rationed loans.

Technology. I assume that aggregate productivity z follows an AR(1) process as shown in (1). To match the productivity process in Southern Europe I use persistence $\rho = 0.88$ per quarter and a standard deviation $\sigma_\epsilon = 0.03$ of a standard normally distributed shock in line with Arellano and Bai (2014).

The matching function elasticity ψ is calibrated following Merz (1995), $\psi = 0.4$. The match efficiency $\mu = 0.04$ results from targeting an unemployment rate of around 7 percent in the long run without default. I estimate the exogenous job destruction rate ξ to match the rather low monthly inflow rate into unemployment of $0.4 - 1.1$ percent observed in Portugal and Spain (Elsby, Hobijn, and Şahin (2013)). This yields an estimate of $\xi = 0.03$.

5.2 Simulation results

I use simulation techniques to understand whether the model can replicate the dynamics of labor market variables around debt crises and default events and to evaluate the model's quantitative performance. I draw random productivity shocks for 1,000,000 periods and

[17] Alternatively, one might consider adopting a Hagedorn and Manovskii (2008) calibration by assuming a much higher replacement rate.

Moment	Description	Data	Model $\gamma \in [0.1, 0.9]$
Mean			
$\mathbb{E}(B/Y)$	Debt ratio	69%	69 to 115%
$\mathbb{E}(d)$	Default probability	3%	1.5 to 3%
$\mathbb{E}(u)$	Unemployment rate	7%	7 to 11%
Correlation			
$corr(Y, spr)$	GDP and spread	-6%	-5 to 25%
$corr(Y, TB)$	GDP and trade balance	1%	-7 to 23%

Table 3: Model prediction and Portuguese data: Debt ratio 2000-2011 and GDP correlations 1995-2015.

discard the first 1000 periods, starting the simulations from mean productivity and zero debt.

As detailed below, this model can resolve some of the key quantitative challenges in the sovereign default literature: generating empirically realistic debt ratios, rationalizing defaults in relatively good times and producing clustered default events. This section also serves to highlight the frictions that underlie the mechanism by which default impacts on unemployment via bank lending.

5.2.1 High debt ratios from persistent and asymmetric default costs

Although the debt-to-GDP ratio was not targeted in the calibration, the model naturally generates debt ratios, which are consistent with the level of indebtedness in European countries, despite keeping default frequencies realistic (see Table 3). The borrowing ratio to quarterly GDP in the baseline is between 69 and 115 percent annually while being able to target standard default probabilities of three percent.

High debt ratios at reasonable default frequencies are hard to rationalize with standard quantitative default models. When debt-to-GDP ratios of around 50 percent for emerging market economies are successfully targeted, it is common for the models to miss the average default frequency by an order of magnitude.[18] The quantitative shortcomings of standard default models appear even more severe when one considers that developed countries are on average more indebted than emerging market economies.[19]

The success of the model to generate these high debt ratios while keeping considerable default frequencies hinges on two features of the employment cost of default: its persistence and its asymmetry. While the persistence of default costs can explain high debt levels due

[18] Aguiar, Chatterjee, Cole, and Stangebye (2016) discuss in detail the difficulty of sovereign default models in matching high debt ratios and simultaneously generate plausible default frequencies.

[19] Moreover, Dias, Richmond, and Wright (2014) find higher debt levels for emerging economies by using more sophisticated measures of indebtedness than face values.

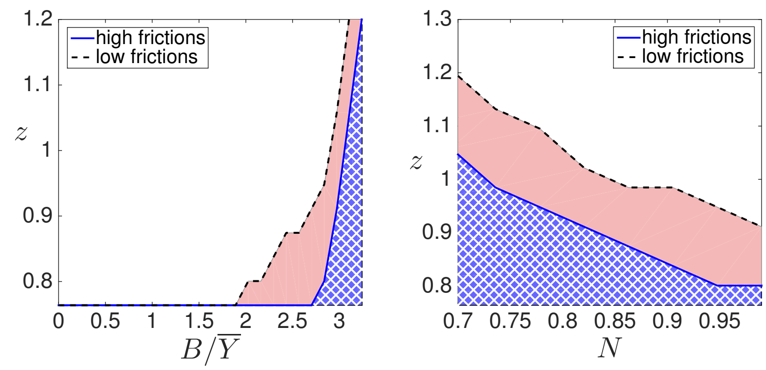

Figure 6: Labor frictions and default regions: Default thresholds in the debt-productivity state space given average employment (left) as well as for the employment-productivity state space for average indebtedness (right). Lowering labor market frictions enlarges shaded default regions.

to high default costs, asymmetry is needed to also simultaneously generate enough default in equilibrium. An exclusive increase in default costs would raise debt levels but at the same time decrease the willingness of the government to ever default in order to avoid the payment of just those higher costs.

Persistence of default costs. Since the default cost materializes in form of unemployment, its persistence is directly related to the persistence of unemployment which is increasing in labor market frictions. Comparing the implications of different degrees of frictions in the labor market sheds light on the importance of matching frictions and the persistence of unemployment for generating realistic sustainable debt ratios. In the following exercise I compare two cases that only differ in their match efficiency.[20] In one case, the match efficiency is moderate and employment takes about 8 quarters to recover after default with an average job finding rate of 0.4. In the other case, I increase the match efficiency such that the job finding rate almost doubles and employment recovers much faster.

Doubling the match efficiency lowers the debt-to-GDP ratio that is sustained over the ergodic set by about 10 percent and shifts default thresholds. The solid blue line in Figure 6 plots the default threshold for moderate match efficiency in the debt-productivity (left) and employment-productivity (right) space at mean employment and mean indebtedness, respectively. Above the solid blue line it is optimal for the government to repay its debt but to default below (blue hatched area). Evidently, default is more likely for higher debt, lower employment and lower productivity. Increasing the match efficiency shifts the thresholds up to the black dashed lines, adding the red shaded intermediate area to the default region. At the same productivity and employment level, less debt can be sustained. The extent

[20] To make comparison easier in the following analysis, I model the link between sovereign bond prices and the interest rate in the private sector in reduced form by setting the interest rate R to the inverse of the debt price within $[1, 1.12]$. While simplifying the model, it captures the countercyclicality of the finance premium of the baseline model.

