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FINANCIAL FRICTIONS IN THE EURO AREA AND THE UNITED STATES: A BAYESIAN ASSESSMENT

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This paper assesses the empirical relevance of financial frictions in the Euro Area (EA) and the United States (US). It provides a comprehensive set of comparisons between two models: (i) a Smets and Wouters (SW) [F. Smets and R. Wouters, Shocks and frictions in US business cycles: A Bayesian DSGE approach, *American Economic Review* 97(3), 586–606 (2007)] model with financial frictions originating in nonfinancial firms and (ii) a SW model with frictions originating in financial intermediaries. The introduction of financial frictions in either way improves the models' fit compared to a standard SW model, and the empirical comparisons reveal that the latter model outperforms the former both in the euro area and in the United States. Two main factors explain this result: first, the magnitude of the financial accelerator effect, and second, the role of the investment-specific technology shock in affecting financial variables.

Keywords: Financial Frictions, DSGE Models, Bayesian Estimation

1. INTRODUCTION

In the aftermath of the financial crisis, the structure of the financial system has received increasing attention in the literature [see Brunnermeier et al. (2012) for a survey]. The features of external financing are particularly relevant because of its impact on business cycle fluctuations. Since the onset of the crisis, developments in credit markets have changed substantially: total financing to nonfinancial corporations has declined both in the euro area (EA) and in the United States (US). At their peak following the collapse of Lehman Brothers, the credit spreads skyrocketed.

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The dynamic stochastic general equilibrium (DSGE) literature offers alternative micro-foundations of financial market frictions. The influential model of Bernanke et al. (1999) (BGG) is considered a workhorse for the analysis of credit market imperfections in DSGE modeling. The BGG model features constrained firms that are the source of frictions in the form of a costly state verification problem [Townsend (1979)]. Much of the macroeconomic literature stemming from BGG emphasizes credit market constraints on nonfinancial borrowers and treats financial intermediaries largely as a veil. Gertler and Karadi (2011) (GK), instead, explicitly model the banking sector as a source of financial frictions due to the presence of a moral hazard problem. Another approach is offered by the seminal paper of Stiglitz and Weiss (1981), who focus on adverse selection as a source of financial frictions [see also Christiano and Ikeda (2011)].

Given such a variety of approaches, this paper investigates which type of financial frictions is favored by the data. It empirically compares, for the period 1983Q1–2008Q3, using EA and US data, (i) the Smets and Wouters (2007) (SW) model; (ii) the SWBGG model, which incorporates financial frictions à la Bernanke et al. (1999)—where lenders pay a fixed monitoring cost to observe the borrowers' realized return—in a SW economy; and (iii) the SWGK model, where the financial intermediary (FI, henceforth) faces endogenously determined balance sheet constraints. In the literature there are other papers presenting a SW economy with the financial accelerator à la BGG; examples are Queijo von Heideken (2009), Gelain (2010), Carrillo and Poilly (2013), Del Negro and Schorfheide (2013), and Christiano et al. (2014). The choice of these two modeling strategies—BGG and GK—for micro-founding financial frictions can be explained by (i) the established importance of the BGG approach in the mainstream DSGE literature on financial frictions; (ii) the important role assigned to financial intermediaries in the GK model; and (iii) their relative analytical tractability. These two models also share a common feature: financial frictions originate in the group of agents that borrow, and borrowing capacity is linked to net worth. An empirical comparison between the two approaches is novel in the DSGE arena.

As a first step, this paper finds that the introduction of financial frictions à la either BGG or GK improves the models' fit, suggesting that these frictions are empirically relevant both in the EA and the US, and this is in line with what Queijo von Heideken (2009) finds by comparing the SW and BGG models. The paper then focuses on the comparison between the SWBGG and SWGK models by examining business cycle moments, models-implied spread, impulse responses, variance decomposition, and forecasting performance. The novel result is that the SWGK model outperforms the SWBGG model for two main reasons. First, impulse response function analysis reveals that the magnitude of the financial accelerator effect is different across the two models. The presence of the banking sector acts as a powerful amplification channel. The financial accelerator effect embedded in the SWGK model is indeed stronger than that in the SWBGG

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model for the shocks that are the main drivers of business cycle fluctuations. Disruptions in financial markets are generally associated with a rise in the credit spread and a contraction in the quantity of credit. However, although a rise in the spread causes a decline in the net worth of firms in the SWBGG model, financial intermediaries benefit from a rise in the spread because of the positive effects on the relevant net worth in the SWGK model. This mechanism generally leads to a stronger rise in the spread in the SWGK model with more severe effects on investment and, hence, on output than in the SWBGG model. Therefore, the SWGK model provides a better solution to the so-called “small shocks, large cycles” puzzle [Bernanke et al. (1996)]. The second reason is that the investment-specific technology shock plays different roles in the two models, both in the EA and in the US: it explains a larger fraction of the spread in the SWBGG model than of that in the SWGK model. However, this shock does not replicate the co-movement between output and investment and the countercyclical behavior of the spread. Hence, its larger role in the SWBGG model provides another reason for the better empirical performance of the SWGK model. Point forecast evaluation reveals that the SWGK model is favored along this dimension in the EA, whereas in the US there is no clear evidence of an outperformed model in terms of forecasting accuracy.

The structure of the paper is as follows. Section 2 briefly presents the models. Section 3 describes the data and discusses the estimation strategy. Section 4 compares the estimated models, discusses the propagation mechanisms, and presents models’ forecasting performance. Finally, Section 5 concludes. An Online Appendix complements the paper by providing (a) the full details of the models; (b) an analysis aiming at disentangling the effects of the magnitude of the financial frictions on impulse response functions; (c) a series of robustness checks for the empirical results.

2. THE MODELS

This section briefly sketches the three DSGE models. Compared with the standard SW economy, the different features are (i) a utility function comparable with those of Smets and Wouters (2003) and Gertler and Karadi (2011); (ii) the Dixit–Stiglitz aggregator for final output and composite labor, as in Galí et al. (2011); (iii) price mark-up, wage mark-up, and government shocks modeled as in Smets and Wouters (2003); and (iv) the presence of financial frictions in the SWBGG and SWGK models, which changes the production side of the economy. To simplify the optimization problems of intermediate goods firms, retailers are the source of price stickiness.

In all models the economy is populated by households; labor unions; labor packers; retailers; final good firms; intermediate goods firms; and the policy maker. In the SWBGG and SWGK models the economy is also populated by capital producers, whereas the SWGK model incorporates FI.

Households consume, save, and supply labor. A labor union differentiates labor and sets wages in a monopolistically competitive market. Competitive labor packers buy labor service from the union, package it, and sell it to intermediate goods firms. The good market has a similar structure: retailers buy goods from intermediate goods firms, differentiate them, and sell them in a monopolistically competitive market. The aggregate final good is produced by perfectly competitive firms assembling a continuum of intermediate goods. The policy maker sets the nominal interest rate following a Taylor rule.

In the SWBGG model, intermediate goods firms maximize the flow of discounted profits by choosing the quantity of factors for production and stipulate a financial contract to obtain funds from lenders. At the end of period t, firms buy capital K_{t+1} that will be used throughout time $t+1$ at the real price Q_t. The cost of purchased capital is then $Q_t K_{t+1}$. A fraction of capital acquisition is financed by their net worth, N_{t+1}, and the remainder by borrowing. To ensure that entrepreneurial net worth will never be enough to fully finance capital acquisitions, it is assumed that each firm survives until the next period with probability θ and its expected lifetime is consequently equal to $1/(1-\theta)$. At the same time, the new firms entering receive a transfer, N_t^e, from firms that die and depart from the scene.[1] There is a problem of asymmetric information about the project' s ex post return because the return to capital is sensitive to an idiosyncratic shock. Whereas the firm can costlessly observe the realization of the shock, the lender has to pay a fixed auditing cost to observe the borrower's return. If the firm pays in full, there is no need to verify the project's return; but in the case of default, the lender verifies the state and pays the cost. As a consequence, the financial contract implies an external finance premium, EP(·), i.e., a difference between the cost of external and internal funds, that depends on the inverse of the firm's leverage ratio. FI are just a "veil" in the model [Gilchrist and Zakrajšek (2011)]. Capital producers purchase investment and depreciated capital to transform them into capital sold to intermediate goods firms and used for production.

In the SWGK model, within each household there are two types of members at any point in time: a fraction g of the household members are workers and a fraction $(1-g)$ are bankers. The FI have a finite horizon in order to avoid the possibility of full self-financing. Every banker stays a banker the next period with a probability θ, which is independent of history. Therefore, every period $(1-\theta)$ bankers exit and become workers. Similarly, a number of workers become bankers, keeping the relative proportion of each type of agents constant. The household provides its new banker with a start-up transfer, which is a small fraction, χ, of total assets. Each banker manages a financial intermediary. The production sector is also made up of intermediate goods firms and capital producers. The optimization problem of capital producers is the same as in the SWBGG model. The intermediate goods firms finance their capital acquisitions each period by obtaining funds from the FI. Although there are no financial frictions in this activity, there is a problem of moral hazard between FI and households, because the former can choose to divert a fraction λ of available funds from the project. Hence an incentive compatibility constraint should hold in order to make households willing to deposit money in the FI; as a result, the assets the FI can acquire depend positively on their net worth.

The detailed linearized models are shown in Table 1.[2]

3. DATA AND ESTIMATION STRATEGY

In each model there are seven orthogonal structural shocks: the technology, ε_t^a; the investment-specific technology, ε_t^x; the monetary policy, ε_t^r; the capital quality, ε_t^k;[3] the government, ε_t^g; the price mark-up, ε_t^p; and the wage mark-up, ε_t^w, shock. In each model, the shocks follow an AR(1) process.

