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Banks, Sovereign Risk and Unconventional Monetary Policies*

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Abstract

We develop a two-country model with an explicitly microfounded interbank market and sovereign default risk. Both features interact and give rise to a debt-banks-credit loop by which sovereign default risk can have large contractionary effects on the economy. Calibrated to the Euro Area, the model performs well in matching key business cycle facts on real, financial and fiscal time series. We then use the model to assess the effects of the Great Recession and quantify the potential effects of alternative unconventional policies on the dynamics of European economies. All the policies considered can bring sizable reductions in the welfare losses from the Great Recession, but policies targeted at sovereign bonds and interbank loans are more efficient than standard credit interventions.

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JEL Classification: E32, E44, E58, F34.

1 Introduction

In this paper, we analyze the interaction between interbank markets and default risk using a two-country dynamic general equilibrium model, with a focus on the transmission of the recent financial crisis and unconventional monetary policies. In particular, does the sovereign risk / interbank market feedback loop affect the transmission of a large negative shock? Does it alter the effectiveness of unconventional monetary policies and how? Interbank markets are at the crossroad of financial and real spheres, as they match creditor and debtor banks. Their dynamics crucially affect the amount of credit in the economy, with effects on investment and GDP. They are also critical in the conduct of monetary policy, as Central Banks implement open market operations to control the interest rate in the overnight interbank market to affect the yield curve.

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As such, they play a central role in the transmission of monetary policy decisions, as well as in the transmission of potential financial crises.

Following the introduction of euro, financial integration within the Euro Area opened the door for banks to hold sovereign debts from member countries. As shown by Guerrieri, Iacoviello and Minetti (2012), who use combined data from the Bank for International Settlements and the Bank of France, the ratio of French banks' holdings of Periphery's sovereign debt over their holdings of French government debt was 56% in the last quarter of 2009, up from 19% in the first quarter of 2005. As a consequence, European banks were increasingly exposed to the sovereign default risk of Periphery countries at that time. This vicious spiral of twin crisis between banks and sovereigns imposes potential losses for banks who invest massively in the sovereign market, and may result into a stop in credit growth.

The rising interdependence between interbank and sovereign bonds markets was at the heart of ECB's concerns about rising sovereign risk in the Euro Area. It was also partly exploited by ECB's unconventional monetary policies, to release tensions on both markets at the same time. To capture this interdependence, we develop a two-country model of a monetary union with sovereign default risk, an integrated interbank market and financial intermediaries. We particularly want to analyze the role of banks in the transmission of financial shocks to the economy. In the model, financial markets interact with the real economy through the balance sheet of banks. Saving banks collect deposits and optimize a portfolio made of domestic and foreign sovereign bonds and interbank loans. Commercial banks use interbank loans to grant loans to capital producers. The existence of an interbank market is ensured by assuming that both types of banks interact as suppliers and demanders of interbank liquidity. Both types of banks face agency problems *à la* Gertler and Karadi (2011), that introduces constraints on leverage ratios and leads to a financial accelerator mechanism and endogenous spreads among available assets. These features generate a strong relation between developments on sovereign bond markets, bank liquidity, and loans, and foster macroeconomic and financial interdependence between both regions.

Our model draws on Gertler and Karadi (2011), as the agency problem of both types of banks is derived from their contribution. It proposes a more complex representation of funding in the economy however, as we consider a larger number of assets in our economy (sovereign bonds, interbank loans) and heterogeneity in the banking system with two types of banks. In addition, the model features two countries, whose banks interact on an integrated interbank market. Both characteristics bring our model closer to the situation of banks in the Euro Area. The model also borrows from Corsetti, Kuester, Meier and Mueller (2014) for the sovereign risk channel. We assume that sovereign default risk is increasingly and positively related to a country's public debt-to-GDP ratio, and that default matters *ex-ante* for the pricing of assets, but not *ex-post*. We differ from Corsetti et al. (2014) however in that taxes used to stabilize the debt-to-GDP ratio bear on labor supply and are distortionary. Doing so is actually crucial to introduce a propagation mechanism from fiscal variables to the real economy. In our model, default risk has serious real consequences, even in absence of any actual default. Default risk raises equilibrium sovereign rates, lead debt to GDP and distortionary taxes to rise, with clear negative effects on output, consumption and investment.

First, the model is calibrated to the Euro Area and found to match key business cycle features quite well. Second, we proceed to the analysis of our model through the lens of a capital quality shock, as in Gertler and Karadi (2011). This analysis shows that our specific assumptions (two types of banks, an interbank market and sovereign default risk) play a crucial role in the quantitative response of the model after the shock. They act as strong amplifiers in comparison to Gertler and Karadi (2011) and increase the persistence of the response after the shock. Third, we mimic the effects of the Great Recession in the Euro Area differentiating Core and Periphery countries. We build on a joint capital quality shock, public spending shocks and default risk shocks. These ingredients are shown to reproduce particularly well the dynamics of output, debt to GDP and sovereign spreads in Core countries and in the Periphery. In particular, our simulations reproduce quite well the rise in public debt to GDP ratios at the beginning of the Great Recession, and the prolonged slump in countries of the Periphery. These countries are affected by a much larger default risk shock, which raises debt to GDP, labor income taxes and lowers output – or more precisely, delays output recovery. Fourth, we use this simulation as a benchmark, and investigate the effects of two alternative unconventional monetary policies in the spirit of Gertler and Karadi (2011): one that intermediates assets managed by saving banks – interbank loans and sovereign bonds – and one that intermediates assets managed by commercial banks – loans to capital producers. We find that the former is more efficient in stabilizing the economy than the latter, although both policies reduce significantly the welfare losses from the Great Recession.

The paper is organized as follows. Section 2 relates the paper to the literature. In Sections 3 and 4, we respectively describe the model and present the calibration. A business cycle matching exercise is proposed in Section 5. In Section 6, we perform simulation experiments, with or without unconventional monetary policies. Finally, Section 7 concludes.

2 Literature Review

There are very few studies on the joint frictions in the credit and sovereign markets. The existing studies about the role of banks in global economies pay little attention on sovereign debt problems. Devereux and Yetman (2010) study a two-country economy in which investors hold domestic and foreign assets but are exposed to leverage constraints. They find that if global financial markets are highly integrated, productivity shocks will be propagated through investors' financial portfolios, which will generate a strong output comovement. Mendoza and Quadrini (2010) build a two-country model with different degrees of financial development. Their model analyzes the cross-country spillover effects of shocks to bank capital. Both Kollmann, Enders and Muller (2011) and Kalemli-Ozcan, Papaioannou and Perri (2013) consider a two-country environment with a global banking sector, their models generate synchronized business fluctuations across countries.

Our paper also relates to some of the recent literature on sovereign default or interbank markets.

For sovereign default risk, Guerrieri et al. (2012) build a two-country model calibrated to the Euro Area. They assume that partial sovereign default is exogenous and simulate the shock of partial sovereign default of 10% Periphery country's GDP. Their results show sizeable spillover effects of sovereign default from Periphery to the Core through the financial channel. Mendoza and Yue (2012) establish a general equilibrium model and explains the link between sovereign defaults and deep recessions which happened to small open economies. They show that sovereign default excludes the country from international credit market, which limits the country to get financing to buy imported intermediate goods from the international market. Bi (2012) implements sovereign default risk and bank runs into a baseline model derived from Gertler and Karadi (2011) and Gertler and Karadi (2013), and focuses on the interaction between sovereign default and domestic financial system. She finds that when bank run is possible, sovereign default risk is stagflationary and has dramatic and negative influence on domestic economy. van der Kwaak and van Wijnbergen (2014) integrate sovereign default risk and financial intermediaries building on Gertler and Karadi (2011), and study the interactions among bank rescues, sovereign risk, and financial fragility. They show that the maturity structure of government debt plays a crucial role in sovereign debt crisis. Bocola (2015) studies two channels through which sovereign default risk may hamper financial intermediaries: the liquidity channel and the risk channel. Calibrated to Italian data, his model shows that the risk channel is sizable. Due to the precautionary motive of banks, credit is actually not sensitive to Central Bank interventions.

Concerning the interbank market, Allen, Carletti and Gale (2009) build a theoretical model to analyze Central Bank's intervention on the interbank market. They show that there will be excessive price volatility on the interbank market when banks lack of opportunities to hedge liquidity shocks, and that the use of open market operations by the Central Bank helps stabilizing the short term interest rate. Dib (2010) proposes a micro-founded DSGE model that incorporates an interbank market. There are two banks that differ in terms of their liquidity requirement. The model is used to study the effects of conventional and unconventional monetary policies. Gertler and Kiyotaki (2010) develop a comprehensive model of the financial sector. They show that the net benefits from Central Bank's credit market interventions are increasing in the severity of the crisis. Focusing on systemic banking crisis, Boissay, Collard and Smets (2016) build a DSGE model with interbank market, explaining that moral hazard and asymmetric information may lead to financial crisis and deep recession during the period of credit boom.

On the policy side, Gertler and Karadi (2011) study the effect of unconventional monetary policy on the economy, where they assume that the Central Bank can lend directly to non-financial firms. They find that direct credit intervention can significantly mitigate the contraction caused by negative financial shocks. Stabilization may even be stronger when the Zero Lower Bound (ZLB) is binding. Gertler and Karadi (2013) extend the model developed in Gertler and Karadi (2011) to account for qualitative easing on the bond market. In this paper, they find that LSAPs (large-scale asset purchases) have more significant effects on the economy when the ZLB is binding. Dedola, Karadi and Lombardo (2012) build a two-country model with financial frictions as in Gertler and Karadi (2011). They show that under financial integration, unconventional policies aimed at stabilizing domestic conditions can have positive spillover effects on the foreign economy. Due to the lack of cooperation, in general, stabilization by one country will reduce the other country's incentive to intervene, which results in sub-optimal equilibrium credit policies. Takamura (2013) studies the influence of capital injections facing different shocks. He finds that capital injection is less efficient to counteract the effects of negative productivity shocks, but more efficient on financial shocks. Diniz and Guimaraes (2013) study the trade-off between sovereign debt restructuring and contractionary fiscal policy. By implementing government debt into a model based on Gertler and Karadi (2011) and calibrating it to the Euro Area, they show that losses from financial disruption caused by sovereign debt restructuring are offset by the benefits from less restrictive fiscal policies. Farhi and Tirole (2014) propose a "double-decker" bailout theory of the vicious spiral between sovereign debt and banking risks, that allows both for domestic banks bailouts by government and sovereign debt forgiveness by international lenders. Their theory provides implications for the sovereign debt re-nationalization, macro-prudential policies, as well as the rationale for a banking union.