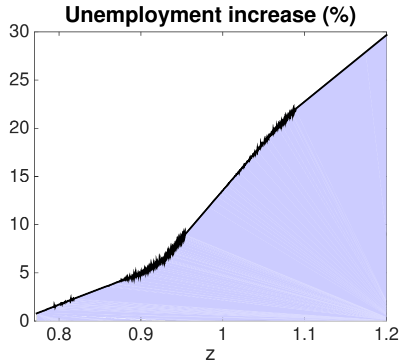

Figure 7: Asymmetric default cost: Default destroys more jobs when productivity is high, increasing unemployment asymmetrically.

to which frictions are present in the labor market affects the size of default costs and debt ratios. When frictions are low, default triggers a rise in the unemployment rate but the labor market can recover almost fully in the following period. In contrast, in frictional labor markets a one-time disturbance drives up unemployment, generating higher employment cost of default because new matches take longer to form. The persistence of unemployment creates an additional disincentive to default that helps create higher debt ratios in equilibrium.

Setting the match efficiency so high as to reach a job finding rate close to one makes the default region extend to almost the entire state space. The frictionless limit, as in an RBC type of labor market, therefore appears unable to sustain any positive debt level. In other words, without labor market frictions that render the increase in unemployment persistent, the model generates too small default costs and zero debt levels at odds with the data.

Asymmetry of default costs.

The asymmetry of default costs relates to the fact that default destroys more jobs when productivity and employment are high and results from the financial frictions that lead to an endogenous match destruction. Without the possibility of firing, default may still increase the interest rate and lower vacancy postings, but the government may prefer to default in times of high (not low) employment, which contradicts empirical findings. The reason is that depressed vacancy postings are less costly when only a few workers are unemployed.[21] To match the empirically relevant default region it is therefore crucial to allow for the possibility that firms fire workers and to impose the cash-in-advance constraint on wages in addition to vacancies. Since more loans are needed when the aggregate wage bill is high, the possibility of firing acts as an asymmetric cost of default that is higher in good times.[22] Here, the wage function implies that higher productivity is accompanied by better wages and therefore a

[21] Unraveling creates another problem when the government defaults in all employment and debt states. If default is more likely in high employment states and if higher borrowing today means higher employment tomorrow, this lowers the current debt price and the government would be less willing to borrow. This results in more unemployment, which decreases the government's ability to raise revenue. The government might therefore eventually default in both high and low employment states and debt becomes unsustainable.

[22] This is crucial for quantitative models (see for example Arellano (2008)).

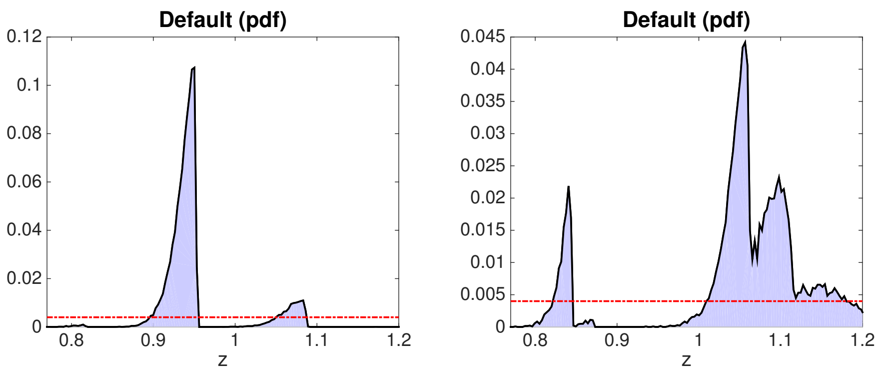

Figure 8: Default probability conditional on productivity: Default in bad and good times. Lowering the domestic debt share (left: $\gamma = 0.9$, right: $\gamma = 0.1$) leads to more default in good times.

bigger aggregate wage bill. A default in times of high productivity leads to a more than proportional increase in unemployment as depicted in Figure 7. Consequently, the default costs are higher when productivity is high.

On the one hand, asymmetric costs allow the government to cheaply borrow large amounts of debt in good times. On the other hand, high indebtedness in high productivity states bears the risk that a sudden decrease in productivity shifts the economy into a state where debt is still high but default costs suddenly plummet. Then a government optimally decides to default. Therefore, the model features considerable default risk at the same time as high debt levels.

Of course, labor market frictions only play a role if the decision to default transmits to the labor market, i.e. if financial frictions are present. If the interest rate of firm loans was independent of the debt price or repayment state and there was no firing, then the default decision would affect neither vacancies nor unemployment. Employment would be the same in repayment and default, but the government could reduce taxes in default. This means that the government would always prefer default to repayment. In equilibrium, debt would be unsustainable and there would be no borrowing at all. Intuitively, this is because there would be no punishment for default. It is necessary that government debt fulfills a collateral function, otherwise the models lacks a link between the sovereign and the private sector. The inability to issue new debt in the period of default alone cannot guarantee the sustainability of debt, as shown by Bulow and Rogoff (1989).

5.2.2 Default in bad and good times

Another result of the simulations is that the model is able to break the typically too tight relationship between output and default that standard models predict. In the data a negative but surprisingly weak relationship between output and default events can be found as pointed out by Tomz and Wright (2007). They call this a “puzzle for standard theories” because

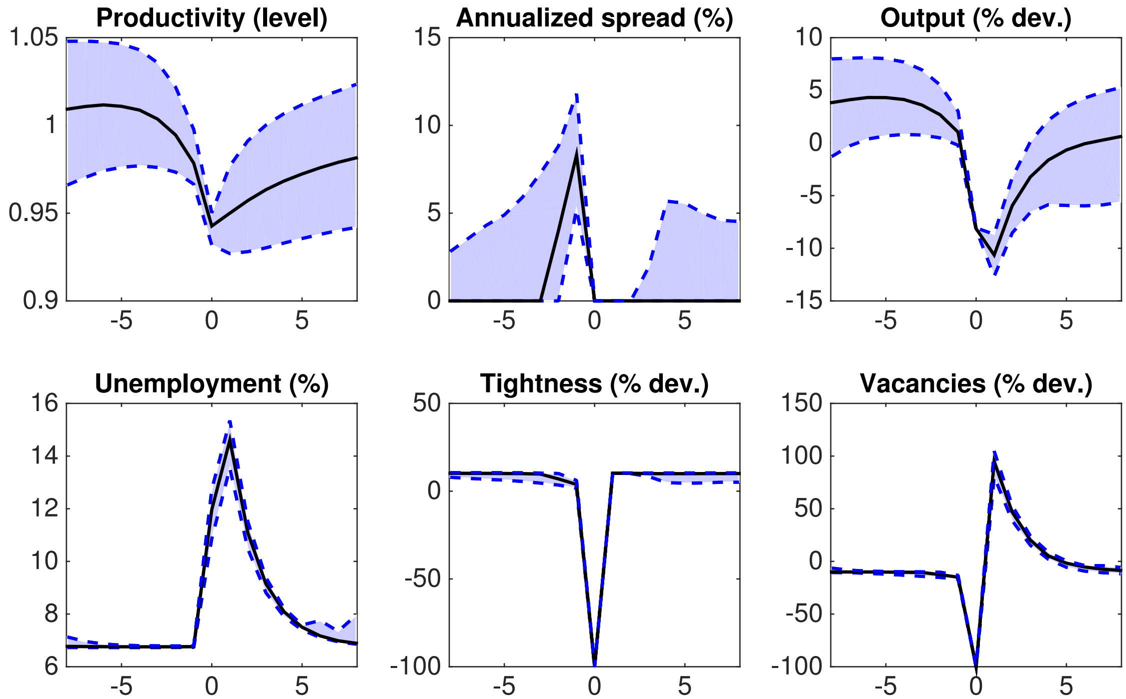

Figure 9: Default when output is low: Insurance motive of the government leads to risky borrowing. Simulation results for preceding as well as succeeding 8 quarters of default at time 0. Median (solid black line) as well as 25rd and 75th quantile (dashed blue lines).

quantitative default models typically predict default in bad times but are unable to also produce default in good times. This model rationalizes default in bad and good times.