The models are estimated with quarterly data for the period 1983Q1–2008Q3, using as observables real GDP, real investment, real private consumption, hours worked, GDP deflator inflation, real wage, and the nominal interest rate. The starting date is the same used by Smets and Wouters (2005), whereas the final quarter corresponds to the precrisis period, because the purpose of this paper is to make a comparison among the models in “normal” times. Moreover, ending in 2008Q3 allows to avoid potential distortionary effects on the estimates of the zero lower bound on the nominal interest rate [Galí et al. (2011)]. Data come from the Area Wide Model database [see Fagan et al. (2005) for an explanation)] for the EA, and from the NIPA tables of the Bureau of Economic Analysis and the Bureau of Labor Statistics for the US. Following Smets and Wouters (2007), all variables are logged, but the nominal interest rate is expressed in quarterly terms. GDP, consumption, investment, and wages are expressed in first differences. The inflation rate is measured as a quarterly log-difference of GDP deflator. US hours of work are multiplied by civilian employment, expressed in per capita terms and demeaned. Data on EA employment are used because there are no data available for hours worked in the EA—equation (12) in Table 1.

The following set of measurement equations shows the link between the observables in the dataset and the endogenous variables of the DSGE model:

$$\begin{bmatrix} \Delta Y_t^o \\ \Delta C_t^o \\ \Delta I_t^o \\ \Delta W_t^o \\ L_t^o \\ \pi_t^o \\ r_t^{n,o} \end{bmatrix} = \begin{bmatrix} \gamma \\ \gamma \\ \gamma \\ \gamma \\ 0 \\ \bar{\pi} \\ \bar{r}^n \end{bmatrix} + \begin{bmatrix} \hat{Y}_t - \hat{Y}_{t-1} \\ \hat{C}_t - \hat{C}_{t-1} \\ \hat{I}_t - \hat{I}_{t-1} \\ \hat{W}_t - \hat{W}_{t-1} \\ \hat{L}_t \\ \hat{\Pi}_t \\ \hat{R}_t^n \end{bmatrix}, \tag{1}$$

where γ is the common quarterly trend growth rate of GDP, consumption, investment, and wages; $\bar{\pi}$ is the steady-state quarterly inflation rate; and $\bar{r}^n$ is the steady-state quarterly nominal interest rate. A circumflex over a variable indicates the log-deviation from steady state.

TABLE 1. Linearized model equations

SW model	
(1) Euler equation	$\frac{1+h}{1-h}\hat{C}_t = \frac{1}{1-h}E_t\left[\hat{C}_{t+1}\right] + \frac{h}{1-h}\hat{C}_{t-1} - \hat{R}_t$
(2) Phillips curve: wages	$\hat{W}_t = \frac{\beta}{(1+\beta)}E_t\left[\hat{W}_{t+1}\right] + \frac{1}{(1+\beta)}\hat{W}_{t-1} + \frac{\beta}{(1+\beta)}E_t\left[\hat{\Pi}_{t+1}\right] - \frac{(1+\beta\sigma_{wi})}{(1+\beta)}\hat{\Pi}_t +$ $\frac{\sigma_{wi}}{(1+\beta)}\hat{\Pi}_{t-1} + \frac{1}{(1+\beta)}\frac{(1-\beta\sigma_w)(1-\sigma_w)}{(1+\varepsilon_w\phi)\sigma_w}\left[\phi\hat{L}_t - \frac{h}{1-h}\hat{C}_{t-1} + \frac{1}{1-h}\hat{C}_t - \hat{W}_t\right] + \varepsilon_t^w$
(3) Capital accumulation	$\hat{K}_{t+1} = \delta(\hat{I}_t + \varepsilon_t^x) + (1-\delta)\left(\hat{K}_t + \varepsilon_t^k\right)$
(4) Optimal capital utilization	$\hat{Z}_t^k = \frac{\zeta}{1-\zeta}\hat{U}_t$
(5) Investment Euler equation	$\hat{I}_t = \frac{1}{\xi(1+\beta)}\left(\hat{Q}_t + \varepsilon_t^x\right) + \frac{1}{(1+\beta)}\hat{I}_{t-1} + \frac{\beta}{(1+\beta)}E_t\left[\hat{I}_{t+1}\right]$
(6) Resource constraint	$\hat{Y}_t = \frac{C}{Y}\hat{C}_t + \frac{I}{Y}\hat{I}_t + \frac{G}{Y}\varepsilon_t^g + Z^k\frac{K}{Y}\hat{U}_t$
(7) Production function	$\hat{Y}_t = \Theta\left[\varepsilon_t^a + \alpha\left(\varepsilon_t^k + \hat{K}_t + \hat{U}_t\right) + (1-\alpha)\hat{L}_t\right]$
(8) Firms' FOCs	$\hat{W}_t = \hat{Z}_t^k - \hat{L}_t + \hat{K}_t + \hat{U}_t$
(9) Phillips curve: prices	$\hat{\Pi}_t = \frac{\sigma_{pi}}{1+\sigma_{pi}\beta}\hat{\Pi}_{t-1} + \frac{\beta}{1+\sigma_{pi}\beta}E_t\left[\hat{\Pi}_{t+1}\right] - \frac{(1-\beta\sigma_p)(1-\sigma_p)}{(1+\sigma_{pi}\beta)\sigma_p}\left[\varepsilon_t^a - \alpha\hat{Z}_t^k - (1-\alpha)\hat{W}_t\right] + \varepsilon_t^p$
(10) Taylor rule	$\hat{R}_t^n = \rho_i\hat{R}_{t-1}^n + (1-\rho_i)\left[\rho_\pi\hat{\Pi}_t + \rho_y\left(\hat{Y}_t - \hat{Y}_t^p\right)\right] + \rho_{\Delta y}\left[\hat{Y}_t - \hat{Y}_t^p - \left(\hat{Y}_{t-1} - \hat{Y}_{t-1}^p\right)\right] + \varepsilon_t^r$
(11) Fisher equation	$\hat{R}_t^n = \hat{R}_t + E\left[\hat{\Pi}_{t+1}\right]$
(12) Phillips curve; employment	$\hat{E}_t = \frac{1}{1+\beta}\hat{E}_{t-1} + \frac{\beta}{1+\beta}E_t\left[\hat{E}_{t+1}\right] - \frac{(1-\beta\sigma_E)(1-\sigma_E)}{(1+\beta)\sigma_E}\left(\hat{L}_t - \hat{E}_t\right)$
(13) Price of capital	$\hat{Q}_t + \hat{R}_t = \frac{Z^k}{Z^k+(1-\delta)}E_t\left[\hat{Z}_{t+1}^k\right] + \frac{(1-\delta)}{Z^k+(1-\delta)}E_t\left[\hat{Q}_{t+1} + \varepsilon_{t+1}^k\right]$
SWBGG model: Equations (1)–(12) +	
(13a) Price of capital	$\hat{R}_t^k = \frac{Z^k}{R^k}\hat{Z}_t^k + \frac{(1-\delta)}{R^k}\left(\hat{Q}_t + \varepsilon_t^k\right) - \hat{Q}_{t-1}$
(14a) External finance premium	$\hat{\mathrm{EP}}_t = \varkappa\left(\hat{Q}_t + E_t\left[\hat{K}_{t+1}\right] - E_t\left[\hat{N}_{t+1}\right]\right)$
(15a) Spread	$E_t\left[\hat{R}_{t+1}^k\right] = \hat{R}_t + \hat{\mathrm{EP}}_t$
(16a) Firms' net worth accumulation	$\frac{1}{\theta R^k}E_t\left[\hat{N}_{t+1}\right] = \frac{K}{N}\hat{R}_t^k - \left(\frac{K}{N} - 1\right)\hat{R}_{t-1} - \varkappa\left(\frac{K}{N} - 1\right)\left(\hat{K}_t + \hat{Q}_{t-1}\right)$ $+\left[\left(\frac{K}{N} - 1\right)\varkappa + 1\right]\hat{N}_t$
SWGK model: Equations (1)–(12) + (13a) +	
(14b) Gain from expanding assets	$\hat{V}_t = \frac{(1-\theta)\beta}{V}[R^k - R]E_t\left[\hat{\Lambda}_{t,t+1}\right] + \frac{(1-\theta)\beta}{V}\left[R^k E_t\left[\hat{R}_{t+1}^k\right] - R\hat{R}_t\right]$ $+\theta\beta X E_t[\hat{X}_{t,t+1} + \hat{V}_{t+1} + \hat{\Lambda}_{t,t+1}]$
(15b) Value of expanding net worth	$\hat{D}_t = \theta\beta Z E_t[\hat{\Lambda}_{t,t+1} + \hat{Z}_{t,t+1} + \hat{D}_{t+1}]$
(16b) Gross growth rate of net worth	$\hat{Z}_{t,t+1} = \frac{1}{Z}\left[\mathrm{lev} R^k E_t\left[\hat{R}_{t+1}^k\right] + R(1-\mathrm{lev})\hat{R}_t + (R^k - R)\mathrm{lev}\hat{\mathrm{lev}}_t\right]$
(17b) Gross growth rate in assets	$\hat{X}_{t,t+1} = E_t\left[\hat{\mathrm{lev}}_{t+1}\right] + \hat{Z}_{t,t+1} - \hat{\mathrm{lev}}_t$
(18b) Leverage (lev)	$\hat{\mathrm{lev}}_t = \hat{D}_t + \frac{V}{\lambda - V}\hat{V}_t$

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TABLE 1. Continued

(19b) FI constraint	$\hat{K}_{t+1} + \hat{Q}_t = \hat{\text{lev}}_t + \hat{N}_t$
(20b) Net worth of existing FI	$\hat{N}^e_t = \hat{N}_{t-1} + \frac{1}{Z}\left[\text{lev}R^k E_t\left[\hat{R}^k_{t+1}\right] + R(1-\text{lev})\hat{R}_t + (R^k - R)\text{lev}\hat{\text{lev}}_t\right]$
(21b) Net worth of new FI	$\hat{N}^n_t = \hat{Q}_t + \hat{K}_t$
(22b) Total net worth	$\hat{N}_t = \frac{N^e}{Y}\frac{Y}{N}\hat{N}^e_t + \frac{N^n}{Y}\frac{Y}{N}\hat{N}^n_t$
(23b) Spread	$\hat{\text{EP}}_t = E_t\left[\hat{R}^k_{t+1}\right] - \hat{R}_t$

Notes: Variables with a circumflex denote percentage deviations from steady state, whereas variables without a time subscript denote steady-state values. The term $\hat{Y}^p_t$ represents the level of output that would prevail under flexible prices and wages without the two mark-up shocks; $\hat{E}_t$ is employment; $\hat{\Lambda}_{t,t+1} = \hat{\text{mu}}_{t+1} - \hat{\text{mu}}_t$; $\hat{\text{mu}}_t = \frac{1}{1-h}\left(h\hat{C}_{t-1} - \hat{C}_t\right)$.