So far, none of the mentioned contributions explores the impact of Central Bank's policy on sovereign default risk through the channel of the interbank market, which is the main focus of our analysis. Our paper integrates sovereign default risk, an integrated interbank market, and unconventional monetary policy interventions in an open-economy environment, and studies their joint interaction during a recession.

3 Model

Our model of financial intermediation is an extension of the Gertler and Karadi (2011) model with two types of banks: saving banks (s) that lend on the interbank market and borrowing banks (b) that borrow and grant loans to entrepreneurs. In addition to interbank loans, saving banks have access to additional assets (risky sovereign bonds) to compose their portfolios.

3.1 Saving Banks

There is a unit continuum of saving banks. The balance sheet of the representative saving banks is

a_t = Portfolio of assets	d_t = domestic deposits
	n^s_t = net worth

The portfolio of saving banks a_t is composed of interbank loans l^s_t, domestic debt b_t and foreign debt b^*_t, paying respectively r_t, the interbank market rate, $r^b_t(1-\chi_t)$ and $r^{b*}_t(1-\chi^*_t)$ the returns on government bonds between period $t-1$ and period t. Variables χ_t and χ^*_t are the potential hair-cuts applied by governments in cases of default. Following Coeurdacier and Martin (2009), the total amount of assets is obtained combining the three assets according to[1]

$$a_t = \left(\mu^{1/\varepsilon}\left(l^s_t\right)^{(\varepsilon-1)/\varepsilon} + \eta^{1/\varepsilon} b_t^{(\varepsilon-1)/\varepsilon} + (1-\mu-\eta)^{1/\varepsilon} b_t^{*(\varepsilon-1)/\varepsilon}\right)^{\varepsilon/(\varepsilon-1)} \tag{1}$$

The optimal allocation on the various assets is obtained minimizing total expenditure

$$a_t = E_t\left(q^s_{t+1} l^s_t + q^b_{t+1} b_t + q^{b*}_{t+1} b^*_t\right) \tag{2}$$

for a given level of assets $\overline{a}$ subject to equation (1), where, defining r^a_{t+1} as the expected return on the portfolio, relative asset prices are given by

$$q^s_{t+1} = r^a_{t+1}/r_{t+1} \tag{3}$$

$$q^b_{t+1} = r^a_{t+1}/\left(r^b_{t+1}\left(1-\chi_{t+1}\right)\right) \tag{4}$$

$$q^{b*}_{t+1} = r^a_{t+1}/\left(r^{b*}_{t+1}\left(1-\chi^*_{t+1}\right)\right) \tag{5}$$

We get

$$l^s_t = \mu E_t\left(r_{t+1}/r^a_{t+1}\right)^{\varepsilon} a_t \tag{6}$$

$$b_t = \eta E_t\left(r^b_{t+1}\left(1-\chi_{t+1}\right)/r^a_{t+1}\right)^{\varepsilon} a_t \tag{7}$$

$$b^*_t = (1-\mu-\eta) E_t\left(r^{b*}_{t+1}\left(1-\chi^*_{t+1}\right)/r^a_{t+1}\right)^{\varepsilon} a_t \tag{8}$$

Once the asset-side of the balance sheet of savings bank has been determined, the balance sheet equation is

$$a_t = d_t + n^s_t \tag{9}$$

[1] Our approach is a quite simple attempt to rationalize the ad-hoc no-arbitrage conditions that would arise with a rougher approach to the bank balance sheet. Notice that with a very large value of the elasticity of substitution like the value that will be used in the calibration, both approaches deliver the same relation between the yields of the different assets according to which expected ex-ante returns are equalized.

and savings banks' net worth evolves according to

$$n^s_{t+1} = r^a_{t+1} a_t - r^d_t d_t + T_t \tag{10}$$

where r^d_t is the deposit rate. In our model, as in Corsetti et al. (2014), default only matters *ex-ante* but not *ex-post*. Saving banks have access to insurance contracts and receive $T_t = r^b_{t+1}\chi_{t+1} b_t + r^{b*}_{t+1}\chi^*_{t+1} b^*_t$, covering their losses in case of sovereign default. Combining both equations gives the dynamics of the saving bank's net worth

$$n^s_{t+1} = \left(r^a_{t+1} - r^d_t\right) a_t + r^d_t n^s_t + T_t \tag{11}$$

The bank maximizes expected net worth given a fixed exit probability $(1-\sigma)$, in which event net worth is rebated to the households, and discounts future outcomes at the stochastic rate $\beta_{t+1} = \beta u_{c,t+1}/u_{c,t}$. We follow Gertler and Karadi (2011), conjecture v^s_t to be linear and assume

$$v^s_t = \gamma^a_t a_t + \gamma^s_t n^s_t \tag{12}$$

In addition, to prevent unlimited expansion of lending due to positive arbitrage opportunities, the representative saving bank may divert a fraction α^s of its assets. This possibility adds the following incentive constraint on saving bank's activities

$$v^s_t = \gamma^a_t a_t + \gamma^s_t n^s_t \geq \alpha^s a_t \tag{13}$$

which will be strictly binding in equilibrium. Let

$$\phi^s_t = a_t / n^s_t = \left(n^s_t + d_t\right) / n^s_t \tag{14}$$

be the leverage ratio of saving banks, the incentive constraint writes

$$v^s_t = \alpha^s \phi^s_t n^s_t \tag{15}$$

Saving banks optimization yields the following conditions for marginal values of arguments of the value function

$$\gamma^a_t = E_t\left((1-\sigma)\,\beta_{t+1}\left(r^a_{t+1} - r^d_t\right) + \sigma\beta_{t+1}\gamma^a_{t+1}\Omega^a_{t+1}\right) \tag{16}$$

$$\gamma^s_t = E_t\left((1-\sigma) + \sigma\beta_{t+1}\gamma^s_{t+1}\Omega^s_{t+1}\right) \tag{17}$$

where $\Omega^s_t = n^s_t / n^s_{t-1}$ is the growth rate of net worth and $\Omega^a_t = a_t / a_{t-1}$ is the growth rate of intermediated assets, respectively evolving according to

$$\Omega_t^s = \left(r_t^a - r_{t-1}^d\right)\phi_{t-1}^s + r_{t-1}^d \tag{18}$$

$$\Omega_t^a = \left(\phi_t^s/\phi_{t-1}^s\right)\Omega_t^s \tag{19}$$

Using the expression of the value function finally allows to reformulate the binding incentive constraint as

$$\phi_t^s = \frac{\gamma_t^s}{\alpha^s - \gamma_t^a} \tag{20}$$

3.2 Commercial Banks

There is also a unit continuum of commercial banks. The representative bank borrows l_t^c from the interbank market, and accumulates net worth. On the asset side, it grants loans to the intermediate goods sector to purchase capital k_t at price q_t. Its balance sheet is thus

$q_t k_t$ = loans to the private sector	l_t^c = borrowing from the interbank market
	n_t^c = net worth

and the balance sheet equation is

$$q_t k_t = l_t^c + n_t^c \tag{21}$$

Net worth evolves according to

$$n_{t+1}^c = r_{t+1}^k q_t k_t - r_t l_t^c \tag{22}$$

where r_t^k is the return on capital. Combining both equations gives the dynamics of the representative commercial bank's net worth

$$n_{t+1}^c = \left(r_{t+1}^k - r_t\right) q_t k_t + r_t n_t^c \tag{23}$$

We also guess the form of its value function

$$v_t^c = \gamma_t^k q_t k_t + \gamma_t^c n_t^c \tag{24}$$

and let α^c be the fraction of the asset side that the commercial bank diverts. Its incentive constraint writes

$$v_t^c = \gamma_t^k q_t k_t + \gamma_t^c n_t^c \geq \alpha^c q_t k_t \tag{25}$$

and will be strictly binding in equilibrium. Letting

$$\phi_t^c = q_t k_t / n_t^c = \left(n_t^c + l_t^c\right)/n_t^c \tag{26}$$

be its leverage ratio, the incentive constraint writes

$$v_t^c = \alpha^c \phi_t^c n_t^c \tag{27}$$

Commercial banks optimization yields the following conditions for marginal values of arguments of the value function

$$\gamma_t^k = E_t \left((1-\sigma) \beta_{t+1} \left(r_{t+1}^k - r_t \right) + \sigma \beta_{t+1} \gamma_{t+1}^k \Omega_{t+1}^k \right) \tag{28}$$

$$\gamma_t^c = E_t \left((1-\sigma) + \sigma \beta_{t+1} \gamma_{t+1}^c \Omega_{t+1}^c \right) \tag{29}$$

where $\Omega_t^c = n_t^c / n_{t-1}^c$ is the growth rate of net worth and $\Omega_t^k = q_t k_t / q_{t-1} k_{t-1}$ is the growth rate of intermediated assets, respectively evolving according to

$$\Omega_t^c = \left(r_t^k - r_{t-1} \right) \phi_{t-1}^c + r_{t-1} \tag{30}$$

$$\Omega_t^k = \left(\phi_t^c / \phi_{t-1}^c \right) \Omega_t^c \tag{31}$$

reformulate the binding incentive constraint

$$\phi_t^c = \frac{\gamma_t^c}{\alpha^c - \gamma_t^k} \tag{32}$$

3.3 Intermediate and capital goods producers

Intermediate goods producers use effective capital $u_t k_{t-1}$ in the production process, where u_t is the variable utilization rate. They also hire labor in quantity n_t, that they combine to build the intermediate good, with the following production function

$$y_t^m = \varsigma_t \left(\xi_t u_t k_{t-1} \right)^\iota n_t^{1-\iota} \tag{33}$$

and sell intermediate goods at real relative price p_t^m. The installed (*i.e.* period $t-1$) effective capital stock can also be affected by a quality shock ξ_t as in Gertler and Karadi (2011). The optimizing conditions with respect to labor and utilization respectively give

$$p_t^m (1-\iota) y_t^m / n_t = w_t \tag{34}$$

$$p_t^m \iota y_t^m / u_t = \delta' (u_t) \xi_t k_{t-1} \tag{35}$$

where w_t is the real wage and where

$$\delta(u_t) = \delta + \overline{\delta} \left(u_t^{1+\kappa} - 1 \right) / (1+\kappa) \tag{36}$$

is the time-varying depreciation rate. The zero-profit condition implies that intermediate goods producers pay the ex-post return on capital to the capital goods producers, *i.e.*

$$r^k_{t+1} = \left(p^m_{t+1}\left(\iota y^m_{t+1}/k_t\right) + q_{t+1}\xi_t\left(1-\delta\left(u_{t+1}\right)\right)\right)/q_t \tag{37}$$