Figure 8 plots the default probability over the productivity space for two different values of the domestic debt share. The conditional pdfs show that the probability mass of default is not only located at low productivity levels, indicating default in bad times, but also where productivity is high, especially if the domestic debt share is low (right). To understand the dynamics surrounding default events, I split the simulation outcomes from Figure 8 (left) into both default regions and compute the median paths of the economy in four year windows around them. I also report 25 and 75 percent confidence intervals.

Figure 9 plots the dynamics of the economy around default episodes in bad times, where 0 is the period of default. Defaults in bad times occur when periods of high or medium productivity are interrupted by a large drop in productivity that sends the economy into a recession. Prior to default, productivity starts falling slowly and output declines and spreads start to rise because the government has an incentive to insure employed workers by borrowing at the cost of paying risk premia. An additional productivity loss induces the government to default. Firms do not adjust much to the upcoming lower value of a job early in the run-up of default, however, when spreads suddenly rise in the two quarters preceding default, firms cut job vacancies. Although output starts to fall together with productivity,

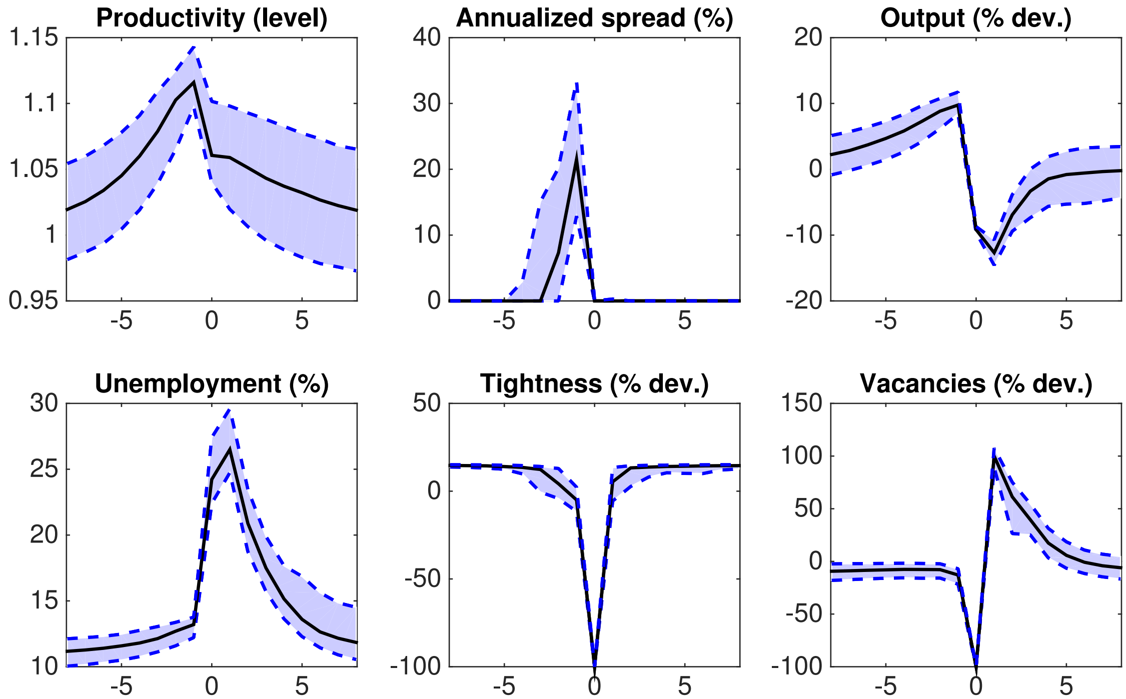

Figure 10: Default when output is high: Loan provision motive of the government leads to risky borrowing. Simulation results for preceding as well as succeeding 8 quarters of default at time 0. Median (solid black line) as well as 25rd and 75th quantile (dashed blue lines).

the biggest default cost materializes post-default when many jobs are destroyed such that the economy enters an extended recession with high unemployment levels. I call this the "employment cost of default". The persistent nature of the output collapse derives from the many workers who lost their job at the time of default and need time to find a new job after a typical default, so that GDP only recovers once jobs are rebuilt in the economy.

In contrast to this, Figure 10 plots default events in good times, centered around 0, after several periods of GDP growth. Prior to default, productivity is above trend and it is unlikely that productivity suddenly drops due to its high persistence. Consequently, spreads stay low. However, a sudden fall in productivity that interrupts the strong growth can prompt default, although productivity and output are still above trend. The abrupt big recession implies that the government is no longer willing to pay default premia to contain the increase in unemployment, but that instead default is optimal because debt repayment becomes too costly. This triggers again persistent employment costs.

Both types of default situations root in a productivity loss that induce the government to default. However, there may be instances where default is optimal although productivity and output are above trend.

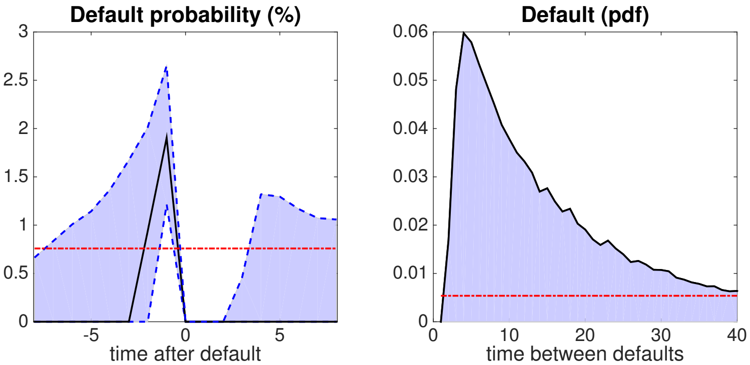

Figure 11: Likelihood of serial default: Default probability rises quickly after default (left) and is higher conditional on recent default (right).