TABLE 2. Calibration of parameters common to both models

Parameter	Value
β, discount factor	0.99
α, capital income share	0.33
δ, depreciation rate	0.025
$\frac{G}{Y}$, government-spending-to-GDP ratio	0.20
ε, elasticity of substitution in goods market	set to target $M = 1.20$
ε_w, elasticity of substitution in labor market	set to target $M^w = 1.20$

The parameters that cannot be identified in the dataset and/or are related to steady state values of the variables are calibrated. The time period in the model corresponds to one quarter in the data.

Table 2 shows the calibration of the parameters common to both models. The discount factor, β, is equal to 0.99, implying a quarterly steady state real interest rate of 1%; the capital income share, α, is equal to 0.33. The depreciation rate is equal to 0.025, corresponding to an annual depreciation rate of 10%. The ratio of government spending to GDP is equal to 0.20. The elasticities of substitution in goods and labor markets are equal to 6 in order to target a gross steady state mark-up of 1.20, as in Christiano et al. (2014), among many others.

The calibration of the financial parameters is shown in Table 3. The parameter θ represents the survival rate of intermediate goods firms in the SWBGG model and of FI in the SWGK model. This parameter is set equal to 0.972, implying an expected working life for bankers and firms of almost a decade; this value is close to those in BGG and GK. In the SWBGG model the parameter pinning down the steady state spread, S, is set to match the steady state spread of 150 basis points. Following BGG, the ratio of capital to net worth is set to 2, implying that 50% of firms' capital expenditures are externally financed. As far as the calibration of the SWGK model is concerned, the fraction of assets given to new bankers, χ,

TABLE 3. Calibration of model-specific parameters

Financial parameter	SWBGG model	SWGK model
θ, survival rate	0.972	0.972
S, steady state spread	150 basis point py	150 basis point py
$\frac{K}{N}$, leverage ratio	2	4
χ, fraction of assets given to the new bankers	—	0.001
λ, fraction of divertible assets	—	0.515

and the fraction of assets that can be diverted, λ, are equal to 0.001 and 0.515, respectively, to target the same steady state spread of 150 basis points and a steady state leverage ratio of 4.[4] The Online Appendix investigates the robustness of the main results to the calibration of the financial parameters.

Table 4 shows the assumptions for the prior distributions of the estimated parameters for both models; the prior distributions are the same for both countries. The choice of the functional forms of parameters and the location of the prior mean correspond to a large extent to those in Smets and Wouters (2003, 2007), where applicable. The priors of some model-specific parameters are as follows. The parameter measuring the inverse of the Frisch elasticity of labor supply follows a normal distribution with a prior mean of 0.33, the value used by Gertler and Karadi (2011), and a loose standard deviation of 0.25. The elasticity of the external finance premium with respect to leverage of firms is assumed to follow a Beta distribution with a prior mean of 0.05 and a standard deviation of 0.05, which implies a [0.002, 0.151] 90% prior interval.

4. MODEL COMPARISON

This section performs empirical comparisons among the models estimated both for the EA and for the US, with a focus on the SWBGG and SWGK models, which are the novel part of the paper. The comparison is made along the following dimensions: (i) the estimated parameters and the likelihood race; (ii) simulated business cycle moments versus those in the data and models-implied spread; (iii) impulse response functions and variance decomposition; and (iv) the forecasting performance. The Online Appendix presents some robustness exercises.

4.1. Estimated Parameters and Likelihood Race

The mean of the estimated parameters for each model is computed with two chains of the Metropolis–Hastings algorithm with a sample of 250,000 draws.[5] Table 4 reports the posterior mean with 95% probability intervals in parentheses for the SWBGG and SWGK models for the EA and the US. Most parameters are remarkably similar across the two models. As in Smets and Wouters (2005), the

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TABLE 4. Prior and posterior distributions of structural parameters

Parameter	Prior distribution			Posterior mean			
				EA		US	
	Distr	Mean	Std./df	SWBGG	SWGK	SWBGG	SWGK
σ_p, Calvo prices	Beta	0.75	0.05	0.82 [0.77:0.87]	0.84 [0.79:0.88]	0.89 [0.86:0.93]	0.89 [0.86:0.93]
σ_w, Calvo wages	Beta	0.75	0.05	0.77 [0.71:0.84]	0.78 [0.72:0.85]	0.82 [0.78:0.87]	0.84 [0.80:0.88]
σ_{pi}, price indexation	Beta	0.5	0.15	0.15 [0.06:0.24]	0.15 [0.06:0.24]	0.35 [0.11:0.58]	0.36 [0.12:0.60]
σ_{wi}, wage indexation	Beta	0.5	0.15	0.37 [0.17:0.56]	0.39 [0.18:0.60]	0.31 [0.13:0.50]	0.34 [0.13:0.53]
σ_E, Calvo employment	Beta	0.5	0.15	0.81 [0.78:0.84]	0.80 [0.76:0.83]	—	—
ξ, inv. adj. costs	Normal	4	1.5	4.59 [3.11: 5.98]	4.95 [3.42:6.43]	4.75 [3.00: 6.45]	4.27 [2.80: 5.74]
ζ, elasticity of capital util	Beta	0.25	0.15	0.95 [0.92:0.98]	0.95 [0.92:0.98]	0.79 [0.69:0.90]	0.83 [0.74:0.92]
h, habit parameter	Beta	0.7	0.1	0.69 [0.62:0.76]	0.65 [0.58:0.72]	0.48 [0.39:0.58]	0.44 [0.35:0.53]
Θ, fixed costs in production	Normal	1.25	0.125	1.33 [1.20:1.47]	1.40 [1.26:1.53]	1.28 [1.17:1.39]	1.34 [1.23:1.43]
ϕ, inverse of Frisch elasticity	Gamma	0.33	0.25	1.34 [0.81:1.86]	1.49 [0.95:2.04]	1.69 [0.95:2.39]	1.81 [1.05:2.57]
$\varkappa$, elast. of external finance	Beta	0 .05	0.05	0.04 [0.03:0.05]	—	0.05 [0.04:0.07]	—
ρ_π, Taylor rule	Normal	1.7	0.15	1.80 [1.61:2.00]	1.73 [1.54:1.93]	1.83 [1.60:2.05]	1.89 [1.66:2.10]
ρ_y, Taylor rule	Gamma	0.125	0.05	0.09 [0.05:0.14]	0.09 [0.05:0.13]	0.12 [0.06:0.17]	0.09 [0.05:0.13]
ρ_{Δ_y}, Taylor rule changes in y	Normal	0.0625	0.05	0.06 [0.03:0.09]	0.08 [0.05:0.11]	0.18 [0.13:0.22]	0.20 [0.16:0.25]
ρ_i, Taylor rule smoothing	Beta	0.80	0.1	0.88 [0.86:0.91]	0.89 [0.86:0.91]	0.84 [0.81:0.88]	0.85 [0.82:0.87]
$\bar{\gamma}$, constant growth rate	Normal	0.40	0.1	0.30 [0.24;0.36]	0.30 [0.24;0.35]	0.35 [0.30;0.41]	0.32 [0.26;0.38]
$\bar{\pi}$, constant inflation	Gamma	0.625	0.1	0.55 [0.44;0.66]	0.63 [0.54;0.73]	0.64 [0.56;0.73]	0.64 [0.56;0.71]