Capital goods producers buy the depreciated capital of intermediate goods producers and choose investment to accrue the total amount of available capital based on the evolution of its real price q_t.[2] Their profits write

$$E_t \sum_{s=0}^{\infty} \beta_{t+s}\left(q_{t+s}i_{t+s}\left(1-\left(\varphi^i/2\right)\left(i_{t+s}/i_{t+s-1}-1\right)^2\right) - i_{t+s}\right) \tag{40}$$

and optimization yields

$$q_t - 1 = q_t\varphi^i\left(x_t\left(1+x_t\right) + x_t^2/2\right) - E_t\left(\beta_{t+1}q_{t+1}\varphi^i x_{t+1}\left(1+x_{t+1}\right)^2\right) \tag{41}$$

where $x_t = i_t/i_{t-1} - 1$. Given this optimizing condition for investment, the law of capital accumulation gives the dynamics of the capital stock

$$k_t - \left(1-\delta\left(u_t\right)\right)\xi_t k_{t-1} = i_t\left(1-\left(\varphi^i/2\right)x_t^2\right) \tag{42}$$

3.4 Final goods producers

Final goods producers j differentiate the intermediate good y^m_t in imperfectly substitutable varieties. The aggregate bundle of the final good and the corresponding aggregate price level are

$$y_t = \left[\int_0^1 y_t\left(j\right)^{\frac{\theta-1}{\theta}}dj\right]^{\frac{\theta}{\theta-1}},\ p_t = \left[\int_0^1 p_t\left(j\right)^{1-\theta}dj\right]^{\frac{1}{1-\theta}} \tag{43}$$

Final goods producers take into account households demands $y_t\left(j\right) = \left(p_t\left(j\right)/p_t\right)^{-\theta}y_t$ when setting prices subject to Calvo price contracts of average length $1/\left(1-\gamma\right)$ with indexation to past inflation γ^p. The optimal pricing conditions are isomorphic to those found in Gertler and Karadi (2011).

[2] More formally, they maximize

$$E_t \sum_{s=0}^{\infty} \beta_{t+s,t+s+1}\left(q_{t+s}\left(k_{t+s} - \left(1-\delta\left(u_{t+s}\right)\right)\xi_{t+s}k_{t+s-1}\right) - i_{t+s}\right) \tag{38}$$

subject to the law of motion of capital accumulation

$$k_t - \left(1-\delta\left(u_t\right)\right)\xi_t k_{t-1} = i_t\left(1-\left(\varphi^i/2\right)\left(i_t/i_{t-1}-1\right)^2\right). \tag{39}$$

3.5 Households

Households face a simple optimization problem as they choose consumption, labor supply and deposits maximizing lifetime welfare

$$E_t\left(\sum_{s=0}^{\infty}\beta^s u\left(c_{t+s},n_{t+s}\right)\right) \tag{44}$$

where $u_{n,t}\leq 0$ and $u_{c,t}\geq 0$ are the first-order partial derivatives with respect to hours worked and consumption, subject to the budget constraint

$$d_t + c_t = r_{t-1}^d d_{t-1} + \left(1-\tau_t\right) w_t n_t + \Pi_t \tag{45}$$

where d_t denote deposits to saving banks returning r_t^d between t and $t+1$, c_t is consumption, w_t denotes the real wage, τ_t a distortionary tax on labor income, n_t hours worked, and Π_t comprises monopolistic profits from final goods producers, and the net worth rebated by bankrupt banks, net from the starting fund allocated to new banks. First-order conditions give

$$E_t\left(\beta_{t+1}r_t^d\right) = 1 \tag{46}$$

$$u_{n,t} + \left(1-\tau_t\right)u_{c,t}w_t = 0 \tag{47}$$

3.6 Governments

We adopt the approach of sovereign default from Corsetti et al. (2014). Actual *ex post* default is neutral while the *ex ante* probability of default is the key for the pricing of government bonds, which has direct impacts on the interest rates, credit spreads, sustainability of the country's indebtedness, and GDP growth. As in the literature[3], we assume that the default risk follows a distribution that is non-linearly correlated to the country's debt-to-GDP ratio. Focusing on the domestic economy, the *ex ante* probability of default, p_t, at a certain level of sovereign indebtedness, $by_t = b_t^g/\left(4y_t\right)$, will be given by the cumulative distribution function of the beta distribution:

$$p_t = F_{beta}\left(by_t/by_{max},\alpha_p,\beta_p\right) \tag{48}$$

where by_{max} denotes the upper end of the support for the debt to GDP ratio. Actual default occurs with probability p_t so that

$$\chi_t = \Delta \text{ if } \mathcal{B}\left(p_t\right)=1 \tag{49}$$

$$\chi_t = 0 \text{ if } \mathcal{B}\left(p_t\right)=0 \tag{50}$$

[3]For example, Eaton and Gersovitz (1981), Arellano (2008), Bi (2012), and Corsetti et al. (2014).

where $\mathcal{B}(p_t)$ is a Bernoulli. Given these assumptions, the budget constraint of the government writes

$$b_t^g = r_t^b (1 - \chi_t) b_{t-1}^g + g_t - \tau_t w_t n_t + T_t^b \tag{51}$$

Once again, potential losses from default are fully compensated, so that only *ex-ante* default risk matters. As a consequence

$$T_t^b = r_t^b \chi_t b_{t-1}^g \tag{52}$$

and the consolidated budget constraint writes

$$b_t^g = r_t^b b_{t-1}^g + g_t - \tau_t w_t n_t \tag{53}$$

The stability of public debt in the long run is granted by the following tax rule

$$\tau_t - \tau = \rho_\tau (\tau_{t-1} - \tau) + d_b (by_t - by) \tag{54}$$

Finally public spending evolve according to

$$\log(g_t) = \rho_g \log(g_{t-1}) + (1 - \rho_g) (log(g) - d_{gy} \log(y_t/y)) \tag{55}$$

Although actual default is not considered in our set-up, sovereign default risk has major real consequences. A rise in default risk raises the real sovereign rate r_t^b, leads to a rise in public debt that subsequently triggers a rise in the distortionary tax rate. As the latter goes up, hours worked, output, investment, asset prices and inflation collapse. So even in the absence of actual default, sovereign default risk can be a major driver of the dynamics of the economy.

3.7 Central bank

The Central Bank controls the nominal interest rate i_t^n. The relation between the nominal rate and national deposit rates is

$$i_t^n = r_t^d E_t (\pi_{t+1}) = r_t^{d*} E_t (\pi_{t+1}^*) \tag{56}$$

The Central Bank commits to the following policy rule

$$\log i_t^n = \rho_i \log i_{t-1}^n + (1 - \rho) (\log i^n + d_\pi \log \pi_t^u + d_y (\log y_t^u - \log \widetilde{y}_t^u)) \tag{57}$$

where π_t^u is the union-wide inflation rate and y_t^u the union-wide level of output, $\widetilde{y}_t^u$ being its natural level.[4]

[4] As in Gertler and Karadi (2011), variations in the union-wide mark-up will serve as a proxy for variations in the union-wide output gap.

3.8 Aggregation

3.8.1 Banking sector

At the end of the period, a fraction $1-\sigma$ of each type of bankers will become households. Dividends are paid to households only when bankers exit. The net worth of continuing bankers is simply carried to the next period, so that aggregate continuing banks net worths evolve according to

$$n_t^{e,s} = \sigma \Omega_t^a n_{t-1}^s \tag{58}$$
$$n_t^{e,c} = \sigma \Omega_t^k n_{t-1}^c \tag{59}$$

In addition, households provide a starting net worth to new banks, equal to a fraction $\varphi^s / (1-\sigma)$ or $\varphi^c / (1-\sigma)$ of the total assets of old exiting bankers, so that the net worths of new banks are

$$n_t^{n,s} = \varphi^s a_{t-1} \tag{60}$$
$$n_t^{n,c} = \varphi^c \xi_t q_t k_{t-1} \tag{61}$$

Overall, aggregate net worths evolve according to

$$n_t^s = \sigma \Omega_t^a n_{t-1}^s + \varphi^s a_{t-1} \tag{62}$$
$$n_t^c = \sigma \Omega_t^k n_{t-1}^c + \varphi^c \xi_t q_t k_{t-1} \tag{63}$$

3.8.2 Goods markets

The clearing condition on the intermediate goods market is

$$y_t^m = \int_0^1 y_t(j)\, dj = y_t dp_t \tag{64}$$

where $dp_t = \int_0^1 (p_t(j)/p_t)^{-\theta} dj$ is the dispersion of prices. On the final goods market, the clearing condition simply writes

$$y_t = c_t + i_t + g_t \tag{65}$$

3.8.3 Financial markets

Given that the interbank market is unified within the monetary union, the market clearing condition is

$$l_t^s + \varrho l_t^{s*} = l_t^c + \varrho l_t^{c*} \tag{66}$$

where ϱ is the relative size of the foreign economy. This equation determines the interbank market rate. Finally, government bonds markets clearing conditions are

$$b_t^g = b_t + \varrho b_{*,t} \tag{67}$$

$$\varrho b_t^{g*} = \varrho b_t^* + b_{*,t}^* \tag{68}$$

where $b_{*,t}$ and $b_{*,t}^*$ are the holdings of domestic and foreign debt (respectively) from foreign savings banks.