5.2.3 Serial defaults

Another striking fact is that defaults tend to occur in temporal clusters – the so-called "serial defaults" (Reinhart and Rogoff (2004)).[23] The combination of a stronger propensity to default in high unemployment states and persistently high unemployment after default is responsible for a more likely second default shortly following the first.

Figure 11 (left) shows the likelihood of default in simulations of the baseline model, with the default event centered around 0. It shows that the default probability rises above the mean (red dashed-dotted line) before a default, which is followed by a new increase in the default probability above the mean right after a default event took place. This indicates the presence of serial defaults. The right panel of Figure 11 supports this interpretation because the default probability conditional on the time elapsed since the last default is highly skewed towards short times. The mode of time between two distinct default events is 6 quarters.

The model ingredients that underlie the mechanism by which it can produce clustered default events are in the first instance that serial defaults are feasible. Standard models that feature prolonged exclusions from markets cannot produce a second default while the government is not able to borrow in the aftermath of the first. In addition, the fact that clustered defaults are even more likely to be observed in the model depend also on the persistence and asymmetry of default costs: The default punishment in form of an increase in unemployment, which exhibits persistence due to matching frictions and makes another default less costly due to the asymmetry of costs, is the main reason that the model is capable of generating clustered default events.

5.3 Anticipation effects from labor market dynamics

While the previous section focuses on outright defaults and how the model can address some key challenges of the quantitative default literature, this section is concerned with

[23]See also Sturzenegger and Zettelmeyer (2006) and Reinhart (2010). Tomz and Wright (2013) provide a survey of the empirical research on sovereign debt and default.

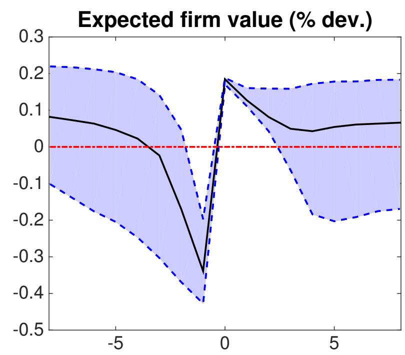

Figure 12: Expected firm value: Anticipation effects of default at time 0. Median (solid black line) as well as 25rd and 75th quantile (dashed blue lines).

debt crises. The fact that in standard models the default decision itself triggers (exogenous) changes in the economy, implies that default *risk* alone does not have a profound impact on economic activity. However, the recent debt crises in Southern Europe showed increases in unemployment even absent outright default, e.g. in Portugal and Spain (see Section 2). The proposed model in this paper features anticipation effects of default that hinge on the dynamic nature of the labor market and the effect of spreads on private lending.

In a dynamic labor market firms are forward-looking and discount the future firm value in the run-up to a crisis due to higher financing costs and a higher probability of separation in default (Figure 12). On the one hand, without the forward-looking behavior of the private sector, employment may at most react to changes in current productivity, wages or interest rates but not to default risk because the model lacks anticipation effects. However, the present wage setting yields a constant firm profit at each possible productivity level for a given loan rate (red dashed-dotted line). Only if the debt price falls due to a higher default likelihood and so the loan rate increases, non-dynamic firms make lower profits. On the other hand, without the effect of spreads on loan rates before an actual default event but with dynamic firm optimization, firms may indeed consider a change in the future separation probability when posting a vacancy but not the fact that vacancies become more expensive. Here, both forces affect the expected firm profits before default (solid line with confidence bounds). As previously discussed, fewer vacancy postings and higher unemployment lead up to default, which is consistent with the empirically relevant decline in employment that often accompanies elevated spreads before an actual default. However, the decline in expected firm value would also be present if default was avoided ex-post. As a result, vacancies decline and unemployment rises even absent an outright default.

Figure 13 illustrates instances where sovereign spreads rise substantially but do not lead to default. I define these "debt crises" as episodes where four consecutive quarters exhibit a mean annualized spread of at least five percent but are neither preceded nor succeeded by default in the four year window. I plot the last quarter of these elevated spreads at time 0. In the baseline with $\gamma = 0.9$, debt crises typically occur as a result of a long

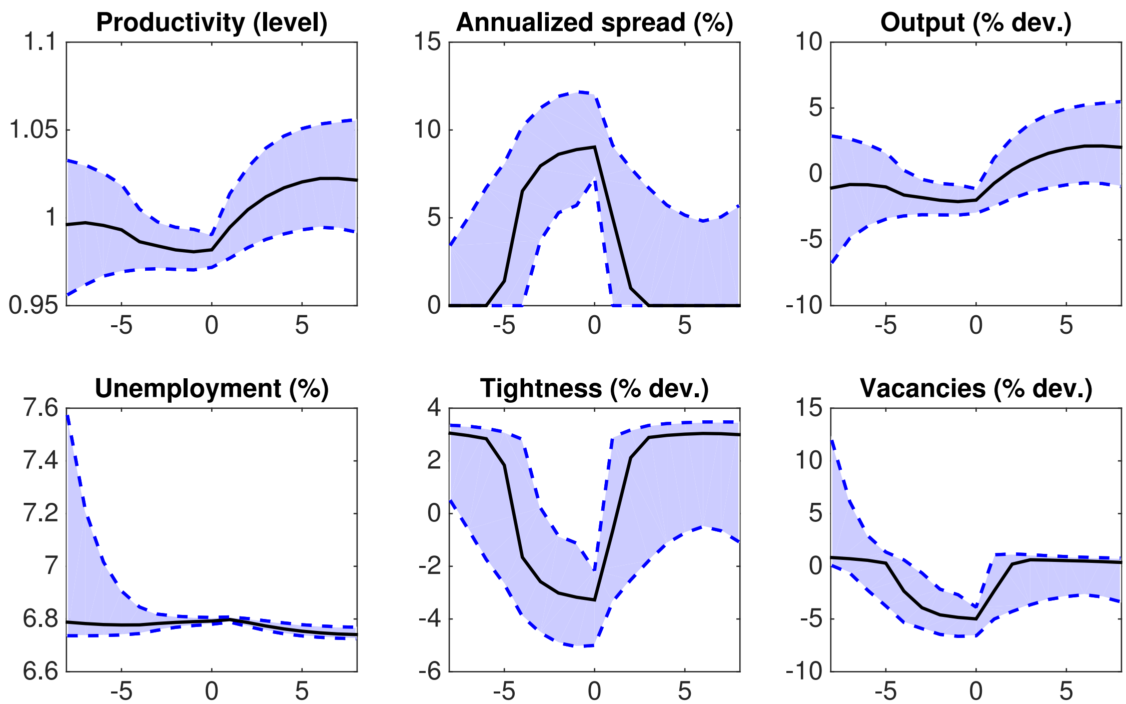

Figure 13: Debt crisis: Simulation results for preceding as well as succeeding 8 quarters of last crisis period at time 0. Median (solid black line) as well as 25rd and 75th quantile (dashed blue lines).

and moderate fall in productivity. During the slow decline in productivity the value of providing insurance outweighs the cost of default and the government pays an increasing risk premium. In response, firms adjust to higher loan rates and higher default probabilities with lower vacancy postings and labor market tightness decreases slowly. However, layoffs are not forced on firms. The typical debt crisis ends when the productivity drop reverses and produces a much stronger recovery in the economy than default episodes. Despite the fact that vacancies and tightness fall by roughly five and three percent, respectively, the employment effects are small because the government successfully facilitates private lending so that firing can be avoided over the entire period. This changes substantially if increases in spreads affect the loan market more dramatically, as observed during the recent European debt crisis.