TABLE 4. Continued

Parameter	Prior distribution			Posterior mean			
				EA		US	
	Distr	Mean	Std./df	SWBGG	SWGK	SWBGG	SWGK
ρ_a, pers. of tech shock	Beta	0.5	0.2	0.87 [0.82:0.93]	0.90 [0.86:0.94]	0.92 [0.88:0.97]	0.94 [0.89:0.99]
ρ_k, pers. of capital quality shock	Beta	0.5	0.2	0.99 [0.98:0.99]	0.99 [0.98:0.99]	0.97 [0.96:0.99]	0.99 [0.98:0.99]
ρ_g, pers. of governm shock	Beta	0.5	0.2	0.92 [0.86:0.98]	0.92 [0.87:0.99]	0.95 [0.92:0.98]	0.96 [0.93:0.98]
ρ_x, pers. of investment shock	Beta	0.5	0.2	0.97 [0.95:0.99]	0.97 [0.96:0.99]	0.96 [0.93:0.99]	0.99 [0.98:0.99]
ρ_{ri}, pers. of monetary shock	Beta	0.5	0.2	0.25 [0.12:0.36]	0.24 [0.13:0.35]	0.27 [0.14:0.39]	0.23 [0.11:0.34]
ρ_p, pers. of price mark-up shock	Beta	0.5	0.2	0.81 [0.64:0.98]	0.72 [0.47:0.96]	0.32 [0.06:0.56]	0.31 [0.07:0.56]
ρ_w, pers. of wage mark-up shock	Beta	0.5	0.2	0.59 [0.42:0.74]	0.58 [0.41:0.76]	0.17 [0.06:0.29]	0.20 [0.07:0.32]
σ_a, std of tech shock	IG	0.1	2	1.09 [0.84:1.33]	0.96 [0.76:1.15]	0.42 [0.36:0.47]	0.40 [0.35:0.45]
σ_k, std of capital quality shock	IG	0.1	2	0.24 [0.18:0.30]	0.17 [0.12:0.21]	0.25 [0.19:0.31]	0.19 [0.14:0.23]
σ_g, std of government shock	IG	0.1	2	1.46 [1.29:1.64]	1.47 [1.30:1.64]	2.23 [1.95:2.51]	2.25 [1.97:2.51]
σ_i, std of investment shock	IG	0.1	2	2.33 [1.27:3.43]	2.11 [1.19:3.02]	1.04 [0.54:1.54]	1.20 [0.67:1.71]
σ_r, std of monetary shock	IG	0.1	2	0.11 [0.09:0.13]	0.11 [0.10:0.13]	0.13 [0.11:0.15]	0.13 [0.11:0.14]
σ_{pm}, std of price mark-up shock	IG	0.1	2	0.07 [0.05:0.10]	0.09 [0.05:0.13]	0.12 [0.09:0.15]	0.12 [0.09:0.15]
σ_{wm}, std of wage mark-up shock	IG	0.1	2	0.12 [0.09:0.16]	0.12 [0.08:0.16]	0.29 [0.25:0.34]	0.28 [0.23:0.33]

fact that in almost all the cases the posterior estimate of a parameter in one model falls in the estimated confidence band for the same parameter of the other model can be considered as a rough measure of similarity.

As far as the EA is concerned, the degree of price stickiness reveals that firms adjust prices about every year and a half, with a higher degree of stickiness in the SWGK model. The Calvo parameter for wage stickiness reveals that the average duration of wage contracts is slightly more than a year, lower than the degree of price stickiness, as in Smets and Wouters (2003). There is a moderate degree of price indexation and a higher degree of wage indexation, similarly to previous estimates for the EA [Adolfson et al. (2008); Gerali et al. (2010)]. The mean of the parameter measuring the elasticity of capital utilization is higher than its prior mean, revealing that capital utilization is more costly than assumed a priori. The estimated value in both models favors high costs of capital utilization, suggesting a minor role for this internal propagation mechanism, in line with the literature [e.g., Adolfson et al. (2007); Christoffel et al. (2008)].[6] The estimates of the parameter measuring the Taylor rule reaction to inflation are also in line with previous estimates for the EA, with a higher value in the SWBGG model. There is also evidence of a short-term reaction to the current change in the output gap. Turning to the exogenous shock processes, all shocks are quite persistent except for the wage mark-up shock. The mean of the standard errors of the shocks is in line with similar studies of the EA, except for the standard deviation of the investment-specific technology shock, which is higher.

As far as the US economy is concerned, the two models with financial frictions feature a higher degree of price stickiness than the value found by Smets and Wouters (2007), because the average length of price contract is more than two years. Our results are in line with those of Del Negro et al. (2013). Similarly to the EA, the estimates of the parameter measuring the elasticity of capital utilization are higher than the prior mean, rather in line with the value found by Smets and Wouters for the period 1984–2004, equal to 0.69. There is evidence of a relatively low external superficial habit in consumption, similarly to the results of De Graeve (2008). The estimates of the shock processes are generally similar among the models, but in the SWBGG model the investment-specific technology shock has a lower persistence and volatility than in the SWGK model.

The estimated mean of the elasticity of the external finance premium with respect to the leverage position is equal to 0.04 in the EA and to 0.05 in the US. Also, in this case, the posterior estimate of this parameter for one country falls into the estimated confidence band for the same parameter for the other country.[7] An estimated elasticity different from zero is a first piece of evidence in favor of a model with financial frictions.

The Bayes factor (BF) is used to judge the relative fit of the models, as in An and Schorfheide (2007), among many others.[8] According to Jeffreys (1998), a BF of 3–10 provides "slight" evidence in favor of model i; a BF of 10–100 provides "strong to very strong" evidence in favor of model i; and a BF greater than 100 provides "decisive evidence."

TABLE 5. Model comparisons

	EA			US		
	SW	SWBGG	SWGK	SW	SWBGG	SWGK
Log data density	−365.86761	−357.26933	−344.74334	−548.12333	−545.60391	−539.27695
	Comparison between SW and SWBGG & SWGK					
Bayes factor	—	5.4×10^3	1.5×10^9	—	12	6.9×10^3
	Comparison between SWBGG and SWGK					
Bayes factor	—	—	2.8×10^5	—	—	5.6×10^2

The main results are shown in Table 5. As a first step, a comparison is made with the SW model featuring perfect financial markets. The introduction of financial frictions à la BGG leads to an improvement of the marginal likelihood for both EA and US data, suggesting that these frictions are empirically relevant. This result confirms the findings of Queijo von Heideken (2009), among others. Second, the empirical relevance of financial frictions in the EA is stronger in the model featuring frictions at the level of financial intermediaries. The Bayes factor points to “decisive” evidence in favor of the SWGK model versus the SWBGG model, as shown in the last row of Table 5. This result is also true for the US: the comparison between the two models with financial frictions provides “decisive” evidence in favor of the SWGK model.

4.2. Business Cycle Moments and Models-Implied Spread

To investigate which features of the data are better captured by the SWGK model, this subsection first shows a comparison between the moments generated by the models and those in the data, as in Iacoviello and Neri (2010). It then investigates whether the estimated models generates proxies of the spread with business cycle fluctuations in line with the data.

Table 6 shows relative standard deviations, cross-correlations, and autocorrelations of output, investment, consumption, inflation, and the nominal interest rate within the 90% highest-posterior-density interval.[9]

As far as the EA is concerned, a comparison of the relative standard deviations of investment and consumption (with respect to output) shows that for both the SWBGG and SWGK models, the confidence bands contain the empirical standard deviations. The SWGK model fits all the variables better than the SWBGG model in terms of the value of the posterior mean. However, both models perform poorly in replicating the relative standard deviations of interest rate and inflation, because the models' business cycle statistics are outside the empirical standard deviations.[10]

Comparison of the cross correlation with output reveals that the SWBGG and the SWGK models cannot reproduce the cross correlation of investment, and the SWBGG performs worse. The SWGK model fits the data better than the SWBGG

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TABLE 6. Moments in the data versus the models

	EA			US		
	Data	SWBGG	SWGK	Data	SWBGG	SWGK
			Standard deviations relative to output			
Output	1.00	1.00	1.00	1.00	1.00	1.00
Investment	2.44	2.92 [1.79;3.89]	2.88 [1.74;3.55]	4.06	3.78 [2.51;4.89]	3.93 [3.03;4.65]
Consumption	1.27	1.63 [0.51;2.50]	1.46 [0.62;2.31]	1.00	1.59 [0.67;2.33]	1.44 [0.72;1.89]
Inflation		0.07 [0.06;0.08]	0.08 [0.07;0.08]	0.11	0.05 [0.04;0.06]	0.06 [0.05;0.07]
Interest rate	0.25	0.07 [0.06;0.08]	0.08 [0.07;0.08]	0.20	0.09 [0.07;0.11]	0.09 [0.07;0.10]
			Cross correlations with output			
Investment	0.75	0.20 [−0.07;0.42]	0.37 [0.33;0.43]	0.64	0.48 [0.41;0.53]	0.60 [0.55;0.66]
Consumption	0.92	0.75 [0.58;0.92]	0.82 [0.71;0.93]	0.93	0.77 [0.63;0.88]	0.84 [0.75;0.92]
Inflation	−0.29	−0.25 [−0.64;−0.01]	−0.27 [−0.53;−0.04]	−0.15	−0.32 [−0.77;−0.01]	−0.28 [−0.58;−0.03]
Interest rate	0.24	0.14 [0.05;0.29]	0.17 [0.05;0.34]	0.26	0.14 [0.1;0.29]	0.13 [0.03;0.27]
			Autocorrelations of order 1			
Output	0.93	0.98 [0.95;0.99]	0.98 [0.95;0.99]	0.87	0.98 [0.95;0.99]	0.98 [0.95;0.99]
Investment	0.95	0.99 [0.97;1.00]	0.99 [0.96;0.99]	0.96	0.99 [0.97;0.99]	0.98 [0.96;0.99]
Consumption	0.94	0.98 [0.96;1.00]	0.98 [0.96;1.00]	0.89	0.93 [0.89;1.00]	0.94 [0.90;0.99]
Inflation	0.54	0.86 [0.80;0.91]	0.79 [0.74;0.85]	0.50	0.85 [0.75;0.98]	0.75 [0.65;0.84]
Interest rate	0.94	0.96 [0.94;0.99]	0.96 [0.94;0.99]	0.95	0.96 [0.95;0.98]	0.96 [0.95;0.98]

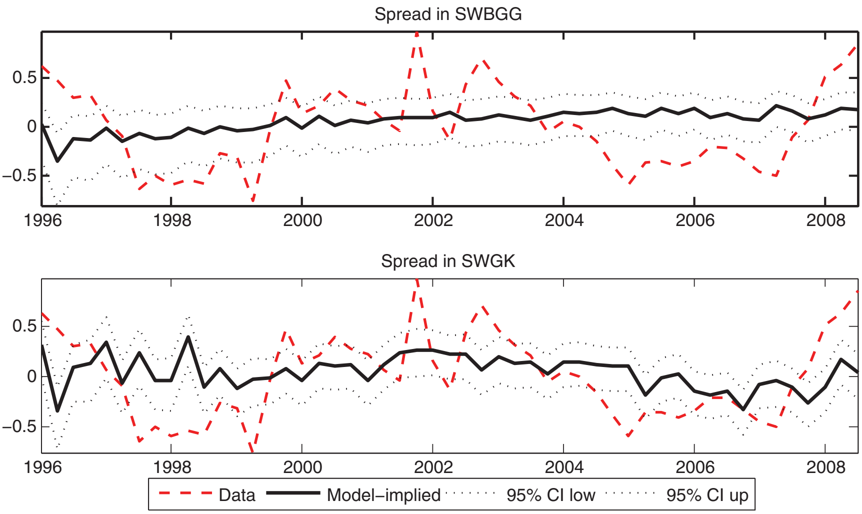

FIGURE 1. Model implied spread versus EA data (percent deviations from steady state and HP(1600) trend, respectively); data are extracted from the ECB.

model in terms of cross correlations of consumption, inflation, and interest rate, although results are rather similar, because business cycle statistics of the data are within confidence bands of both models.

