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HOW IMPORTANT ARE FINANCIAL FRICTIONS IN THE U.S. AND EURO AREA?

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Abstract

This paper aims to evaluate the importance of frictions in credit markets for business cycles in the U.S. and the Euro area. For this purpose, I modify the DSGE financial accelerator model developed by Bernanke, Gertler and Gilchrist (1999) and estimate it using Bayesian methods. The model is augmented with frictions such as price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. My results indicate that financial frictions are relevant in both areas. Using the Bayes factor as criterion, the data favors the model with financial frictions both in the U.S. and the Euro area in five different specifications of the model. Moreover, the size of the financial frictions is larger in the Euro area.

Keywords: DSGE models; Bayesian estimation; financial accelerator
JEL: E3, E4, E5

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1 Introduction

The works of Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997), where endogenous procyclical movements in entrepreneurial net worth magnify investment and output fluctuations, constitute the corner stone of most recent theoretical papers with financial frictions.[1] Bernanke, Gertler, and Gilchrist (1996) develop the so-called financial accelerator, a mechanism based on information asymmetries between lenders and entrepreneurs that creates inefficiencies in financial markets, which affect the supply of credit and amplify business cycles. Specifically, during booms (recessions), an increase (fall) in borrowers' net worth decreases (increases) the borrowers' cost of obtaining external funds, which further stimulates (destimulates) investment amplifying the effects of the initial shock. The financial accelerator approach has become widely spread in the literature and many studies have introduced these types of frictions in DSGE models (Bernanke, Gertler, and Gilchrist (1999), henceforth BGG; Christiano, Motto, and Rostagno (2004)). The same idea has been used in growth models (Aghion, Bacchetta, and Banerjee (2004), Aghion, Howitt, and Mayer-Foulkes (2003)) as well as in open economy models (Gertler, Gilchrist, and Natalucci (2003), Gilchrist, Hairault, and Kempf (2002)).

Despite the ample theoretical work based on the financial accelerator, little has been done when it comes to the econometric estimation of these models. I only know of four papers estimating closed economy models with a financial accelerator. Christiano, Motto, and Rostagno (2004) estimate a DSGE model with a financial accelerator but they fix the parameters related to the financial frictions and use the same calibration as in BGG. They ask which shocks had a more important role in the Great Depression and if a different monetary policy could have moderated the crisis. Christensen and Dib (2004) estimate the standard BGG model for the U.S. using maximum likelihood and find evidence in favor of the financial accelerator model. Meier and Muller (2005) use minimum distance estimation based on impulse responses to estimate a model with financial accelerator in the U.S., and find that financial frictions do not play a very important role in the model. Levin, Natalucci, and Zakrajsek (2004) use nonlinear least squares to estimate the structural parameters of a canonical debt contract model with informational frictions. Using microdata for 900 U.S. firms over the period 1997Q1 to 2003Q3, they reject the null hypothesis of frictionless financial markets.

Given the paucity of empirical work on the financial accelerator, the purpose of this paper is to answer two basic questions. First, I want to determine

[1] There exists a large literature emphasizing the role of financial frictions in business cycles, see Kiyotaki and Moore (1997), Greenwald and Stiglitz (1993).

if a model with frictions in financial markets delivers a better description of the data than a model without such frictions, even if realistic frictions in goods and labor markets are added to the model. Second, I want to investigate if the magnitude of financial frictions is similar in the U.S. and the Euro area. One motivation for this is the existence of a common perception that financial markets are more developed in the U.S., and consequently, more efficient.

To answer these questions, I modify the standard BGG model and estimate it using Bayesian methods for U.S. and European data. Specifically, I extend the BGG model introducing price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. One benefit of using Bayesian methods is that we can include prior information about the parameters, especially information about structural parameters from microeconomic studies. Another benefit is related to the fact that some parameters have a specific economic interpretation and a bounded domain, which can be incorporated in the priors.

The paper contributes to the existing literature in two main respects. First, it empirically investigates the importance of frictions in credit markets for business cycles both in the U.S. and the Euro area, and second, it uses Bayesian methods to estimates a DSGE model with a financial accelerator.

The results indicate that financial frictions are relevant in both areas. Using the so-called Bayes factor as the evaluation criterion, I find that the data favors the model with financial frictions both in the U.S. and the Euro area. This is true for all five specifications of the model. Moreover, consistent with common perceptions, the size of financial frictions is larger in the Euro area.