By lowering the domestic debt share to $\gamma = 0.1$, the bankers have less collateral for loan creation and employment responds more strongly to rising bond spreads (14). I compare the debt crisis simulations of the model to Portuguese data between 2010 and 2014 (red dashed-dotted line). Debt crises occur more often in good times expanding the confidence bounds because – similarly to default events – debt crises take place both in high as well as low productivity states. The output simulations cover a wide range of possible paths, including the Portuguese output variation during this period. The unemployment rate peaks

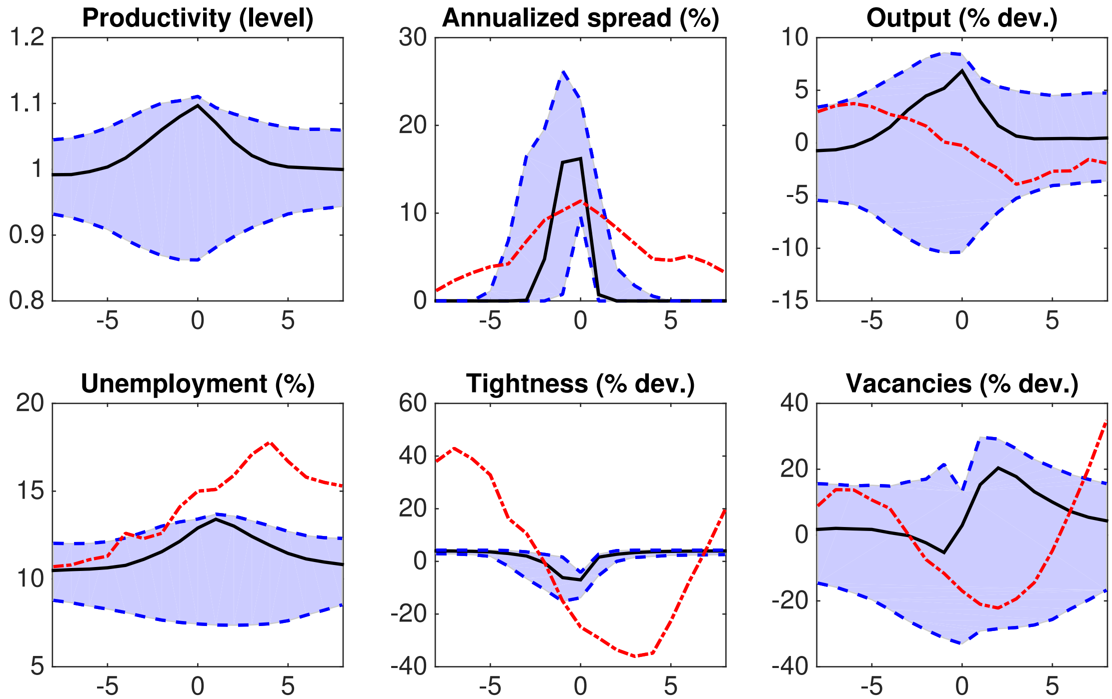

Figure 14: Debt crises with lower debt exposure of banks: A comparison with Portugal 2010-2014 (dash-dotted line). Crisis at time 0. Simulation results for preceding as well as succeeding 8 quarters of last crisis period. Median (solid black line) as well as 25rd and 75th quantile (dashed blue line).

one quarter after the end of the crisis period, earlier than in the data where unemployment continues to rise. However, the definition of a crisis used allows the spread to fall back to low levels much faster than was the case in Portugal. The confidence bounds of vacancy postings contain the Portuguese vacancy dynamics but the simulation shows that the model does not exhibit enough volatility in the tightness during this episode.[24] This exercise illustrates that the sensitivity of vacancy postings and tightness are related to the loan generation function of debt because government borrowing affects not only the default probability but also the price of vacancies.

To sum up, the model is able to produce not only real effects from default but also from default *risk* in debt crises. There is a striking difference between default episodes and debt crises both in terms of their underlying productivity sequence and in terms of the labor market response. Firms cut vacancies when they anticipate default because of the combination of more expensive job vacancies and a higher expected job separation rate. This strategy avoids firing when a country faces a moderate sequence of adverse productivity shocks but not in the case of a more abrupt productivity drop. In the latter case the

[24] One potential way of addressing this is to increase the rigidity of the wage, which in the current calibration is an affine function of productivity with unit slope and thus moves almost as much as productivity.

	$\mathbb{E}(s\|d=0)$	$\mathbb{E}(u\|d=1)$	$\mathbb{E}(u\|d=0)$	Debt	Default
Baseline	5.6%	7.7%	12.7%	1.00	1.00
Labor policies					
Wage subsidy	3.1%	7.4%	10.1%	0.99	1.08
Empl. subsidy	0.0%	7.1%	7.0%	0.96	1.30
Bank regulation					
High capitalization	1.3%	7.2%	8.3%	0.96	1.15
Low debt exposure	9.5%	11.3%	24.2%	1.64	0.47

Table 4: Policy experiments: Average firing and unemployment rates conditional on repayment state. Debt-to-GDP ratio and default frequency relative to baseline.

government defaults which disrupts the loan supply to the private sector and triggers more severe employment effects which materialize post-default.

5.4 Policy experiments

Can the government counteract the negative effects of default on the labor market by simultaneously implementing other policies? What implications do these policies have for the government's ability to commit? I consider wage and employment subsidies as well as bank regulations, and investigate their effects on labor market outcomes, default frequencies and debt ratios. The results are summarized by Table 4, which lists the average firing and unemployment rates conditional on the repayment or default state, together with the average debt-to-GDP ratio and default frequency relative to the baseline model.