Table 6 finally reports the autocorrelation coefficients of order 1. Variables are more autocorrelated in the two models than in the data, as in Gabriel et al. (2011). When it comes to matching inflation, the models are far from replicating its dynamics in the data. Overall, the presence of financial frictions originating in financial intermediaries is preferable in the data compared to a model where financial frictions originate in nonfinancial firms, in particular as far as investment dynamics is concerned.

The comparison of simulated business cycle moments between the two models in the US is similar to that in the EA. Also, for the US, the two models perform poorly in replicating the relative standard deviations of inflation and interest rate, whereas the SWGK model gets closer to the data in replicating the cross-correlation of investment.

Figure 1 reports the models-implied spread, in percent deviations from their steady state values, within a 95% confidence band, along with the percent deviations from HP(1600) trends of a proxy of the credit spread in EA data. The series is computed as BBB rated bonds minus government AAA bonds. Because the series is shorter than the sample period, the charts refer to the period 1996Q1–2008Q3 only. The SWBGG model generates a series of the spread that is rather constant over time, whereas the SWGK model better replicates the business cycle fluctuations of this variable. Recalling that, in the estimate, the standard dataset of macroeconomic variables does not include financial data, the SWGK model

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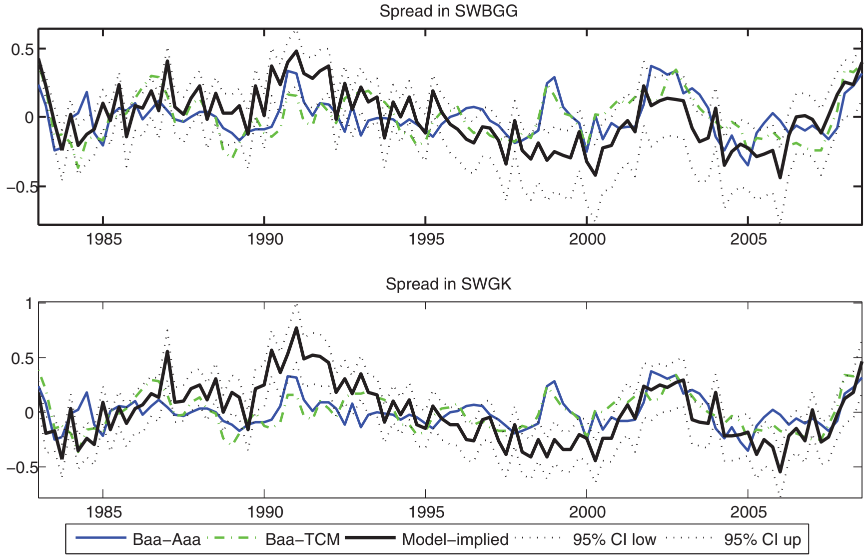

FIGURE 2. Model implied spread versus US data (percent deviations from steady state and HP (1600) trend, respectively); data are extracted from the ALFRED database of the St. Louis Fed.

produces cyclical fluctuations of the financial variable that are closer to those in the data to a certain extent.

Figure 2 reports the models-implied spread, in percent deviations from their steady state values, within a 95% confidence band, along with the percent deviations from HP(1600) trends of proxies of spreads in US data (available in the ALFRED database of the St. Louis Fed). Because of the greater availability of US data on spreads, two measures of spreads are reported in the figure: Moody's seasoned Baa corporate bond yield (Baa) minus Moody's seasoned Aaa corporate bond yield (Aaa); and Baa minus long-term Treasury constant maturity rate (TCM). Although the SWBGG generates a series of the spread more correlated with the latter proxy, the SWGK model replicates a series of the spread more correlated with the first proxy. Both models generate a series of the spread (i) with a comparable order of magnitude of the available proxies and (ii) with an upward trend at the end of the sample, picking up the end-of-sample crisis.

4.3. Impulse Response Functions and Variance Decomposition

This section discusses the impulse response functions (IRFs) and variance decomposition of the two models for the two economies in order to explain why the presence of financial frictions on FI is empirically favored by the data. This section shows the effects on output, investment, inflation, net worth of firms in the SWBGG model and of FI in the SWGK model, and spread to all the seven structural shocks: capital quality (KQ), monetary policy (MP), government spending (Gov), investment-specific technology (IS), technology (TFP), price mark-up (PMU), and wage mark-up (WMU) shocks. All the shocks are set to produce a downturn. In all the figures, impulse responses are normalized so that the size of each shock is the same across the models. The solid lines represent the estimated median and the dotted lines represent the 95% confidence intervals.

The two models embed different transmission mechanisms: whereas in the SWBGG model the financial accelerator effect works through the firms' balance sheet channel, in the SWGK model it works through the bank lending channel. The dynamics of net worth is differently affected by a change in the spread in the two models. Generally speaking, the equations describing the accumulation of net worth of firms and banks—-16a and 20b, respectively, in Table 1—are similar. Both equations contain terms for the net worth of the previous period, the leverage, the rate of return on capital, and the risk-free rate. However, the effect of any exogenous shock on the net worth of firms is dramatically different from the effect of the same shock on the net worth of FI. As explained by Villa and Yang (2011), three factors affect the profits of FI: the lending volume, the spread, and the leverage. Any contractionary shock affects banks' profits either directly or indirectly. The FI decides about the amount of corporate bonds it holds subject to the incentive constraint, the expected capital return, and the deposit return. A fall in the asset price leads to a deterioration of FI balance sheets. The reduction in net worth makes the incentive constraint tighter, leading to a higher spread and, hence, profits. The resulting rise of the spread also has the effect of reducing the demand for loans by firms, leading to a further contraction in investment and, hence, output. This is the essence of the financial accelerator effect of the SWGK model. The increase in the spread after a negative shock helps financial intermediaries rebuild their net worth faster. In contrast, in the SWBGG model the rise in the spread causes a further fall in net worth. Hence optimizing financial intermediaries benefit from a rise in the spread. In most shocks the rise in the spread is indeed stronger in the SWGK model. But this causes a more pronounced fall in investment and, hence, output. The SWGK model provides a better solution to the so-called "small shocks, large cycles" puzzle [Bernanke et al. (1996)].

For all the shocks estimated for the EA, except for the investment-specific technology and the price mark-up shocks, the financial accelerator effect embedded in the SWGK model is indeed amplified compared with that in the SWBGG model, as shown by Figures 3 and 4. The propagation mechanism of the capital quality shock—which is the main driver of GDP at all horizons, as shown in Table 7—is as follows. In the SWBGG model the capital quality shock affects only the demand side of the credit market through two main mechanisms: (1) because of the simulated recession, there is a fall in asset prices and the return on capital, causing a downward shift in the demand for capital; (2) the fall in net worth due to the reduction in the return on capital, of capital and the price of capital, causes an increase in leverage. This leads to a rise in the spread, and hence a further fall in investment. The fall in net worth is persistent, because this variable is well

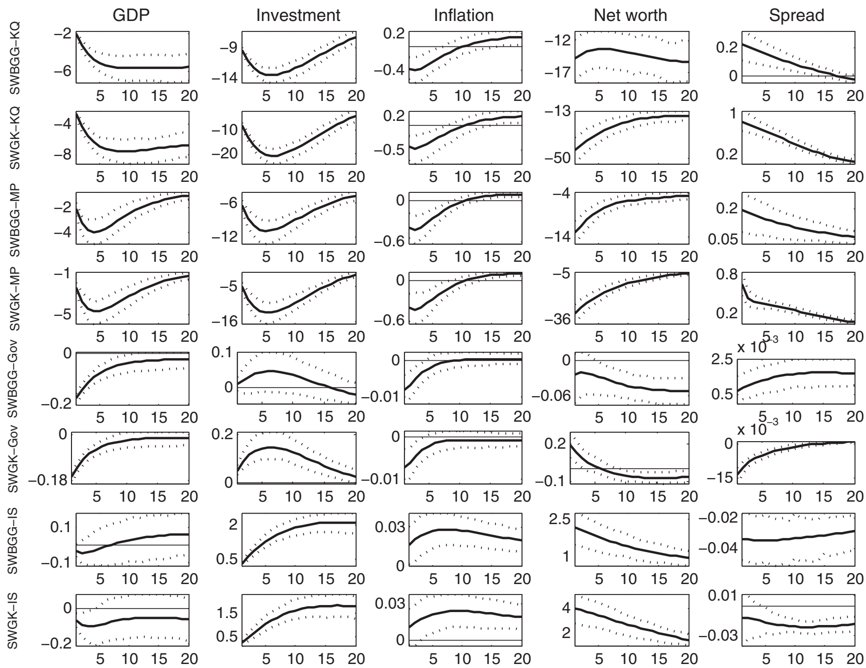

FIGURE 3. EA estimated impulse responses in the SWBGG and SWGK models to the following shocks: capital quality (KQ), monetary policy (MP), government spending (Gov), and investment-specific technology (IS). Solid lines represent mean IRF, and dashed lines represent the 95% confidence intervals. The size of the shocks is normalized to one standard deviation.

below steady state after 20 quarters. In the SWGK a capital quality shock directly translates into a shock to banks' balance sheets because of the identity between capital and assets. Because of the presence of moral hazard, depositors require banks not to be overleveraged. Hence they are forced to reduce lending. The reduction in the lending volume makes the incentive constraint tighter, leading to a higher spread and, hence, to a higher profitability. Compared with the SWBGG model, the increase of the spread from its steady state is much larger. On one hand, net worth tends to rise back to its steady state. On the other, nonfinancial firms observe a rise in borrowing costs and consequently reduce their demand for capital. The fall in investment is indeed much more pronounced in the SWGK model.