The rest of the paper is organized as follows. In Section 2, I describe an alternative to the standard BGG model which incorporates other frictions to the economy while maintaining the existence of financial frictions. This model is going to be our benchmark model. Section 3 presents the estimation methodology while Section 4 presents the results. In Section 5, I discuss the results. Section 6 concludes.

2 The Model

The specification of the model follows the work of BGG who incorporate financial market frictions through a financial accelerator mechanism in a general equilibrium model. The main idea of the financial accelerator is that there exits a negative relationship between the external financial premium (the difference between the cost of funds raised externally and the opportunity cost of funds) and the net worth of potential borrowers. The intuition is that firms with higher leverage (lower capital to net worth ratio) will have a greater probability of defaulting and will therefore have to pay a higher premium. Since net worth is procyclical (because of the procyclicality of profits and asset prices), the external finance premium becomes countercyclical and amplifies business cycles through an accelerator effect on investment, production and spending.

Moreover, and following the recent literature in DSGE models, I modify the original BGG model to improve its empirical performance by introducing a number of alternative real and nominal frictions commonly considered in the literature. More specifically, I allow for external habit formation in consumption, variable capital utilization and Calvo prices and wages with full indexation to previous period inflation. Christiano, Eichenbaum, and Evans (2005) show variable capital utilization and wage stickiness to be fundamental frictions for explaining inflation inertia and persistent, hump-shaped responses in output after policy shocks. The other frictions in the model help to account for the response of other variables such as consumption and investment. Then, I ask whether financial frictions are still empirically important.

Overall, the model is most similar to the one in Christiano, Motto, and Rostagno (2004), but with several differences. First, I do not include a banking sector.[2] Second, the return on deposits received by households is in real terms, while in their paper it is nominal, which allows for a 'debt deflation' effect. Third, capital is produced with different technology functions: I follow BGG by assuming the existence of adjustment costs in the production of capital, rather than costs of changing the investment flow. Fourth, in my model, variable capital utilization arises because of higher depreciation rates, while in their model high capital utilization gives rise to higher cost in terms of goods. Last, I introduce external habit formation in consumption, while Christiano, Motto, and Rostagno (2004) use internal habits.

There are seven types of agents in the model: households, retailers, wholesale sector, capital producers, entrepreneurs, financial intermediaries and government. The following subsections describe the behavior of these agents.

2.1 Households

Consider a continuum of monopolistically competitive individuals, indexed by j, whose total mass is normalized to unity. In each period, each of these households maximizes its expected lifetime utility choosing a final consumption good, c_t^j, nominal bonds, nb_{t+1}^j, and real deposits held at financial

[2] Even if I include financial intermediaries in my model, Christiano, Motto, and Rostagno (2004) consider a larger banking sector which manages different kinds of deposits and loans, and requires capital and labor services.

intermediates, d^j_{t+1}, which pay a real gross free risk rate r_t. Moreover, as in Erceg, Henderson, and Levin (2000), each household supplies differentiated labor services to the wholesale sector, l^j_t. Households discount the future at a rate β.

The representative household's period utility and budget constraint are:

$$U_t = \nu_t \left[\frac{1}{1-\sigma} \left(c^j_t - hc_{t-1} \right)^{1-\sigma} - \frac{\xi_t}{2} \left(l^j_t \right)^2 \right]$$

and

$$\frac{\mathrm{nb}^j_{t+1}}{p_t} + d^j_{t+1} + c^j_t = \frac{w^j_t}{p_t} l^j_t + r_{t-1} d^j_t + r^n_{t-1} \frac{b^n_{j,t}}{p_t} - t_t + \mathrm{div}_t,$$

where w^j_t is the nominal wage of household j, p_t is the nominal level of prices, t_t are lump sum taxes and div_t are dividends received from ownership of firms. ν_t and ξ_t are shocks to consumer preferences for intertemporal consumption and leisure respectively, which follow $AR(1)$ processes with mean equal to one.

The introduction of external habit formation in consumption mainly helps to account for the gradual and hump-shaped response of consumption observed in the data after a monetary policy shock.