5.4.1 Labor market policies

The effects of labor market policies depend crucially on their exact implementation, in particular whether subsidy payments are paid upfront or as a reimbursement to firms. A reimbursement subsidy in default fails to extenuate the decrease in loan supply and is ineffective in alleviating the bottleneck in the transmission of sovereign policy to the private sector. For this reason this section is concerned with upfront payments of the government.[25]

Wage subsidy. I first consider a *wage subsidy* – a direct transfer from the government to firms matched with a worker in order to decrease the firm's wage burden in default. In the example, the government finances five percent of the aggregate wage bill by taxes during

[25] Imagine a subsidy is implemented in a way that firms are reimbursed for parts of their wages or vacancies at the end of the period. This increases the surplus of a firm in default and may increase the number of firm entrants that renders the free entry condition binding. However, as shown in the simulation in the previous section, default episodes are usually accompanied by a slack free entry condition. Matched firms face the same constraints and only the ones able to stay enjoy the benefits of a wage subsidy. There is no effect on entry or firing.

defaults. Given the same amount of loan supply but a smaller aggregate wage bill, the number of exiting firms decreases. A wage subsidy therefore moderates the consequences of default on the economy. Defaults occur at a higher frequency than in the baseline. Note that the policy also affects the average unemployment rate in repayment, which falls by 0.3 percentage points, because a lower separation rate in default increases the value of a job and thus the value of a vacancy. In normal times more firms enter and the unemployment rate decreases.

The policy weakens the link between labor costs and productivity and reduces the cost of labor relative to the fall in productivity during a default. More importantly, the government redistributes from employed workers to firm owners by changing the after-tax wage. Nevertheless, employed workers may still be better off, despite earning a lower after-tax income, if they would otherwise have been fired and left with a lower consumption level as well as the need to find a new job. Note that, since the government has access to lump-sum taxation, the policy amounts to a simple wage reduction without any further distortionary effect on the economy. A wage subsidy not only softens the cost of default but can also be beneficial even for the workers who have to pay higher taxes, and so be welfare-improving.

Employment subsidy. To take this further, I consider the case where the government steps in to make sure all matched firms continue to operate during default. I call this policy an *employment subsidy*. The employment subsidy covers the exact amount needed to avoid any firing that would otherwise occur in default. Table 4 shows that by construction firing is now zero in default. The remaining effects are qualitatively the same as the case of a wage subsidy, except that they are more pronounced: debt ratios fall and default rates increase relative to the baseline. Since this intervention is expected by firms it changes their valuation of a job both in default as well as in repayment.

5.4.2 Bank regulation

The political discussion in Europe during the recent debt crisis concentrated to a much greater extent on bank regulation rather than labor market reforms. Although the intended goal was to stabilize the banking system as a whole, it is likely that such regulations also affect the real economy. I consider the implications of two policy counterfactuals by changing key parameters of the model: bankers' minimum equity and the sovereign debt share in their balance sheets.

Higher capital requirement. I compare the baseline to a model variation with a 10 percent higher minimum equity holding of bankers, κ. We can think of this as a policy that regulates the minimum *capital requirement* of banks.

In default states, firing falls by 75 percent compared to the baseline in default, implying a smaller default cost. A higher capital requirement therefore decreases the government's ability to commit to repayment. Accordingly, the average debt ratio falls and the default frequency rises. In repayment states, the regulation affects the real economy to the extent that it changes loan supply. As long as government debt can still fulfill its loan generation function, i.e. when loan supply is high enough to prevent firing, the effect is small. However, if lower debt ratios induce the overall loan supply to fall, the higher capital requirement is helpful in default but hurts the economy in normal times.[26]

Debt exposure of banks. A lower *debt exposure* of banks changes the results dramatically. Most striking is that firing and unemployment rates in default almost double while the government chooses to default only half the time. In normal times, the debt-to-GDP ratio reaches 1.6 times the baseline indebtedness and unemployment increases to 11.3 percent on average.

To understand this it is important to note that defaults are more often preceded by good times of rising (rather than falling) productivity but they are still triggered by an abrupt and large productivity drop. Output does not start to fall in the run-up to the default (see Section 5.2.2). The government borrows at high risk premia predominantly in good times because a lower domestic debt share hinders loan provision. More loans are required when high productivity and low unemployment mean that a high aggregate wage bill needs to be pre-financed. The labor market response to default is stronger because default occurs at higher wage levels. The government's incentive to issue debt is dominated by labor market concerns rather than its impatience (as in the baseline).

Since the extent to which the banking sector is exposed to government risk in normal times does not affect the loan supply in default, the unemployment level in the period of default in a given state is unchanged. However, two counteracting effects govern the default frequency. On the one hand, higher debt levels make default more appealing as the savings from refusing repayment are higher. On the other hand, the economy relies more heavily on higher debt issuance and is more sensitive to increases in bond spreads in repayment states because loans are more scarce. Lower domestic debt shares therefore help the government to credibly commit, reducing default frequencies and increasing sustainable debt ratios. This is in contrast with the mechanism outlined by Chari, Dovis, and Kehoe (2016) who show that financial repression can increase the government's commitment ability. The reason for the difference is that, in this paper, financial repression facilitates the provision of lending and so weakens one of the reasons for the government to refrain from defaulting.

6 Conclusion

This paper presents a model of sovereign debt, in which the government not only faces a trade-off between taxation and the financial disruptions caused by defaulting on domestic bankers, but is also concerned with preventing unemployment from rising well in advance of

[26] An important caveat is that this counterfactual disregards what happens if the bankers were unable to have a higher capitalization.

an actual default. I endogenize the cost of default via bank lending to firms and offer a new explanation for the domestic default cost – the employment cost of default. The model is based on the interaction between financial frictions and a dynamic labor market. The recent European debt crisis provides ample evidence for this channel.

The model is calibrated to Southern Europe and captures the empirical employment pattern in defaults and debt crises. The forward-looking vacancy-posting behavior of firms, which is induced by matching frictions in the labor market, is crucial for the model's ability to match the empirically observed decline in labor market tightness that accompanies increases in bond spreads before an actual default event. Persistent unemployment is key for the government to sustain high debt-to-GDP ratios in equilibrium because it creates an additional disincentive to default. Asymmetric default costs ensure that default frequencies are kept at reasonable levels. The persistence and asymmetry of the employment cost of default are also responsible for the ability of the model to generate clustered default events and defaults after periods of growth.

I consider counterfactual wage and employment subsidies that alleviate the employment costs of default only if they circumvent the financing constraints of the firms. Higher capital requirements of banks limit layoffs and the rise in unemployment during default. A lower debt exposure of domestic banks can increase the government's ability to commit to debt repayment.