A contractionary monetary policy shock is shown in the third and fourth rows of Figure 3. Although the signs of the impact responses are similar between the models, the transmission mechanism is different. In both models an increase in the nominal interest rate reduces investment and therefore output. Demand downward pressures feed through changes in the output gap to inflation. This

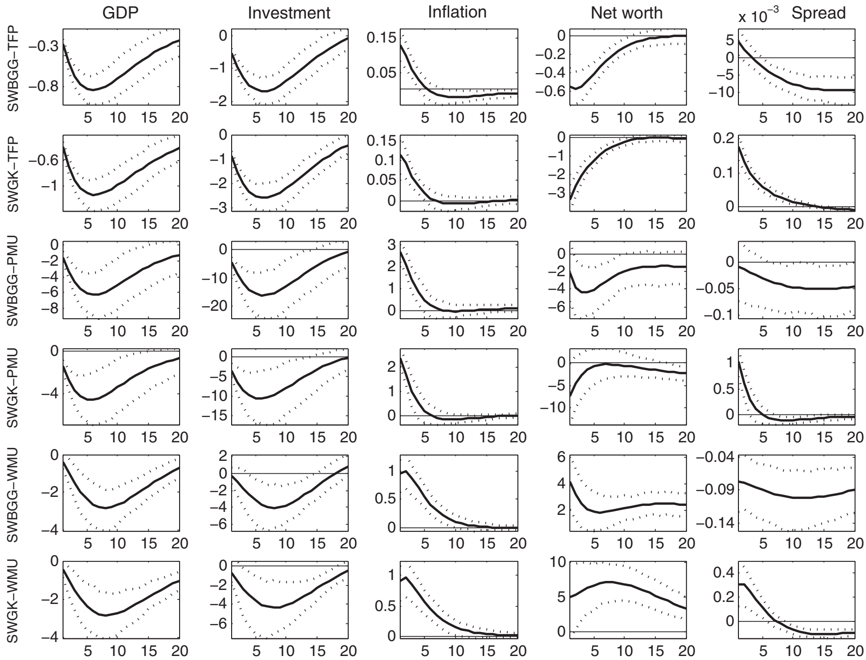

FIGURE 4. EA estimated impulse responses in the SWBGG and SWGK models to the following shocks: TFP, price mark-up (PMU), and wage mark-up (WMU). Solid lines represent mean IRF, and dashed lines represent the 95% confidence intervals. The size of the shocks is normalized to one standard deviation.

causes a downward shift in aggregate demand, which reduces inflation on impact. This standard transmission mechanism of the monetary policy shock is enhanced through its impact on credit markets. In the SWBGG model the decline in the price of capital due to the tightening of monetary policy causes a fall in the net worth of intermediate goods firms. This implies that the potential divergence of interests between firms and lenders is greater and therefore agency costs increase. As a result, the rise in the spread further reinforces the simulated contraction in capital and investment. In the SWGK model, because of the retrenchment in investment, loans decrease as well. At the same time, the fall in asset prices worsens FIs' balance sheets. The deterioration in intermediary balance sheets pushes up the spread. The increase in financing costs causes a further decline in loans and investment.

The contractionary government spending shock leads to a positive wealth effect, leading to a crowding-out effect on consumption and investment. As is evident from Table 7, this shock plays a marginal role in affecting all the variables at any horizon.

A more detailed explanation is needed for the investment-specific technology shock, depicted in the last two rows of Figure 3. This shock causes a rise in the

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TABLE 7. Variance decomposition for the EA

	Structural shocks						
Horizon	TFP	Gov. spending	Mon. policy	Invest. specific	Capital quality	Wage mark-up	Price mark-up
				Output			
1	19.4; 29.1	15.3; 12.2	11.1; 13.6	1.5; 4.2	48.8; 37.9	0.5; 0.5	3.4; 2.6
4	27.7; 37.1	2.8; 1.9	8.9; 11.1	0.5; 2.4	52.1; 41.9	1.9; 1.6	6.2; 4.0
8	27.7; 37.6	1.1; 0.7	6.2; 8.3	0.2; 1.4	55.1; 45.7	3.1; 2.6	6.6; 3.6
20	18.4; 29.7	0.5; 0.3	3.4; 5.2	0.6; 0.9	70.8; 59.3	2.6; 2.7	3.7; 2.0
40	11.4; 20.7	0.3; 0.2	2.2; 3.5	1.2; 1.3	81.1; 71.1	1.6; 1.9	2.3; 1.3
Uncon.	7.8; 12.6	0.2; 0.1	1.5; 2.2	1.5; 2.1	86.3; 81.1	1.1; 1.1	1.5; 0.8
				Investment			
1	12.1; 23.5	0.0; 0.2	8.4; 11.0	24.1; 10.3	51.0; 52.1	0.1; 0.2	4.3; 2.6
4	13.0; 23.5	0.0; 0.2	6.4; 9.2	32.3; 15.8	42.9; 48.2	0.4; 0.5	5.0; 2.5
8	11.6; 21.8	0.0; 0.2	4.6; 7.4	44.5; 24.7	34.4; 43.2	0.6; 0.7	4.3; 2.0
20	5.6; 14.0	0.0; 0.1	2.2; 4.2	73.2; 52.1	16.8; 28.0	0.4; 0.6	1.8; 0.9
40	3.2; 9.1	0.0; 0.1	1.2; 2.8	79.1; 67.6	15.1; 19.4	0.3; 0.4	1.1; 0.6
Uncon.	2.0; 6.9	0.0; 0.1	0.7; 2.1	77.7; 65.4	18.7; 24.9	0.2; 0.3	0.7;0.5
				Spread			
1	0.3; 44.8	0.0; 0.7	4.4; 8.0	66.9; 1.1	27.6; 30.1	0.9; 2.1	0.0; 13.3
4	0.1; 38.3	0.0; 0.6	3.8; 6.8	72.2; 2.1	22.9; 41.9	1.0; 2.6	0.0; 7.8
8	0.2; 31.6	0.0; 0.5	3.2; 7.3	77.4; 4.4	17.9; 48.3	1.3; 2.0	0.1; 5.9
20	0.8; 25.7	0.1; 0.4	2.3; 7.5	85.3; 12.1	9.7; 47.2	1.7; 2.2	0.1; 4.9
40	1.1; 24.5	0.1; 0.4	1.7; 7.1	85.4; 16.3	10.0; 44.8	1.7; 2.4	0.1; 4.6
Uncon.	0.9; 24.3	0.1; 0.4	1.3; 7.0	73.1; 17.0	23.4; 44.4	1.3; 2.3	0.1; 4.6

Note: The first number refers to the SWBGG model whereas the second refers to the SWGK model.

price of capital, Q_t, which has two opposite effects in the SWBGG model, as also explained by Kamber et al. (2012): (i) investment falls as well as output; and (ii) net worth of firms increases because of the higher return on capital [equation (16a) in Table 1]. The latter effect causes a fall in the spread. This in turn determines an increase in investment. This latter effect dominates in the estimated model and investment rises. Hence this shock does not replicate the positive co-movement between output and investment, at least on impact. Moreover, it accounts for most of the forecast error variance of investment at longer horizons, as is evident from Table 7. This result can explain why both the SWBGG and SWGK models fail to replicate the cross-correlation of investment with output reported in Table 6. In addition, contrary to empirical evidence [e.g., Aliaga-Diaz and Olivero (2011); Agénor et al. (2014)], this shock causes a procyclical response of the spread. This result is particularly interesting when combined with the variance decomposition analysis. The investment-specific technology shock explains 73% of the unconditional variance decomposition of the spread in the SWBGG model, and more than 80% of the variance decomposition of the spread at longer horizons. Hence, it could be argued that in this model, investment and the spread, important variables in explaining the financial accelerator mechanism, are explained by a "counterintuitive" shock. In the SWGK model, an investment-specific technology shock exerts three main effects: (i) the price of capital rises, causing a fall in investment and output; (ii) the retrenchment in investment leads to a lower demand for lending, affecting in turn banks' profits; and (iii) net worth of FI rises because of the higher return on capital, equation (20b) in Table 1. The first two effects act in the direction of reducing investment, whereas the last effect—which turns out to be quantitatively more important—leads to a rise in investment. Overall, the contractionary effect in output prevails. Similarly to the SWBGG model, the spread falls. Table 7 shows that investment-specific technology shock explains 17% of the unconditional variance decomposition of the spread and even lower fractions at different horizons. And this shock, although it is the main driver of investment fluctuations, in particular at longer horizons, explains a smaller fraction of its fluctuations compared to the SWBGG model. This difference is evident at all the horizons. The minor importance of the investment-specific technology shock—in particular on investment and on the spread—provides some explanation for the better fit of the SWGK model reported in the previous section.