4 Calibration

We calibrate the model to the Euro Area. The Periphery comprises Portugal, Italy, Greece and Spain while the Core is made of remaining members of the monetary union. The calibration follows Gertler and Karadi (2011) unless stated otherwise. The time unit is a quarter. The functional form of preferences is

$$u\left(c_t, n_t\right) = \log\left(c_t - hc_{t-1}\right) - \omega n_t^{1+\psi}/1+\psi$$

The discount factor is $\beta = 0.99$. The degree of habits in consumption is $h = 0.815$ and the inverse of the Frisch elasticity on labor supply is $\psi = 3$. This value is much larger than the value considered by Gertler and Karadi (2011) – they use 0.276 – but their calibration relates to the U.S. where the labor market is much more responsive than in the Euro Area.

On the production side, we follow Gertler and Karadi (2011). The share of effective capital is $\iota = 0.33$, the steady state depreciation rate is $\delta = 0.018$ (7% annually), and the elasticity of the marginal depreciation rate to utilization is $\kappa = 7.2$.[5] We impose a 1pp spread (in annual terms) over the risk-less rate for r^k in both regions, which pins down capital to output ratios. The investment adjustment cost parameter is $\varphi_i = 1.728$, Calvo parameters are $\gamma = 0.779$ and $\gamma^p = 0.241$ and the steady-state mark-up is 30%, implying $\theta = 4.33$.

On the monetary and fiscal policy side, we follow Corsetti et al. (2014) for the parameters of the default probability function and default size: $\alpha_p = 3.70$, $\beta_p = 0.54$, $by_{max} = 2.56$ and $\Delta = 0.55$. We assume standard Taylor rule parameters, *i.e.* $\rho_i = 0.8$, $d_\pi = 1.5$ and $d_y = 0.125$. We set the parameter in Equation (54) at $d_b = 0.05$ to ensure the stability of debt to GDP in the medium run. The persistence parameter in Equation (54) and parameters of the public spending rule (55) are set to match key business cycle moments (see next Section, Table 3). We obtain $\rho_\tau = 0.8789$, $\rho_g = 0.6757$ and $d_{gy} = 0.2182$ in the Core region, and $\rho_\tau = 0.8679$, $\rho_g = 0.8485$ and $d_{gy} = 0.1857$ in the Periphery.

[5] Notice that $\overline{\delta}$ is adjusted for the steady-state optimal utilization rate equation to be consistent with the steady-state capital return equation.

In the banking sector, as explained in Appendix A, we impose steady-state leverage ratios $\phi^s = \phi^c = 2.5$ both for saving and commercial banks. This value is taken from ECB data for the aggregate balance sheet of Monetary and Financial Institutions (MFI excluding the Eurosystem). Assets that are not considered in the model are excluded from the data before computation. In addition, we choose not to impose heterogeneity in the banking sector, except for the home bias towards public debt in the portfolios of saving banks (see below for the calibration of these parameters). Further, still based on MFI data in 2008, we match the share of interbank loans over total assets of the banking system. The corresponding share of interbank loans in total assets of saving banks in the model is $\mu = 0.72$. Finally, we set the survival probability of bankers at $\sigma = 0.975$ and the elasticity of substitution between assets in the portfolio of saving banks at $\varepsilon = 1000$, implying that returns on interbank loans will almost perfectly follow returns on sovereign bonds net from expected losses due to default.

Remaining parameters are region-specific and are set based on computations from the data. Using OECD data for 2008, we build subgroup measures of hours worked and find $n = 0.2520$ for the Core region and $n = 0.3049$ for the Periphery. Proceeding similarly, we impose the share of public expenditure in GDP and the levels of public debt to GDP in each region: $s_g = 0.2080$ for the Core region and $s_g = 0.1924$ for the Periphery. Debt to GDP ratios are also imposed and we assume $b^g/(4y) = 0.6542$ in the Core area and $b^g/(4y) = 0.7718$ in the Periphery.[6] We also impose a higher productivity in the Core region, where we assume $\varsigma = 1.2$ while we set $\varsigma = 1$ in the Periphery. Steady-state labor income tax rates are adjusted to satisfy the budget balance of governments, implying $\tau = 0.4667$ in the Core region and $\tau = 0.4546$ in the Periphery. All variables are considered *per capita* but aggregate variables enter in the debt and interbank market clearing equations so we need to fix the relative size of regions. Based on relative GDPs, we normalize the relative size of the Periphery at $\varrho = 0.5959$.

In the banking sector, we apportion the steady-state holdings of government debt to Periphery and Core banks following Guerrieri et al. (2012). For the Core region, the share of domestic debt held by domestic agents reaches 81%, implying $\eta = 0.81\,(1-\mu) = 0.23$. The share of public debt issued in the Periphery that is held domestically is 60.5%, implying $\eta = 0.605\,(1-\mu) = 0.17$.

5 Business cycle moments

Before engaging in various simulation exercises, we first evaluate the ability of our model to generate realistic business cycle moments for a bunch of key variables. The model is fed with various shocks: productivity shocks, public spending shocks, capital quality shocks and monetary policy shocks. More precisely, we consider that ς_t and ξ_t follow AR(1) processes, and that the public spending rule (55) and the monetary policy rule (57) are affected by random shocks. The

[6] See Appendix B for details.

Table 1: Parameter values

Discount factor, β		0.99
Habit formation, h		0.815
Inverse of the Frisch elasticity, ψ		3
Steady state depreciation rate of capital, δ		0.018
Production function, capital parameter, ι		0.33
Steady state depreciation rate of capital, δ		0.018
Elasticity of the depreciation rate to utilization rate, κ		7.2
Private spreads, r^k/r^d		1.0025
Investment adjustment costs, φ_i		1.728
Calvo contracts parameter, γ		0.779
Indexation parameter, γ^p		0.241
Steady-state mark-up, $\theta/(\theta-1)$		1.3
Taylor rule parameter, ρ_i		0.8
Taylor rule parameter, d_π		1.5
Taylor rule parameter, d_y		0.125
Fiscal rule parameter, d_b		0.05
Default probability parameter, α_p		3.70
Default probability parameter, β_p		0.54
Default probability parameter, by_{max}		2.56
Default size, Δ		0.55
Savings banks leverage ratio, ϕ^s		2.5
Comm. banks leverage ratio, ϕ^s		2.5
Interbank lending to savings banks total assets, μ		0.72
Banker's survival probability, σ		0.975
Elasticity of subs. in the portfolio of saving banks, ε		1000
	Core	Peri.
Fraction of time spent working, n	0.2520	0.3049
Productivity scaling factor, ς	1.2000	1.0000
Government debt to annual GDP, $b^g/(4y)$	0.6542	0.7718
Labor income tax rate, τ	0.4667	0.4546
Tax rule persistence, ρ_τ	0.8789	0.8679
Public spending rule persistence, ρ_g	0.6757	0.8485
Public spending rule reaction to output, d_{gy}	0.2182	0.1857
Government spending to GDP, s_g	0.2080	0.1924
Relative size of the Periphery, ϱ	–	0.5492
Domestic debt to savings banks total assets, η	0.2300	0.1700

persistence and standard deviation of productivity shocks are set to 0.9 and 1% respectively in both countries. Other shock parameters (persistence and standard deviations) as well as parameters of the public spending rule (55) and persistence parameters of the tax rule (54) are estimated. We use the Simulated Method of Moments, where moments matched are those reported in Table 3 below. Table 2 reports the value of estimated parameters.

Table 2: Estimated parameter values for business cycle analysis

Persistence of productivity shocks, ρ_ς	0.9000	
Standard deviation of productivity shocks	0.0100	
Standard deviation of monetary policy shocks	0.0010	
	Core	Peri.
Tax rule persistence, ρ_τ	0.8789	0.8679
Public spending rule persistence, ρ_g	0.6757	0.8485
Public spending rule reaction to output, d_{gy}	0.2182	0.1857
Standard deviation of public spending shocks	0.0034	0.0068
Persistence of capital quality shocks, ρ_ξ	0.2019	0.9991
Standard deviation of capital quality shocks	0.0045	0.0005

Table 3 reports business cycle moments (standard deviations, autocorrelations and contemporaneous correlations with output) pertaining to quarterly GDP, private consumption, investment, public spending, private spreads (per quarter), loans, deposits, sovereign spreads (per quarter) and the debt to annual GDP ratio. Left panels report moments computed from the data and panels on the right report moments from our simulated model. Moments are calculated on HP-filtered time series from the data or generated by our (linearized) model with a smoothing parameter $\lambda = 1600$.[7]

Data suggest that output has a standard deviation around 1.3-1.4%, that consumption is less volatile than output, that investment is about two times more volatile than output and that public spending is less volatile than output. GDP components are quite persistent, with an average autocorrelation around 0.8-0.9. The main differences between the Core region and the Periphery are that consumption is smoother and public spending more countercyclical in the Core region. Private spreads exhibit little volatility, quite a large persistence and are countercyclical. They are more volatile and slightly more persistent in the Periphery than in the Core region. Loans and deposits are 2 to 3 times more volatile than output in both regions, moderately persistent (less than output, especially in the Periphery) and procyclical. Sovereign spreads exhibit very little volatility in the Core region, much more in the Periphery. They are persistent and countercyclical in both regions, and more persistent and countercyclical in the Periphery. Finally, debt to GDP ratios are quite volatile and strongly countercyclical.

Our model, driven by standard shocks, is able to reproduce almost all these features. In

[7] Appendix B provides all the details about the data, how we treat them and how moments are computed.