A Appendix

A.1 Growth decomposition

	Portugal	Spain	Greece
GDP	−8.52	−6.48	−30.59
Contribution			
1 Labor services	−5.75	−8.42	−10.95
1.1 Labor quality	2.83	1.73	1.88
1.2 Labor quantity	−8.58	−10.15	−12.83
2 Capital services	5.91	6.16	7.76
2.1 ICT capital	5.11	1.73	4.76
2.2 Non-ICT capital	0.80	4.43	3.00
3 TFP growth	−8.68	−4.24	−27.40

Table 5: Decomposition of growth 2008-2013. Source: The Conference Board Total Economy Database.

The table is calculated using annual data from 2008-2013. GDP growth rates are computed as log differences and stated in percent. The data is taken from The Conference Board Total Economy Database.[27]

A.2 Financial families

A banker j, who starts a period with wealth $W_{j,t}$, obtains deposits $X_{j,t}$ and makes loans $L_{j,t}$ to firms, has a balance sheet:

$$L_{j,t} = W_{j,t} + X_{j,t} \tag{35}$$

All assets are used to provide loans $L_{j,t}$ that yield the return R_t but depositors earn a non-contingent gross return $R_{x,t}$ by giving funds to bankers. The growth in equity depends on the difference between the return on loans R_t and the interest rate on deposits $R_{x,t}$ as well as the amount of assets $L_{j,t}$:

$$\begin{aligned} W_{j,t+1} =& R_t L_{j,t} - R_{x,t} X_{j,t} & (36) \\ =& R_t L_{j,t} - R_{x,t}(L_{j,t} - W_{j,t}) & (37) \\ =& (R_t - R_{x,t}) L_{j,t} + R_{x,t} W_{j,t} & (38) \end{aligned}$$

[27]The Conference Board. 2015. The Conference Board Total Economy Database, September 2015, http://www.conference-board.org/data/economydatabase/

Bankers supply loans in period t if:

$$R_t \geq R_{x,t} \tag{39}$$

The first order condition of the depositors implies $R_{x,t} = 1$. With market imperfection equation (39) may be slack, which is the case considered here. Such an arbitrage opportunity makes it optimal for bankers to build up net worth until they become depositors (even with the option to pay dividends). A banker j's objective is therefore to maximize expected terminal wealth $P_{j,t}$:

$$\begin{aligned} P_{jt} =& \max \mathbb{E}_t \sum_{s=t}^{\infty} (1-\phi)\phi^{s-t} \left(\tfrac{1}{1+r}\right)^{s-t} W_{j,s+1} && (40) \\ =& \max \mathbb{E}_t \sum_{s=t}^{\infty} (1-\phi)\phi^{s-t} \left(\tfrac{1}{1+r}\right)^{s-t} \left[(R_s - R_{x,s})L_{j,s} + R_{x,s}W_{j,s}\right] && (41) \end{aligned}$$

The problem can be reformulated as

$$\begin{aligned} P_{j,t} =& \nu_t L_{j,t} + \eta_t W_{j,t} && (42) \\ \nu_t =& \mathbb{E}_t \{(1-\phi)(R_t - R_{x,t}) + \phi\left(\tfrac{1}{1+r}\right)\mathtt{x}_{t,t+1}\nu_{t+1}\} && (43) \\ \eta_t =& \mathbb{E}_t \{(1-\phi)R_{x,t} + \phi\left(\tfrac{1}{1+r}\right)\mathtt{z}_{t,t+1}\eta_{t+1}\} && (44) \end{aligned}$$

where $\mathtt{x}_{t,t+1} = \dfrac{L_{j,t+1}}{L_{j,t}}$ is the gross growth rate in assets and $\mathtt{z}_{t,t+1} = \dfrac{W_{j,t+1}}{W_{j,t}}$ is the gross growth rate in net worth.

An incentive constraint limits the bankers' ability to borrow from households:

$$P_{j,t} \geq \lambda L_{j,t} \tag{45}$$

The incentive constraint (45) is motivated by a moral hazard problem between bankers and depositors. In each period, bankers can choose to divert their assets and depositors can only recover a share $(1-\lambda)$. The incentive constraint can be expressed as a linear function of net worth:

$$L_{j,t} \leq \frac{\eta_t}{\lambda - \nu_t} W_{j,t} = \chi_t W_{j,t} \tag{46}$$

Notably, the leverage ratio χ_t – the ratio between assets to equity – depends on R_t and is time-varying. With a binding the incentive constraint, the assets a banker can acquire depend positively on the banker's net worth:

$$L_{j,t} = \chi_t W_{j,t} \tag{47}$$

$$W_{j,t+1} = [(R_t - R_{x,t})\chi_t + R_{x,t}] W_{j,t} \tag{48}$$

$$\mathtt{z}_{t,t+1} = (R_t - R_{x,t})\chi_t + R_{x,t} \tag{49}$$

$$\mathtt{x}_{t,t+1} = \frac{\chi_{t+1}}{\chi_t} \mathtt{z}_{t,t+1} \tag{50}$$

Since χ_t does not depend in firm specifics j, aggregate loans and total net worth in the economy are:

$$L_t^b = \chi_t W_t \tag{51}$$

$$W_t = \phi \left[(R_{t-1} - R_{x,t-1})\chi_{t-1} + R_{x,t-1} \right] W_{t-1} + \kappa + \gamma q_t B_{t+1} \tag{52}$$

The first term of (52) reflects net worth accumulation of the share ϕ of bankers surviving, the right term reflects the share $(1-\phi)$ of newly endowed bankers. Let $\gamma \in [0,1]$ be the domestic share of total government bonds B_{t+1}. Then new bankers' wealth comprises the fixed amount κ and all domestically held sovereign debt priced at q_t.

Static limit. In the calibration, I investigate the static limit arising from a zero survival probability of bankers ($\phi = 0$). I further use the first order condition of the depositors for within-period lending, yielding a zero return ($R_{x,t} = 1$). A banker j solves the maximization problem:

$$P_{j,t} = \max_{L_{j,t}} (R_t - 1) L_{j,t} + W_{j,t} \tag{53}$$

$$\text{s.t. } L_{j,t} \leq \frac{1}{\lambda - \frac{R_t - 1}{1+r}} W_{j,t} \tag{54}$$

Bankers only supply loans if $R_t \geq 1$ and the incentive constraint is binding for $R_t < \lambda(1 + r) + 1$. Aggregate net worth is $W_t = \kappa + \gamma q_t B_{t+1}$ and constrained bankers' total supply of loans is:

$$L_t^b = \frac{\kappa + \gamma q_t B_{t+1}}{\lambda - \frac{R_t - 1}{1+r}} \tag{55}$$

A.3 Recursive formulation

The private sector's state is given by the aggregate state $\Omega = (z, B, N, W_e)$ consisting of productivity, sovereign assets, aggregate employment and total pre-existing net worth, a current government's policy $\delta = (B', \tau, d)$ and a sequence of future policies $(B^{'',\infty}, \tau^{',\infty}, d^{',\infty})$, where the superscripts indicate the first and last period of the sequence of future policies. However, in this paper I consider Markov-perfect equilibria. Therefore, it is w.l.o.g. to restrict attention to future government policies that are given by a constant function of the state $\mathcal{D} : \Omega \to (B', \tau, d)$ and index the private sector value functions with this government policy. Given Ω, δ and $\mathcal{D}$ the private sector agents choose their actions. Further, the private sector take the aggregate laws of motion as given with $\Omega' = (z', B', N', W_e')$ denoting the next period's aggregate state.