The technology shock, shown in Figure 4, has a direct impact on output by making factors less productive, and leads to an increase in prices because of the contraction in aggregate supply. Investment and consumption decline because of the contraction in output. In the SWBGG model the lower return on capital and the decrease in the price of capital affect the net worth of firms, which decreases. There is a moderate rise of the spread, which contributes to the fall in investment. In the SWGK model the decrease in asset prices also worsens the FI's balance sheet. This deterioration leads to an increase in the spread, and hence in profits. This makes it possible for net worth to come back to steady state faster than in the SWBGG model. The higher borrowing costs discourage the demand for borrowing, leading to a further and a more pronounced retrenchment in investment.

A positive price mark-up shock exerts a contractionary effect on real activity, leading to a decline in output, investment, and consumption. The inflation rate increases and, because the Taylor rule is operating, this leads to a rise in the nominal interest rate. This shock tends to reduce both the return on and the price of capital. Hence, net worth of firms in the SWBGG model and of FI in the SWGK model falls.

The role of the price mark-up shock in explaining variations in real and financial variables is very limited in both models, as shown by Table 7. A similar argument applies to the wage mark-up shock: it leads to an increase in the prices of factors of production, causing a fall in their equilibrium quantity. This exerts a contractionary effect on output, as shown by the last two rows of Figure 4. The rise in prices is accompanied by a rise in the nominal interest rate. Differently from the price mark-up shock, the wage rises. This causes an increase in the marginal product of capital, Z^k, as also evident from equation (8) in Table 1. This, in turn, leads

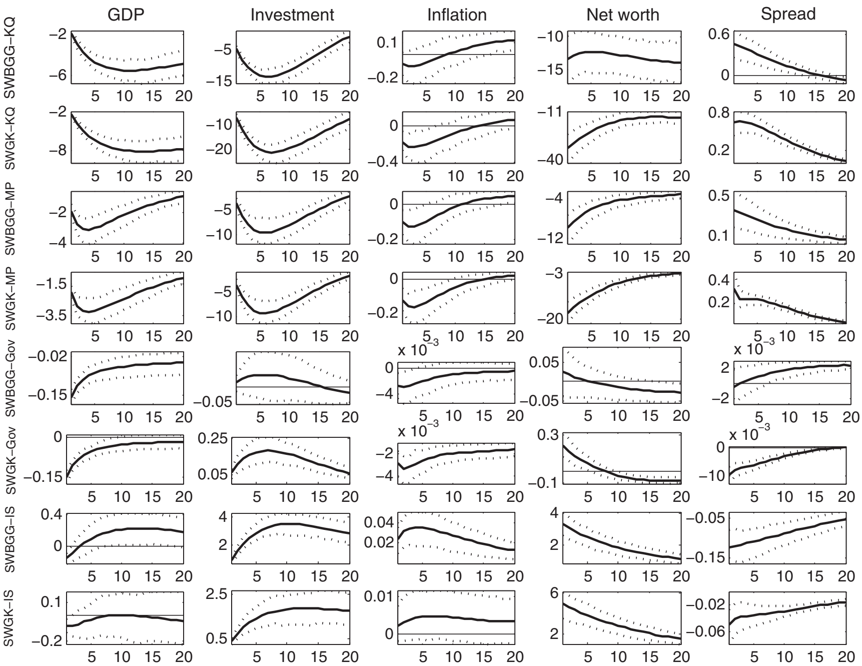

FIGURE 5. US demand shocks: capital quality (KQ), monetary policy (MP), government spending (Gov). Solid lines represent mean IRF, and dashed lines represent the 95% confidence intervals. The size of the shocks is normalized to one standard deviation.

to a temporary rise in the return on capital and, hence, in net worth in both the SWBGG and SWGK models. In the former, the rise in net worth and the fall in leverage explains the procyclical response of the spread, which falls as in Gelain (2010). In the SWGK model, instead, the spread exhibits countercyclical behavior. Similarly to the price mark-up, the wage mark-up shock plays a marginal role in accounting for fluctuations in real and financial variables.

The impulse responses estimated for the US, Figures 5 and 6, replicate transmission mechanisms similar to the ones observed in the EA. However, the financial accelerator effect of the monetary policy shock on output is slightly larger in the SWBGG model than in the SWGK model. There are two explanations for this result: first, the larger persistence of the monetary policy shock, equal to 0.27 in the SWBGG model and to 0.23 in the SWGK model; and, second, the different financial structures of the two areas. In the EA the main fraction of external finance of the corporate sector is constituted by bank loans. Hence, a monetary policy shock transmitted through the bank lending channel has a stronger impact on real activity in the EA than in the US, where the corporate sector has access to markets in addition to financial intermediaries [e.g., Ciccarelli et al. (2013)]. The analysis of the variance decomposition points to results similar to those for the

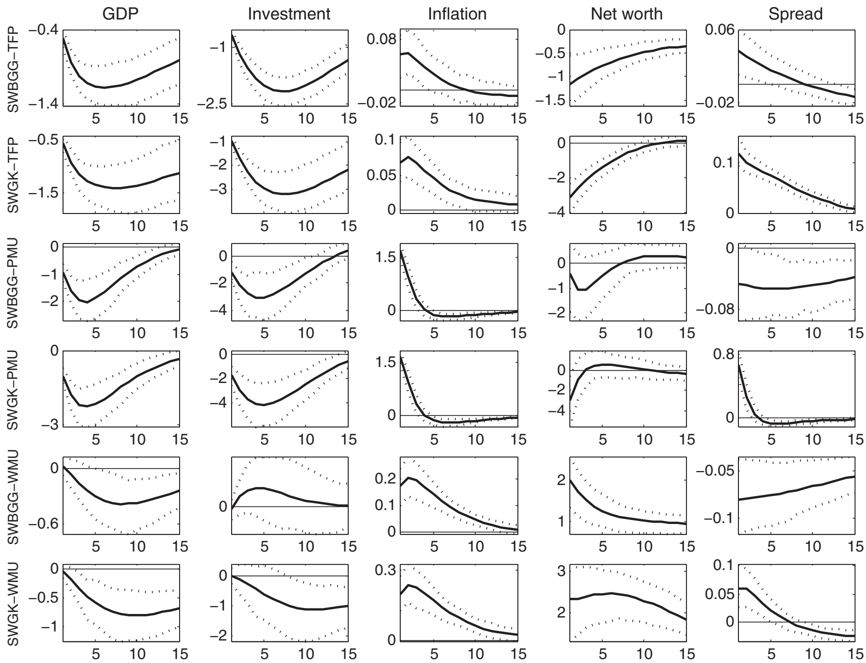

FIGURE 6. US supply shocks: TFP, price mark-up (PMU), and wage mark-up (WMU). Solid lines represent mean IRF, and dashed lines represent the 95% confidence intervals. The size of the shocks is normalized to one standard deviation.

EA: the investment-specific technology shock accounts for more than 60% of the forecast error variance of the spread in the SWBGG model, whereas it accounts for 16% of the variance of the spread in the SWGK model, as is evident from Table 8. The same shock is the main driver of investment in the SWBGG model—both in terms of unconditional variance decomposition and at longer horizons. In the SWGK model, instead, the capital quality shock is the main driver of investment. As is evident from impulse responses, the investment-specific technology shock features procyclical behavior of the spread and a countercyclical behavior of investment, contrary to the empirical evidence. Hence, its larger role in the SWBGG model could explain the better fit of the SWGK model for the US economy also.

Overall, two main factors could provide some explanations for the better fit of the SWGK model. First, financial intermediaries provide a more powerful endogenous mechanism of amplification because of the more pronounced effect on the spread after a contractionary shock. Second, the important role of investment-specific technology shock in explaining investment and the spread in the SWBGG model is likely to explain the lower fit of the model itself.

TABLE 8. Variance decomposition for the US

	Structural shocks						
Horizon	TFP	Gov. spending	Mon. policy	Invest. specific	Capital quality	Wage mark-up	Price mark-up
				Output			
1	9.7; 12.4	27.3; 25.2	13.2; 14.4	0.0; 3.0	47.1; 41.7	0.0; 0.0	2.6; 3.4
4	12.8; 15.9	6.2; 5.0	11.4; 11.7	1.4; 1.0	64.5; 61.4	0.2; 0.6	3.6; 4.4
8	11.3; 14.5	2.7; 1.9	7.7; 7.8	3.4; 0.4	72.4; 71.5	0.4; 1.3	2.1; 2.6
20	7.5; 9.9	1.2; 0.6	4.0; 3.8	5.8; 0.1	80.5; 83.3	0.3; 1.4	0.8; 0.9
40	5.5; 6.4	0.9; 0.4	2.9; 2.3	6.3; 0.4	83.6; 89.2	0.3; 0.9	0.5; 0.5
Uncon.	4.9;4.0	0.9;0.2	2.6;1.4	6.1; 1.4	84.8; 92.1	0.2; 0.6	0.5;0.3
				Investment			
1	2.9; 6.7	0.1; 0.9	8.5; 8.1	34.8; 11.5	52.2; 71.2	0.8; 0.0	0.8; 1.6
4	3.1; 7.1	0.1; 0.9	7.4; 7.0	39.5; 13.7	48.8; 70.0	0.5; 0.1	0.7; 1.3
8	3.1; 7.3	0.1; 0.9	6.2; 5.9	45.9; 16.9	44.0; 68.0	0.3; 0.2	0.5; 0.9
20	2.5; 6.5	0.0; 0.7	4.4; 4.1	62.6; 28.6	30.0; 59.4	0.2; 0.4	0.2; 0.5
40	1.9; 5.2	0.0; 0.6	3.2; 3.2	61.8; 42.7	32.7; 47.8	0.2; 0.3	0.2; 0.4
Uncon.	1.4; 3.4	0.0; 0.4	2.4; 2.1	58.7; 40.9	37.2; 52.8	0.2; 0.2	0.1;0.3
				Spread			
1	0.6; 8.2	0.0; 1.8	5.9; 5.5	52.4; 11.7	39.4; 47.4	1.7; 0.9	0.1; 24.5
4	0.5; 7.7	0.0; 1.7	5.5; 4.7	56.5; 10.8	35.6; 64.6	1.9; 0.9	0.1; 9.6
8	0.3; 6.8	0.0; 1.5	5.1; 5.0	61.4; 11.5	30.9; 68.3	2.1; 0.6	0.1; 6.3
20	0.3; 5.9	0.1; 1.3	4.4; 5.1	69.5; 14.8	22.8; 67.0	2.7; 0.8	0.2; 5.1
40	0.5; 6.0	0.3; 1.3	3.8; 4.9	67.5; 15.8	25.2; 66.1	2.6; 1.0	0.1; 4.9
Uncon.	0.5; 5.9	0.3; 1.3	3.5; 4.8	63.4; 15.9	29.8; 66.1	2.5; 1.0	0.1; 4.9

Note: The first number refers to the SWBGG model, whereas the second refers to the SWGK model.