Table 3: Business cycle moments

	Core region					
	Data			Model		
$x \downarrow$	$\sigma(x)$	$\rho(x)$	$\rho(x,y)$	$\sigma(x)$	$\rho(x)$	$\rho(x,y)$
Output	1.43	0.89	1.00	1.14	0.93	1.00
Consumption	0.37	0.77	0.78	0.67	0.95	0.70
Investment	2.07	0.90	0.94	5.26	0.94	0.92
Public spending	0.34	0.78	−0.41	0.38	0.62	−0.37
Private spread $\left(r_{t+1}^{k}/r_{t}^{d}\right)$	0.10	0.84	−0.25	0.17	0.72	−0.49
Loans $(q_t k_t)$	1.90	0.86	0.26	1.32	0.60	0.48
Deposits (d_t)	3.24	0.82	0.42	4.65	0.80	0.40
Sovereign spread (r_{t+1}^{b}/r_t)	0.03	0.84	−0.27	0.01	0.95	−0.61
Debt-to-GDP ratio (by_t)	2.86	0.88	−0.61	2.72	0.95	−0.60
	Periphery region					
	Data			Model		
$x \downarrow$	$\sigma(x)$	$\rho(x)$	$\rho(x,y)$	$\sigma(x)$	$\rho(x)$	$\rho(x,y)$
Output	1.31	0.88	1.00	1.40	0.93	1.00
Consumption	0.67	0.88	0.72	0.72	0.96	0.47
Investment	1.91	0.80	0.89	7.31	0.94	0.92
Public spending	0.62	0.54	−0.03	0.75	0.67	−0.02
Private spread $\left(r_{t+1}^{k}/r_{t}^{d}\right)$	0.17	0.88	−0.18	0.20	0.74	−0.60
Loans $(q_t k_t)$	1.78	0.79	0.41	1.23	0.48	0.41
Deposits (d_t)	1.89	0.54	0.03	3.94	0.83	0.04
Sovereign spread (r_{t+1}^{b}/r_t)	0.27	0.93	−0.58	0.03	0.95	−0.75
Debt-to-GDP ratio (by_t)	2.18	0.67	−0.53	3.05	0.95	−0.75

The standard deviations of output, private and sovereign spreads, and the debt to GDP ratio are in level, in percents. The standard deviations of consumption, investment, public spending, loans and deposits are expressed relative to the standard deviation of output. Core and Periphery aggregates are computed from the data as explained in Appendix B, which also contains details about data sources.

particular, public spending is more countercyclical in the Core region, owing to the larger persistence of public spending in the Periphery, giving less weight to the countercyclical endogenous response of the public spending rule in this region. Investment is a bit too volatile. Private spreads are just a bit more volatile than in the data, almost as persistent and countercyclical. The business cycle behavior of loans and deposits is well matched, although persistence could be a bit higher, especially for loans. Sovereign spreads are countercyclical, and about three times more volatile in the Periphery than in the Core region. The level of sovereign spread volatility is relatively well matched in the Core region but should be larger in the Periphery. Last, the volatility of debt to GDP ratios generated by our model is well matched, the persistence is a bit too large and the correlation with GDP is a bit too negative.

Overall the model performs well in matching business cycle moments, and provides a good representation of the business cycle in the Euro Area.

6 Experiments

Various versions of the model are now simulated using a non-linear solution method over 500 periods under various assumptions. We first contrast the dynamics of the model (with constant public spending) after a capital quality shock with the dynamics produced by a standard two-country version of the Gertler and Karadi (2011) model. Then, we contrast the effects of the same capital quality shock on the Core and Periphery regions when public spending evolve as observed in the early quarters of the Great Recession. We also augment the dynamics with default risk shocks in both regions, calibrated to capture the rise in sovereign spreads observed in the data. We consider this simulation as our benchmark scenario, and produce two counterfactuals in which unconventional monetary policies (UMP) are conducted: (*i*) the Central Bank intermediates a fraction of the assets of saving banks and (*ii*) the Central Bank intermediates a fraction of the assets of commercial banks. Both cases are analyzed, compared to the benchmark, and the welfare effects of each type of UMPs are computed.

6.1 Capital quality shock

As in Gertler and Karadi (2011), we model the Great Recession as a negative and unexpected shock to the quality of the effective capital stock ξ_t. More precisely, we assume $\xi_t = (1 - \rho_\xi) + \rho_\xi \xi_{t-1} + s_{\xi,t}$ and feed the model with $s_{\xi,t} = -0.03$ assuming $\rho_\xi = 0.66$. The shock affects the quality of the capital stock of both regions, Core and Periphery. We compare our model with the one of Gertler and Karadi (2011), *i.e.* neglecting the saving banking sector and the default risk channel. In both cases, we assume $g_t = g$ instead of having the public spending rule (55) in place, hence restricting the reaction of governments to the implied economic downturn.

Basically, the two-country version of the model of Gertler and Karadi (2011) amounts to neglect equations that relate to saving banks and to consider that commercial banks use deposits directly – instead of interbank loans – to grant loans to capital producers. Consequently, the deposit rate enters in the first-order conditions of commercial banks and replaces the interbank rate. Further, the equilibrium of sovereign bonds markets is modified since savings banks do not buy them anymore. We thus assume that sovereign bonds are held by households and priced through a standard Euler equation. Finally, shutting down the sovereign default risk channel simply amounts to assume $p_t = \chi_t = 0$.

Figure 1 reports the dynamics of our baseline model and of the Gertler and Karadi (2011) model for the Core region.[8] Quantities are reported in percentage deviations from their steady-state values, rates are reported in percent *per annum*, ratios in percentage point deviations and spreads in basis points deviations from their steady-state values.

Figure 1 shows that our assumptions of heterogeneity in the banking sector (savings vs. commercial banks) and of sovereign default risk both act as amplifiers of the shock. As the shock generates a large economic downturn characterized by a large fall in GDP, debt to GDP rises, which in turn raises the default probability. Equilibrium on sovereign bonds markets requires that governments offer larger returns, which raises the interbank rate, and hence the rate at which commercial banks grant loans. The loan rate and the sovereign rate rise more than the deposit and the interbank rate respectively, leading private and sovereign spreads to increase significantly. Compared to Gertler and Karadi (2011), our model generates a much larger fall in GDP, consumption and private investment, hence a larger rise in public spending to GDP and debt to GDP. Private spreads are magnified due to the sovereign risk / banks feedback loop.

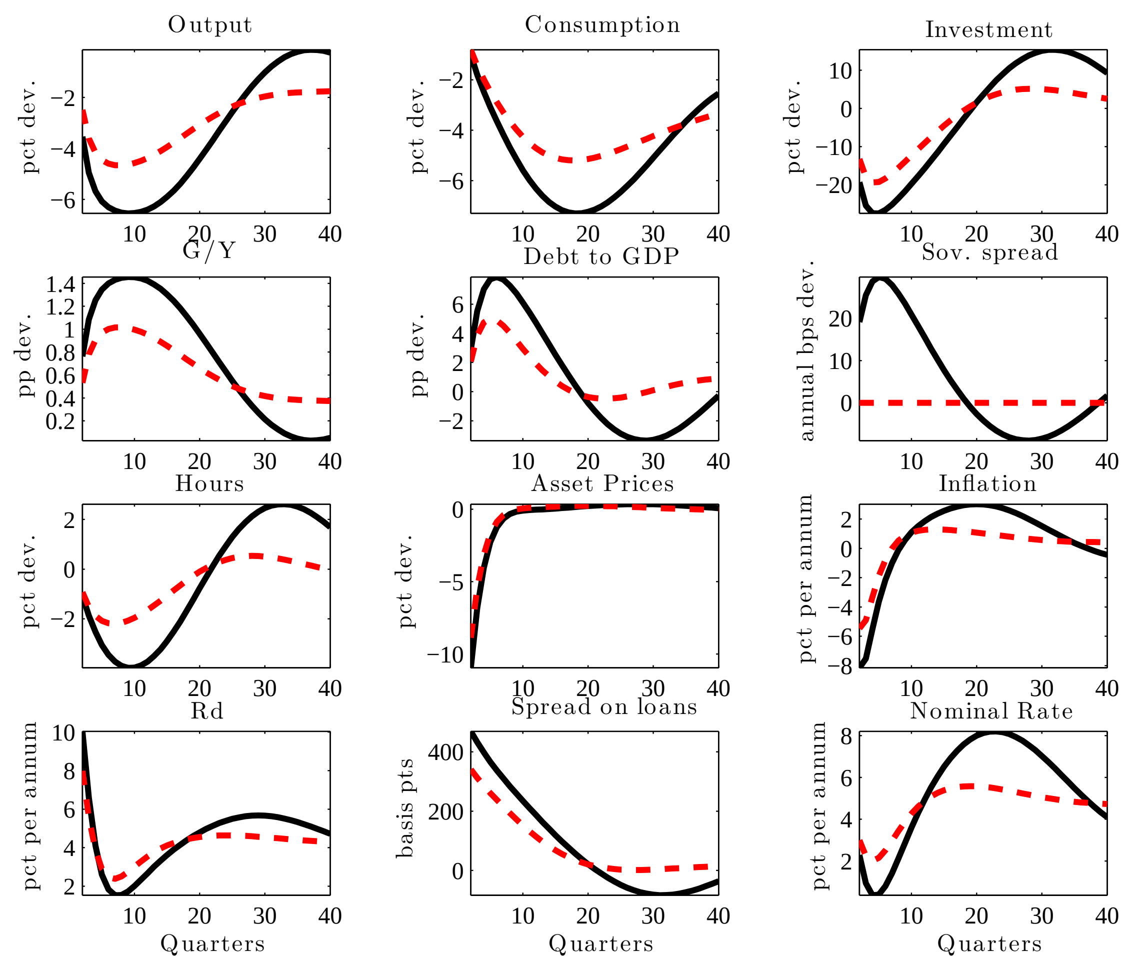
6.2 Great Recession

We investigate the dynamics of our model when both countries are hit by the same capital quality shock but feed the model with additional driving forces to replicate the Great Recession. We consider that time zero is the last quarter of 2007 and that the capital quality shock hits the economy in the first quarter of 2008. We then feed the model with the "observed" dynamics of public spending from 2008Q1 to 2013Q4 and with default risk shocks calibrated to match the observed sovereign spreads. What we have in mind is the differentiated effects of the Great Recession in countries of the Core region and in countries of the Periphery depending on the adjustment of public spending chosen by governments and on the default risk perceived by investors on financial markets.

The "observed" path of public spending is computed from the data as follows. We take the log of public spending quarterly time series (for the Core and for the Periphery) and detrend

[8]The dynamics for the Periphery region is qualitatively similar and therefore reported in Figure 5 in Appendix C.