Let $\mathcal{E}(\Omega, \delta, \mathcal{D})$ and $\mathcal{U}(\Omega, \delta, \mathcal{D})$ be the values of an employed and unemployed worker, respectively. The workers' problem can be recursively defined as:

$$\begin{aligned}
\mathcal{E}(\Omega, \delta, \mathcal{D}) =& (1-s)\Big(\mathbf{u}(w-\tau) + \beta\mathbb{E}_z\{(1-\xi)\mathcal{E}(\Omega', \mathcal{D}, \mathcal{D}) + \xi\mathcal{U}(\Omega', \mathcal{D}, \mathcal{D})\}\Big) \\
&+ s\mathcal{U}(\Omega, \delta, \mathcal{D}) \qquad (56) \\
\mathcal{U}(\Omega, \delta, \mathcal{D}) =& \mathbf{u}(T) + \beta\mathbb{E}_z\{\lambda_w(1-(1-s)N, v)\mathcal{E}(\Omega', \mathcal{D}, \mathcal{D}) \\
&+ (1-\lambda_w(1-(1-s)N, v))\mathcal{U}(\Omega', \mathcal{D}, \mathcal{D})\} \qquad (57)
\end{aligned}$$

Firms' expected profits, before the realization of current operational costs k_i, can be expressed recursively as:

$$\mathcal{J}(\Omega, \delta, \mathcal{D}) = (1-s)\Big(z - Rw - \mathbb{E}_k(k|k \leq \hat{k}) + \tfrac{1}{1+r}\mathbb{E}_z\{(1-\xi)\mathcal{J}(\Omega', \mathcal{D}, \mathcal{D})\}\Big) \qquad (58)$$

The value of a vacancy is:

$$\mathcal{V}(\Omega, \delta, \mathcal{D}) = -Ra + \lambda_f(1-(1-s)N, v)\tfrac{1}{1+r}\mathbb{E}_z\{\mathcal{J}(\Omega', \mathcal{D}, \mathcal{D})\} \qquad (59)$$

Free entry determines the number of vacancies v and the non-negative profit condition pins down separations s. The firms' pre-financing condition shows up in the interest payments R on wages and vacancies.

Let P be the value of the bankers and let $\mathcal{G}$ be the value function of a financial family. The problems of the financial families can be written recursively:

$$\begin{aligned}
P(\Omega, \delta, \mathcal{D}) =& \max_{W_e', L^b}(1-\phi)W_e' + \phi\big(\tfrac{1}{1+r}\big)\mathbb{E}_z\{P(\Omega', \mathcal{D}, \mathcal{D})\} \qquad (60) \\
\text{s.t. } W_e' =& (R-R_x)L^b + R_xW_e \qquad (61) \\
\lambda L^b \leq& P(\Omega, \delta, \mathcal{D}) \qquad (62) \\
\mathcal{G}(\Omega, \delta, \mathcal{D}) =& \max_{c^f, X} c^f + \big(\tfrac{1}{1+r}\big)\mathbb{E}_z\{\mathcal{G}(\Omega', \mathcal{D}, \mathcal{D})\} \qquad (63) \\
\text{s.t. } c^f =& \pi + d\gamma(B - qB') + R_xX - X \qquad (64)
\end{aligned}$$

A.4 Computation

I use collocation methods to solve for the value functions on a grid for $\Omega = (z, B, N)$ and not only approximate the value functions but also the expected value functions, the law of motions for employment and the bond price function. The solution algorithm involves the following steps:

1. Grid
   The grid over $\Omega = (z, B, N)$ consists of equispaced collocation nodes with grid size $N_z = 21$, $N_B = 25$ and $N_N = 22$. Note that chosen debt levels and next period's productivity and employment states are not restricted to lie on this grid but are fully continuous. The limits for productivity are set such that the lower bound on the probability of z is 0.00001. The space for debt B lies between 0 and 3 in the baseline, making sure this limit is not hit. Employment is chosen to lie between 10 and 99 percent. Note that the range of grids is parameter-dependent.

2. Initialization
   A set of parameter values is fixed. Wages as a function of productivity are calculated. Initial guesses for the value functions are chosen, debt prices are set to the maximum and default probabilities equal zero.

3. Pre-computation
   I approximate the response of the private sector to a one-time deviation over states, net worth, continuation values and prices. This includes solving for the loan and labor market outcome such that it delivers an approximation of the law of motion of employment H.

4. Solving of value and policy functions by collocation methods
   I approximate each value function in the private sector by solving for the $N_s = N_z \times N_B \times N_N$ coefficients using linear splines. Given a guess for the coefficients, I iterate until the coefficients solve the N_s equations for each value function given by the Bellman equations using standard methods.

   In the computation I limit the innovations to lie within the 0.00001 and 0.99999 interior of the normal cdf that I split into 200 equispaced grid points and recover the shock values using the inverse cdf on this grid. Each shock value is associated with a certain productivity level given by the AR(1) process of z. I compute expectations using a linear spline to evaluate the expected value functions at these 200 productivity levels and weigh them by the probability mass around the shocks.

5. Approximate implementability constraints
   I use the value functions obtained in the previous step together with the law of motion of employment from the pre-computation to approximate implementability constraints that are dependent on the one-time deviation. These include future employment, current firing and current job finding probabilities.

6. Best possible one-time deviation δ
   Using the expected value functions, I compute the best possible one-time deviation of the government using golden search. In this step, for each possible B' the price function delivers q, the implementability constraints deliver N', s and p and the government

budget constraint delivers τ to maximize the value of repayment. Note that the search is entirely continuous in debt issuance. I check for multiplicity in employment and a single optimum.

7. Update bond price
   Given the new value of repayment, I maximize over repayment and default states to update the price function.

8. Iterate until convergence
   I compute the indirect value functions of the private sector. I compare all value and price functions together with the law of motion for employment to the ones of the previous iteration. If the norm is smaller than a fixed convergence criterion I stop, otherwise I go back to step 4.

In the procedure, I update of the government value functions and debt price schedule slowly to ensure convergence. The underlying difficulty is that since the value functions of the government also enter the constraint (the bond pricing) it is not a contraction.

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