4.4. Forecasting Accuracy

This subsection evaluates the two models from a forecasting viewpoint. Following Kolasa et al. (2012) and Bekiros and Paccagnini (2014, in press), the out-of-sample forecast performance is based on four horizons—ranging from one up to four quarters ahead. The recursive forecasting estimate considers the evaluation period from 2001Q1 to 2007Q4 (with 28 forecast periods in the last recursive sample). The root-mean-squared forecast error (RMSFE) is used to evaluate point forecasts. In particular, RMSFEs are computed based on recursive estimation sample starting from 1983Q1–2000Q4 and ending in 1983Q1–2007Q4 ($h = 1$), 1983Q1–2007Q3 ($h = 2$), 1983Q1–2007Q2 ($h = 3$), and 1983Q1–2007Q1 ($h = 4$), respectively.

Table 9 reports the RMSFEs for the two models and the two economies for the following variables: GDP growth, investment growth, inflation, and the nominal interest rate. As far as the EA is concerned, the accuracy of output growth forecasts from the SWGK model is significantly higher than that from the SWBGG model

TABLE 9. Root-mean-squared forecast errors of unconditional forecasts with different horizons

	SWBGG				SWGK			
Horizon	1	2	3	4	1	2	3	4
				EA				
GDP growth	0.93	0.78	0.90	0.91	0.71	0.67	0.72	0.67
Investment growth	2.54	2.17	2.20	2.13	1.44	1.55	1.49	1.40
Inflation (GDP price index)	0.73	0.68	0.66	0.60	0.81	0.72	0.65	0.57
Nominal interest rate	1.58	1.53	1.48	1.45	1.57	1.50	1.42	1.35
				US				
GDP growth	0.91	0.90	0.85	0.73	0.94	0.93	0.83	0.73
Investment growth	2.26	2.25	2.04	1.62	2.41	2.24	2.06	1.56
Inflation (GDP price index)	0.34	0.40	0.43	0.42	0.33	0.38	0.42	0.41
Nominal interest rate	1.38	1.31	1.26	1.23	1.37	1.31	1.27	1.22

at all horizons. A similar result also holds for forecasts of investment growth, where the forecasting accuracy of the SWGK model is even higher in percentage terms than that of GDP growth. For inflation forecasts results are mixed, although the difference is not very pronounced: the RMSFEs from the SWBGG model are lower in the first and second horizons, whereas for the other horizons the RMSFEs from the SWGK model are lower. The SWGK model performs better in terms of forecasting the nominal interest rate. Overall, the SWGK model outperforms the SWBGG model in forecasting real as well as nominal variables, with the exception of shorter horizon forecasts of inflation.

In the US there is no clear evidence of an outperformed model in terms of forecasting accuracy. The values of the RMSFEs are remarkably similar across the two models. The RMSFEs for GDP growth are lower in the SWBGG model at shorter horizons and in the SWGK model at longer horizons. Results are mixed also for the RMSFEs for investment growth, whereas inflation forecasts are better in the SWGK model at all horizons. For the nominal interest rate RMSFEs from the two models almost coincide.

5. CONCLUSION

Since the onset of the financial crisis, the link between financial intermediation and real activity has received increasing attention both in academia and in policy institutions. This paper provides an empirical comparison of DSGE models that have a Smets and Wouters (2007) economy in common but feature different types of financial frictions: the SWBGG model with financial frictions originating in intermediate goods firms because of a costly state verification problem à la Bernanke et al. (1999) and the SWGK model with financial frictions embedded in financial intermediaries because of a moral hazard problem à la Gertler and Karadi

(2011). The main result is that the SWGK model is always favored both by EA and US data. The reasons for the better empirical performance of the SWGK are mainly two: first, impulse response function analysis reveals that the presence of the banking sector acts as a powerful amplification channel for the shocks hitting the economy. This is caused by the different effect of a change in the spread on the relevant net worth in the models. As a result, the financial accelerator effect embedded in the SWGK model is stronger than that in the SWBGG model. Second, the investment-specific technology shock plays a different role in the two models, both in the EA and in the US. In particular, it explains a larger fraction of the dynamics of the spread and investment in the SWBGG model than of those in the SWGK model. However, this shock does not replicate the co-movement between output and investment and the countercyclical behavior of the spread. Hence, its larger role in the SWBGG model provides another reason for the better empirical performance of the SWGK model. This paper also finds that introducing frictions affecting the banking sector tends to improve the quality of point forecasts of GDP growth, investment growth, and the nominal interest rate in the EA. In the US, instead, neither model clearly dominates the other in terms of forecasting accuracy and the root-mean-squared forecast errors are remarkably similar across the two models.

The results presented in this paper offer some avenues for future research. First, it would be interesting to analyze a model featuring both types of financial frictions, at the firms level and in the banking sector, in order to examine the transmission mechanism of the shocks and the accelerator/attenuator effects. And second, such a model could also incorporate the same form of financial friction (costly state verification or moral hazard at both levels) in order to empirically verify which modeling device is preferred by the data. DSGE models with a comprehensive structure of financial markets would improve our understanding of business cycle fluctuations.

NOTES

1. Following Christensen and Dib (2008), consumption of exiting firms—a small fraction of total consumption—is ignored in the general equilibrium.

2. More details are presented in the Online Appendix available at https://sites.google.com/site/stefaniavilla3/research.

3. The Smets and Wouters (2007) model features a risk premium shock, which is meant to proxy frictions in the process of financial intermediation (not explicitly modeled). Because the SWBGG and SWGK models provide an explicit microfoundation for financial frictions, the risk premium shock has been replaced with the financial shock proposed by Gertler and Karadi. Exercises for the EA [Villa (2013)]—with a different filtering technique—show that the main result of the paper still holds in the presence of the risk premium shock instead of the capital quality shock.

4. Compared with Gertler and Karadi (2011), the higher value of the steady state spread is targeted with a higher calibration of the parameter λ.

5. Version 4.3.3 of the Dynare toolbox for Matlab is used for the computations. For details on the Bayesian estimation procedure see Fernández-Villaverde (2010), among others.

6. In a calibrated real business cycle model, Villa (2012) shows that capital utilization plays a limited role in amplifying the effects of the shocks hitting the economy. It should also be noted that

parameter ζ is a transformation of parameter ψ, estimated by Smets and Wouters (2003): $\zeta = 1/(1+\psi)$. Following Smets and Wouters (2007), the parameter $\zeta \in [0, 1]$ is estimated.

7. Queijo von Heideken (2009) finds that financial frictions are high in the EA than in the US because the estimates of monitoring costs are higher in the first country. Our estimation strategy is not necessarily in contrast with her results. Following Meier and Muller (2006), Kamber et al. (2012), and Fernández and Gulan (in press), from the value of the elasticity it is possible to trace out the values of the deep parameters of the financial contract, which are also consistent with the calibrated parameters shown in Tables 2 and 3. As far as the EA is concerned, these values are a share of monitoring costs equal to 0.22 and a standard deviation of the idiosyncratic shock to firms' return equal to 0.25; the resulting quarterly business failure rate is 0.02/4. For the US they are a share of monitoring costs equal to 0.17 and a standard deviation of the idiosyncratic shock to firms' return equal to 0.32; the resulting quarterly business failure rate is 0.025/4.

8. Such a comparison is based on the marginal likelihood of alternative models. Let m_i be a given model, with $m_i \in M$, θ the parameter vector, and $p_i(\theta|m_i)$ the prior density for model m_i. The marginal likelihood for a given model m_i and common dataset Y is

$$L(Y|m_i) = \int_\theta L(Y|\theta, m_i) p_i(\theta|m_i) d\theta,$$

where $L(Y|\theta, m_i)$ is the likelihood function for the observed data Y conditional on the parameter vector and on the model and $L(Y|m_i)$ is the marginal data density. The Bayes factor is the ratio between the marginal likelihoods. The log data density of the three models is computed with the Geweke (1999) modified harmonic mean estimator.

9. Theoretical moments are computed from the state-space representation for 1, 000 random draws from the posterior distributions—which produce 1, 000 sets of theoretical moments. Data are linearly detrended.

10. Because the models fail in replicating the relative standard deviations of interest rate and—to a minor extent—of inflation, there could be some doubt on the overall ability of the models to fit the data. As a robustness check, the models are then estimated allowing for measurement errors in inflation and wages, as well as for a moving-average component in the price and wage mark-up shocks. In this case there is indeed an improvement in the ability of the models to replicate the relative standard deviation of inflation and, to a minor extent, the nominal interest rate. The log data density reveals that the ranking of the reestimated models is not affected and the SWGK model is still the preferred one. Details are available in Online Appendix C. An alternative way to improve the relative standard deviations of inflation and interest rate could be to include innovations to trend inflation in the NK Phillips curve, as suggested by Cogley and Sbordone (2008).

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