Figure 1: Capital quality shock (Core region)



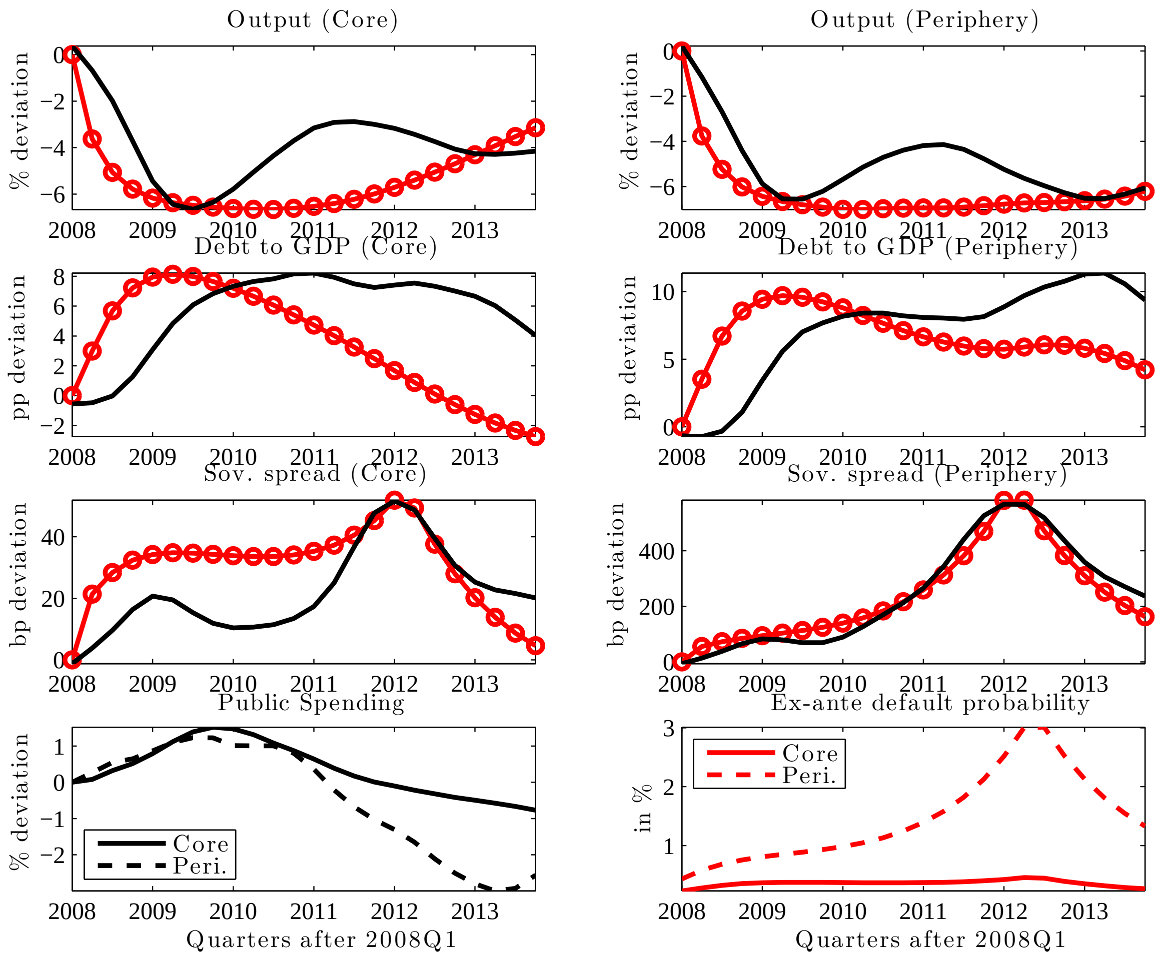
Black: baseline model, red: model of Gertler and Karadi (2011) with two-country them using an HP-filter with $\lambda = 10000$. We want to remove the trend, but we also want to prevent the filter from absorbing too much of the effects of the Great Recession. The resulting time series are then smoothed with an HP-filter with a very low value ($\lambda = 1.5$) to remove unimportant high frequency movements. Finally, series are normalized to express log-deviations from their 2008Q1 values until 2013Q4, and are assumed to return smoothly to the steady state after 2013Q4 – assuming an AR(1) process with a 0.75 autoregressive parameter.

Default risk shocks are designed to match the dynamics of sovereign spreads and are computed from the data in the very same way than public spending. Looking at Core and Periphery sovereign spreads reveals that they peaked at the end of 2012. Before they peaked however, default risk was also present and rose progressively. In addition, the decrease in default risk, although rapid, was not immediate. We thus feed the model with a joint default risk shock that shares the very same features. The magnitude of the shock in the Core and Periphery regions is adjusted to match the level of the peak in 2012Q4.

The model is thus simulated with those three different shocks. The resulting dynamics of output, public debt and sovereign spreads are reported in Figure 2, and compared to their observed dynamics. The dynamics of output, public debt to GDP and sovereign spreads are computed from the data using the same method that was used to compute observed public spending time series.

The model replicates particularly well the dynamics of sovereign spreads – default risk shocks are calibrated to target this time series – and the dynamics of output as well. The size of the recession and its first dip are particularly well matched. The dynamics of public debts are also captured correctly. The size of the initial rise of public debt to GDP ratios is nicely reproduced, although the model-based increase is a bit too early compared to the data. The persistence of public debt predicted by our model is also a bit low as debt starts falling after a few quarters according to our model while it remains high in the data. The effects of default risk shocks are coming into play after 8 to 10 quarters. The rise in the perceived probability of default leads sovereign rates to rise in equilibrium – even in absence of any actual default – which raises the debt to GDP ratio and forces governments to raise taxes through the tax rule, especially in the Periphery where the shock is much larger. This rise in distortionary taxes then depresses the economy and leads GDP to remain quite low for an additional bunch of quarters. The much larger rise of default risk in the Periphery significantly extends the length of the Great Recession, exactly as in the data. It also leads to an additional rise in the debt to GDP ratio, that is observed in the data as well. Overall, our model fed with a capital quality shock and country-specific public spending and default risk shocks performs well in replicating the macroeconomic dynamics observed during the Great Recession in European countries.

Figure 2: Great Recession experiment



Black: data, Red: model

6.3 Unconventional monetary policies

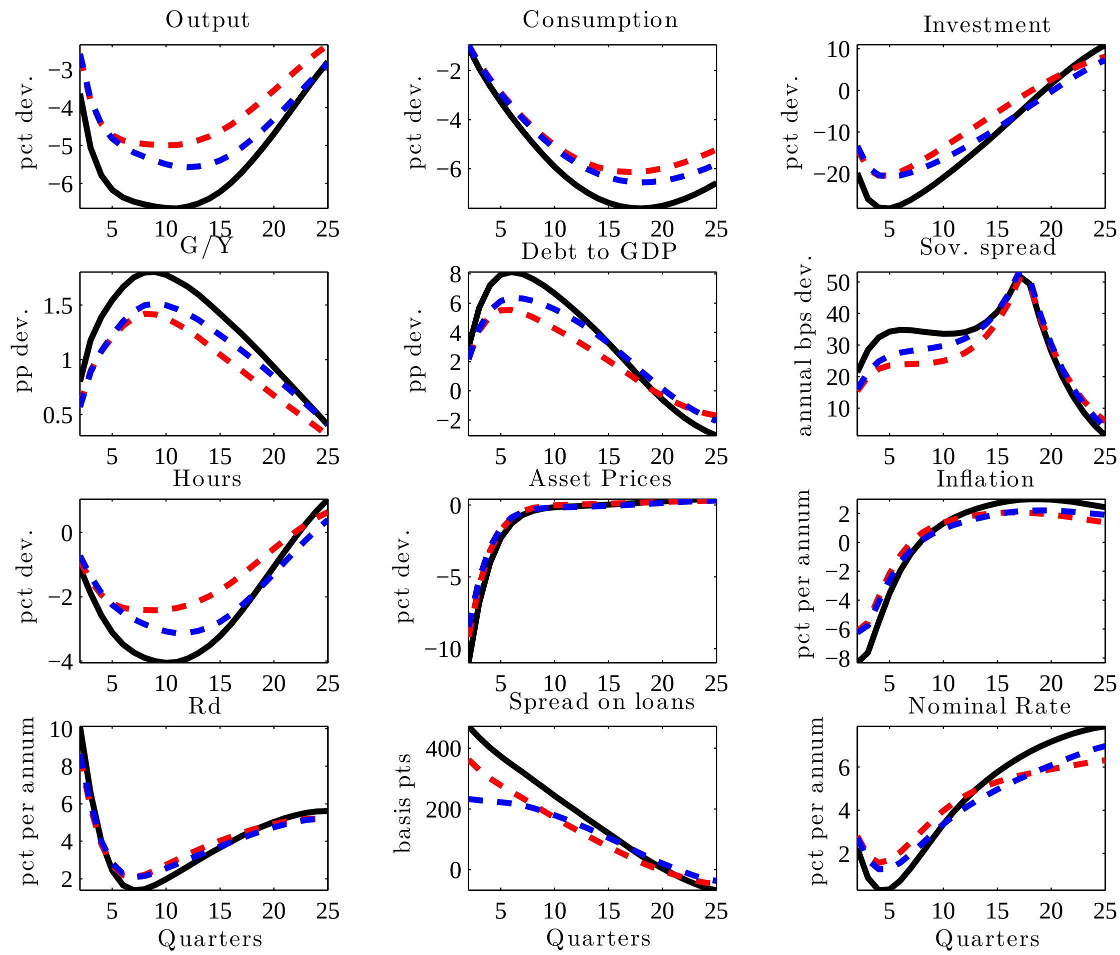
We investigate two counterfactual scenarios where the Central Bank of the monetary union implements UMPs. In the first scenario, the Central Bank intermediates a fraction of the assets held by saving banks, *i.e.* a fraction of their portfolios. This policy does more than just lowering interbank market rates by increasing the supply of interbank liquidity, and should also contribute to relieve sovereign default risk. In the second scenario, the Central Bank intermediates a fraction of the total assets of commercial banks, *i.e.* grants loans directly to the capital producers. In both cases, we follow Gertler and Karadi (2011) in their formulation of interventions. The Central Bank issues bonds to intermediate bank assets. These bonds are either purchased by households – and considered perfect substitutes to deposits when the policy intermediates saving banks assets – or by the Central Bank directly – and considered perfect substitutes to interbank loans when the policy intermediates commercial banks assets. Finally, UMPs induce a small efficiency loss expressed in units of output and proportional to the total amount of assets intermediated by the Central Bank (we set it to 0.1% of intermediated assets).

We consider a symmetric implementation of the policy in period 1 while asymmetric implementation is investigated in the welfare analysis. In the data, UMPs represented between 0.7% of Euro Area GDP in the form of interbank liquidity for the ECB after the default of Lehman Brothers to more than 9.4% of U.S. GDP in mortgage-backed securities when the FED implemented its QE1 program. We choose a figure somewhere in between and assume that the Central Bank intermediates an amount of assets that represents 5 percents of the pre-crisis annual GDP. This amount of intermediated assets then decreases slowly over time according to an AR(1) process with persistence 0.9. Consequently the total amount of assets intermediated is only 8% of the initial amount after 24 quarters. Figure 3 below reports the effects of each type of UMP in the Core region. It also plots the dynamics without these interventions for comparison. Figure 4 reports the dynamics of the Periphery.

Figure 3 and 4 show that both policies limit the fall in output, consumption, investment, limit the rise in public spending to GDP and debt to GDP, the rise in sovereign and private spreads, and the fall of hours worked and asset prices. However, both policies are not fully equivalent. The most efficient intervention in terms of output stabilization is the UMP targeted at saving banks. It leads to a smoother path for almost all variables. Only asset prices and private spreads are better stabilized under the UMP targeted at commercial banks.

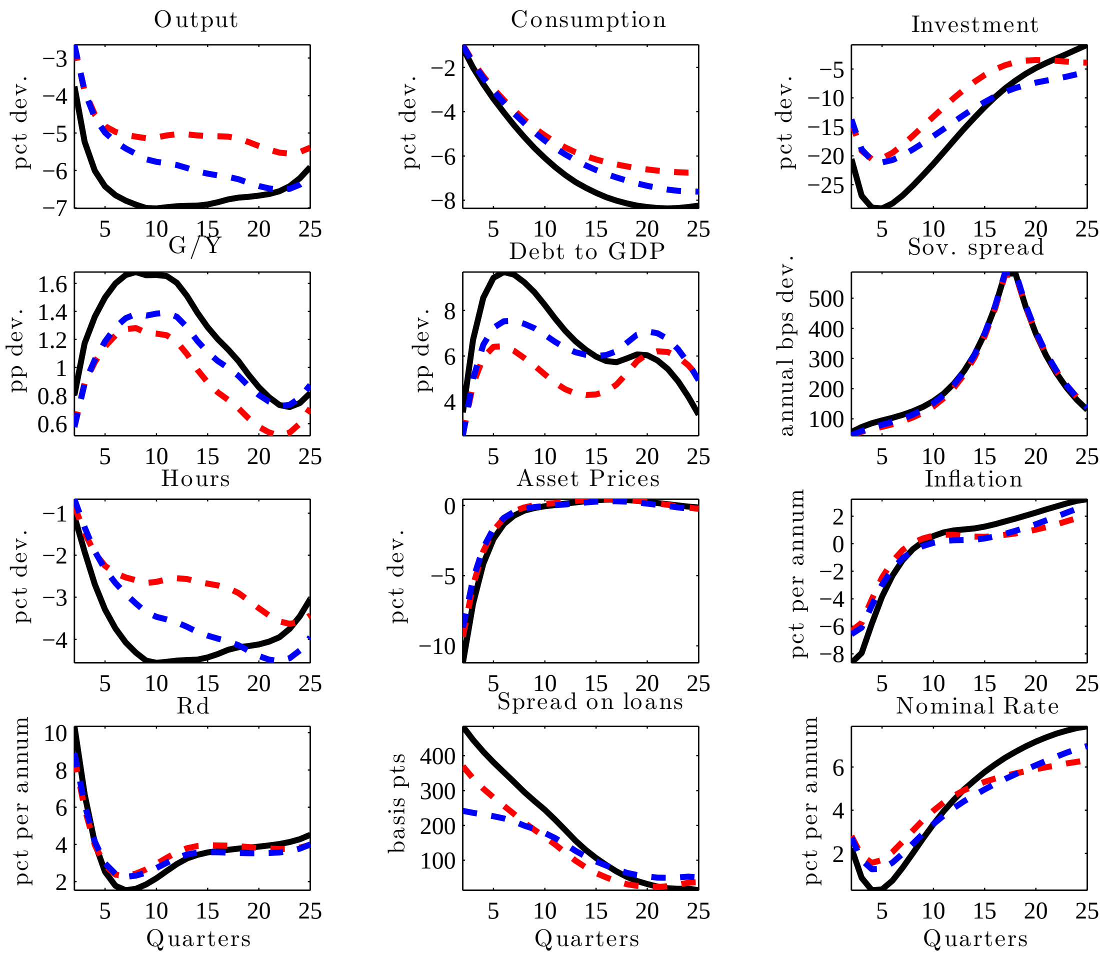
The reasons behind these differences are twofold. First, the UMP targeted at saving banks operates at an earlier stage of the supply of funds in the economy, thereby affecting jointly the returns on interbank loans and the returns on loans granted to capital producers. The reverse is not true, as interventions targeted at commercial banks do not feed back to saving banks directly. Second, distortionary taxes make interventions that stabilize sovereign spreads more desirable,

Figure 3: Great Recession with UMP in the Core



Black: no UMP, Red: UMP targeted at savings banks, Blue: UMP targeted at commercial banks

Figure 4: Great Recession with UMP in the Periphery



Black: no UMP, Red: UMP targeted at savings banks, Blue: UMP targeted at commercial banks as a stabilized sovereign spreads imply lower debt-to-GDP ratios, lower distortionary taxes and then higher levels of GDP, consumption and investment.

What are the welfare effects of these policies? To address this question, the specific welfare criterion is the constant percentage of consumption that the representative household would be ready to pay that leaves it indifferent between a particular path of the economy and the original path where the economy remains at its initial steady state, namely the value of ζ that solves:

$$\sum_{t=0}^{J} \beta^t u\left(c_t\left(1-\zeta\right), n_t\right)\right) = u(c,n) \sum_{t=0}^{J} \beta^t. \tag{69}$$

Table 4 below provides a quantification of the welfare effects of the Great Recession at various horizons J, as well as an evaluation of what welfare losses would have been if UMPs had been implemented, at the same horizons. As a robustness check, we also contrast the effects of an asymmetric implementation of each type of policy, either in the Core region or in the Periphery.

Table 4: The welfare losses of the Great Recession without and with UMPs, in % of permanent consumption

	NO QE	QE Savings banks			QE Commercial banks		
		Joint	Core	Peri.	Joint	Core	Peri.
↓ Horizon			Core				
4	5.22	4.71	4.85	4.99	4.84	4.98	5.04
16	6.37	5.54	5.79	6.03	5.61	5.71	6.24
40	5.73	4.81	5.09	5.36	5.08	5.12	5.67
∞	2.45	2.15	2.24	2.33	2.23	2.26	2.42
↓ Horizon			Periphery				
4	5.47	4.84	5.00	5.20	5.07	5.10	5.37
16	6.48	5.53	5.80	6.09	5.72	6.15	5.98
40	6.37	5.36	5.66	5.97	5.81	6.18	5.95
∞	2.71	2.39	2.48	2.58	2.53	2.63	2.59

Joint means that the UMP is implemented in both countries at the same time. Core or Peri. means that the UMP is implemented asymmetrically in either the Core region or the Periphery.

Table 4 shows that the welfare losses from the Great Recession without UMPs are massive. At the horizon of 4 quarters, they reach 5.22% of consumption equivalent in the Core region and 5.47% in the Periphery. In general, whatever the horizon considered, losses are larger in the Periphery. It comes from the fact that, with or without UMPs, the Great Recession is both deeper and more persistent in this region. Losses grow at the 16 quarters horizon but then start to fall as the effects of the Great Recession slowly vanish. In the infinite horizon case, our economies return to the steady state.[9] The level of welfare losses thus stabilizes to 2.45% in the Core region and 2.71% in the Periphery.

[9] This assumption may not be verified in practice. To date, countries from the Periphery did not start going back to their pre-2008 level of output.

UMPs produce the expected effects as they lower quite significantly the size of welfare losses, at all horizons. The effects of joint UMPs are larger than those of asymmetric UMPs, something that was also expected. Table 4 confirms that UMPs targeted at saving banks, *i.e.* that jointly affect sovereign spreads and the returns of interbank loans, are more efficient in stabilizing the economies and produce larger reductions in welfare losses. Interestingly, policies implemented in the Core region only are more efficient than policies implemented in the Periphery only, although this effects is probably related to the scale of interventions. Interventions are tailored to deliver a total amount of assets intermediated by the Central Bank that represents 5% of GDP: an asymmetric implementation in the Core region, that has a larger intial level of GDP, results in a larger amount of intermediated assets.

What is also interesting is that asymmetric UMPs yield reductions in welfare losses for both regions. Because interbank markets are fully integrated and because saving banks hold both types of sovereign bonds, this is not fully surprising but has to be stressed. Once again, the spillovers from asymmetric UMPs are larger when UMPs are implemented in the Core region, and larger when UMPs are targeted at saving banks. Notice that none of the UMPs considered in our experiments leads one of the two regions of the monetary union to be worse off with UMPs than without.

While the above policies are not intended to mimic any of the actual policies implemented by the European Central Bank, they shed some light on the impact that should be expected from these policies. In particular, because our model is able to capture both “business as usual” features of the economy – business cycle moments, and unusual episodes – the Great Recession, we think it imbeds key characteristics of the European economy. In particular, the sovereign debt / banks / loans loop featured in our model suggests that unconventional policies targeted at the reduction of sovereign spreads are potentially quite efficient in stabilizing the economy and preventing a deepening of the effects of the Great Recession, or a new recession that would be specific to European countries. In this perspective, the scale and design of the recent QE program promoted by the ECB goes in the right direction.

7 Conclusion

This paper builds a two-country model of a monetary union with sovereign default risk, two types of banks and an interbank market. Properly calibrated, the model is able to reproduce most features of the business cycle of European countries and provides a reliable representation of the European economy. Fed with an exogenous financial shock, with public spending data and a properly calibrated default risk shock, our model also reproduces the dynamics of European countries during the Great Recession and after. This framework is then used to assess the welfare losses from the Great Recession and the – positive – effects of unconventional monetary policies.

Among the experiments that are conducted, policies that intermediate a large fraction of saving banks assets and that are implemented jointly, deliver the largest reduction in the welfare losses from the Great Recession. This result suggests that the recent QE program proposed by the European Central Bank could have a significant and positive impact in terms of macroeconomic stabilization.

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A Steady state

At the country level, the zero-inflation condition implies that the steady state markup is

$$\mathcal{M} = \frac{\theta}{\theta - 1} = 1/p^m \tag{70}$$

In addition, $\pi = 1$ also implies

$$1 + i = r^d = 1/\beta \tag{71}$$

The price of capital is $q = 1$ and investment growth is $x = 0$. We also impose the steady state value of hours worked n and normalize the exogenous variables values to $\varsigma_t = \varsigma$ and $\xi_t = \xi = 1$. We impose the levels r^k and deduce the value of capital to output ratios

$$k/y^m = \frac{\iota\,(1/\mathcal{M})}{r^k - (1-\delta)} \tag{72}$$

From the intermediate goods producers first-order conditions, the following steady-state relation holds between factor prices

$$w = \left(\varsigma \iota^{\iota}\,(1-\iota)^{1-\iota}\,(1/\mathcal{M})\left(r^k - (1-\delta)\right)^{\iota}\right)^{\frac{1}{1-\iota}} \tag{73}$$

which determines w. Output $y^m = y$ is then given by

$$y = nw/\,(1-\iota) \tag{74}$$

k and i by

$$k = \frac{\iota\,(1/\mathcal{M})}{r^k - (1-\delta)} y \tag{75}$$

$$i = \delta k \tag{76}$$

Consumption is given by

$$c = y\,(1 - s_g) - \delta k \tag{77}$$

where $s_g = g/y$ is the imposed share of public spending in output. Given the utility function considered, $u_n = -\omega n^{\psi}$, where ψ is the inverse of the Frisch elasticity on labor supply, and $u_c = (1 - \beta h)\,/\,(c\,(1-h))$. The labor supply equation

$$\omega n^{1/\psi} = w\,(1 - \beta h)\,/c\,(1-h) \tag{78}$$

is then used to compute the adjusted labor disutility parameter ω that makes hours worked match our target.

As in Gertler and Karadi (2011), we also fix the value of leverage ratios and the survival rates of bankers, and adjust relevant parameters. Commercial banks net worths are given by

$$n^c = k/\phi^c \tag{79}$$

which using the definition of leverage ratios also pins down demands for loans on the interbank market

$$l^c = (\phi^c - 1)\, n^c \tag{80}$$

On the government side, we have

$$\begin{aligned} p &= F_{beta}\left(by/by_{max}, \alpha_{b^g}, \beta_{b^g}\right) && (81)\\ \chi &= p\Delta && (82)\\ t_g &= s_g - (by)\left(1 - r^b\right) && (83) \end{aligned}$$

where by is the debt to annual output ratio.

Combining interbank loan supplies with demands pins down the interbank market rate

$$r = \left(\frac{l^c + \varrho l^{c*}}{\mu\,(r^a)^{-\varepsilon}\, a + \varrho\mu^*\,(r^{a*})^{-\varepsilon}\, a^*}\right)^{1/\varepsilon} \tag{84}$$

where a and a^* remain undetermined for now. Similarly, sovereign rates are given by sovereign bonds market clearing conditions

$$\begin{aligned} r^b\,(1-\chi) &= \left(\frac{b^g}{\eta\,(r^a)^{-\varepsilon}\, a + \varrho\,(1-\mu^*-\eta^*)\,(r^{a*})^{-\varepsilon}\, a^*}\right)^{1/\varepsilon} && (85)\\ r^{b*}\,(1-\chi^*) &= \left(\frac{\varrho b^{g*}}{(1-\mu-\eta)\,(r^a)^{-\varepsilon}\, a + \varrho\eta^*\,(r^{a*})^{-\varepsilon}\, a^*}\right)^{1/\varepsilon} && (86) \end{aligned}$$

where, again, a and a^* remain undetermined. Using these expressions to substitute in asset demands

$$\begin{aligned} l^s &= \frac{l^c + \varrho l^{c*}}{1 + (\varrho\mu^*/\mu)\,(r^a/r^{a*})^{\varepsilon}\,(a^*/a)} && (87)\\ b &= \frac{b^g}{1 + (\varrho\,(1-\mu^*-\eta^*)\,/\eta)\,(r^a/r^{a*})^{\varepsilon}\,(a^*/a)} && (88)\\ b^* &= \frac{\varrho b^{g*}}{1 + (\varrho\eta^*/\,(1-\mu-\eta))\,(r^a/r^{a*})^{\varepsilon}\,(a^*/a)} && (89) \end{aligned}$$

pins down the total value of savings banks assets a and a^* using the portfolio equations

$$\begin{aligned} a &= \left(\mu^{1/\varepsilon}\,(l^s)^{(\varepsilon-1)/\varepsilon} + \eta^{1/\varepsilon} b^{(\varepsilon-1)/\varepsilon} + (1-\mu-\eta)^{1/\varepsilon}\, b^{*(\varepsilon-1)/\varepsilon}\right)^{\varepsilon/(\varepsilon-1)} && (90)\\ a^* &= \left(\mu^{*1/\varepsilon}\,(l^{s*})^{(\varepsilon-1)/\varepsilon} + \eta^{*1/\varepsilon} b_*^{*(\varepsilon-1)/\varepsilon} + (1-\mu^*-\eta^*)^{1/\varepsilon}\, b_*^{(\varepsilon-1)/\varepsilon}\right)^{\varepsilon/(\varepsilon-1)} && (91) \end{aligned}$$

and its foreign counterpart once an assumption has been made about relative weights, relative returns on portfolios and relative total assets. Equilibrium interbank and sovereign rates are also pinned down once r^a has been imposed. Notice that we consider values of the elasticity of substitution ε that guarantee $r^k > r$, *i.e.* large values of ε.[10] When total intermediated assets of savings banks a are known, their net worth is

$$n^s = a/\phi^s \tag{92}$$

Finally, the values of φ^s and φ^c are given by

$$\varphi^s = \frac{1 - \sigma\Omega^a}{\phi^s} \tag{93}$$

$$\varphi^c = \frac{1 - \sigma\Omega^k}{\phi^c} \tag{94}$$

and the values of α^s and α^c by

$$\alpha^s = \frac{\gamma^s + \gamma^a\phi^s}{\phi^s} \tag{95}$$

$$\alpha^c = \frac{\gamma^c + \gamma^k\phi^c}{\phi^c} \tag{96}$$

B Data

B.1 Calibration

The calibration matches 2008 measures. Data are taken from the OECD Main Economic Indicators (MEI) database and from the OECD employment and labor market statistics database.

- Hours worked are obtained multiplying hours worked per employee and the total number of employed persons in each sub-region (Core and Periphery). Taking the sum and dividing by total employment gives an average measure of hours worked in each sub-region, that is finally expressed as a percentage of total time awake.
- Using debt to annual GDP ratios for each country of the region, we build a measure of public debt to annual GDP in each sub-region (Core and Periphery).
- Using government expenditure on final goods and GDP measures, we build sub-region measures of public spending to GDP.

B.2 Business cycle moments

- GDP, private consumption expenditure on final goods, total gross fixed capital formation government consumption expenditure on final goods are taken from the OECD Economic

[10] Perfect asset substitutability requires $\varepsilon \to \infty$.

outlook database. Aggregates are volume measures at market prices and the data ranges from 1999Q1 to 2013Q4. Business cycle moments are computed as follows. Series are taken in logs, HP-filtered using a smoothing parameter $\lambda = 1600$ before moments are calculated. The standard deviation of GDP is expressed in absolute terms, the standard deviations of consumption, investment and public spending are expressed relative to the standard deviation of GDP.

- Private spreads are computed from CDS quotes on 5Y private bonds and are taken from Markit. The sample includes 51 firms from the Core region, and 8 firms from the periphery, on a monthly frequency from 2005M4 to 2015M4. We do not have monthly data for GDP (to compute the correlation of private spreads with GDP), and we use the industrial production index from the OECD MEI database. Sub-region indices for CDS are simply averaged. Sub-region industrial production indices are build using 2008 GDP weights. Since the dataset is monthly, we compute business cycle moments using a smoothing parameter $\lambda = 100000$. Standard deviations of private spreads are reported in absolute terms.

- Loans and deposits are taken from the OECD Non-consolidated financial balance sheets by economic sectors. We consider the sum of all sectors. Loans correspond to the items labelled "loans" reported at the asset side of balance sheets, and deposits correspond to the items labelled "deposits" reported at the liability side of balance sheets. The dataset is quarterly and ranges from 1999Q1 to 2013Q4. Amounts are expressed in nominal terms so GDP deflators are used to make them real. Loans and deposits are taken in logs before HP-filtering the series using a smoothing parameter $\lambda = 1600$. Standard deviations are expressed relative to the standard deviation of GDP.

- Sovereign rates per annum are taken from the International Financial Statistics database. We consider long-term rates, *i.e.* rates on 10-years government bonds. The dataset covers the period from 1999Q1 to 2013Q4. We build sub-region measures of sovereign rates using time-varying GDP weights, and compute the spread with the German rate before filtering the time series and computing business cycle moments. Standard deviations of sovereign spreads are reported in absolute terms.

- Public debt to GDP ratios are taken from the OECD Public Sector Debt database. The ratios express general government gross debts, as percentages of annual GDPs. The series are quarterly and range from 2000Q1 to 2013Q4. Sub-region ratios are computed based on time-varying GDP weights before HP-filtering the data and computing business cycle moments. Standard deviations of the ratios are reported in absolute terms.

B.3 Simulations

Simulations use sub-region (Core and Periphery) measures of GDP, public spending, debt to annual GDP ratios and sovereign spreads. The dataset is build using the same methodology as in the business cycle section but data are filtered differently. Time series are detrended using an HP-filter with $\lambda = 10000$, a much higher value than in the business cycle section. We do not want the filter to absorb too much of the effects of the Great Recession. The resulting time series are then smoothed with an HP-filter with a very low value ($\lambda = 1.5$) to remove unimportant high frequency movements. Times series are then considered in deviation or log-deviation from their 2008Q1 values to capture the effects of the Great Recession. Hence data range from 2008Q1 to 2013Q4 in the simulations.

C Additional figures

Figure 5: Capital quality shock (Periphery region). Solid: Baseline model, dotted red: model of Gertler and Karadi (2011).