Households also supply differentiated labor services to the wholesale sector, where the labor aggregator has the Dixit-Stiglitz form:

$$l_t = \left[\int_0^1 \left(l^j_t \right)^{1/(\tau_t+1)} dj \right]^{(\tau_t+1)}$$

and τ_t is a wage (net) mark up shock with mean τ (the steady state wage mark up). Firms minimize the cost of hiring a fixed amount of total labor given the different price of labor. The optimal demand for labor is:

$$l^j_t = \left(\frac{w_t}{w^j_t} \right)^{(\tau_t+1)/\tau_t} l_t.$$

Integrating this equation and imposing the Dixit-Stiglitz aggregator for labor, we can express the aggregate wage index as:

$$w_t = \left[\int_0^1 \left(w^j_t \right)^{-1/\tau_t} dj \right]^{-\tau_t}.$$

I assume that households can reset their wages with probability $(1-\vartheta)$ at each period. Whenever the household is not allowed to reset his wage contract, wages are set at $w^j_t = \pi_{t-1} w^j_{t-1}$, where π_{t-1} is the gross inflation in the last period. According to Christiano, Eichenbaum, and Evans (2005), wage stickiness plays a crucial role in the performance of the model. The first-order condition with respect to wages is:

$$
\begin{aligned}
& E_t \sum_{k=0}^{\infty} (\beta\vartheta)^k \nu_{t+k} \left(c^j_{t+k} - hc_{t-1+k}\right)^{-\sigma} \left(\frac{\widehat{w}^j_t}{p_{t+k}} l^j_{t+k} \left[\frac{1}{\tau_{t+k}}\right]\right) \\
= \; & E_t \sum_{k=0}^{\infty} (\beta\vartheta)^k \nu_{t+k} \xi_{t+k} \left(l^j_{t+k}\right)^2 \left[\frac{(\tau_{t+k}+1)}{\tau_{t+k}}\right].
\end{aligned}
$$

2.2 Final Good Sector

Firms in the final good sector produce a consumption good, y_t, in a perfectly competitive market, combining intermediate goods, y^s_t. The production function transforming intermediate goods into final output is the usual Dixit-Stiglitz aggregator given by:

$$
y_t = \left[\int_0^1 (y^s_t)^{1/(\lambda_t+1)}\, ds\right]^{(\lambda_t+1)},
$$

where $\lambda_t \geq 0$ is a mark up shock with mean λ. Firms take prices as given and choose y^s_t to minimize costs

$$
\min_{y^s_t} \int_0^1 p^s_t y^s_t \, ds
$$

subject to the Dixit-Stiglitz aggregator. The first-order conditions of this problem imply:

$$
y^s_t = \left(\frac{p_t}{p^s_t}\right)^{(\lambda_t+1)/\lambda_t} y_t.
$$

Integrating this equation and imposing the constraint, we can express the aggregate price index as:

$$
p_t = \left[\int_0^1 (p^s_t)^{-1/\lambda_t}\, ds\right]^{-\lambda_t}.
$$

2.3 Wholesale Sector

A variety of intermediate inputs are produced by a continuum of monopolistically competitive firms indexed by $s \in [0,1]$. Each firm hires the services of capital, k^s_t, and labor, l^s_t, to face the demand curve for its product. They rent capital from an entrepreneurial sector, which owns the capital stock.

Firms produce according to the following production function:

$$y_t^s = a_t \left(k_t^s\right)^{\alpha} \left(l_t^s\right)^{1-\alpha},$$

where a_t is a productivity shock which follows a first order autoregressive process with mean one. Firms choose capital and labor to minimize their total costs, taking factor prices as given. The minimization problem can be written as:

$$\min_{l_t^s, k_t^s} \frac{w_t}{p_t} l_t^s + z_t k_t^s$$

subject to the production function, and where z_t is the real rental price of capital.

Moreover, wholesale firms have market power and can choose prices to maximize expected profits with probability $1-\theta$ in each period (Calvo, 1983). As in the case of wages, firms that cannot choose prices index their prices according to last period's inflation rate: $p_t^s = \pi_{t-1} p_{t-1}^s$.

For those firms that can choose prices, $\widehat{p}_t$, the optimal first-order condition is:

$$\begin{aligned} & E_t \sum_{k=0}^{\infty} (\beta\theta)^k m_{t,t+k} y_{t+k} (1/\lambda_{t+k}) \left[\frac{\widehat{p}_t}{p_{t-1}\pi_{t+k}}\right]^{-1/\lambda_{t+k}} \\ = \; & E_t \sum_{k=0}^{\infty} (\beta\theta)^k m_{t,t+k} y_{t+k} (\lambda_{t+k}+1)/\lambda_{t+k} s_{t+k} \left[\frac{\widehat{p}_t}{p_{t-1}\pi_{t+k}}\right]^{-(\lambda_{t+k}+1)/\lambda_{t+k}}, \end{aligned}$$

where $\beta^k m_{t,t+k} = \beta^k \frac{u_c(t+k)}{u_c(t)}$ is the stochastic discount factor between periods t and $t+k$ and s_t is the real marginal cost. Profits are distributed to households.

2.4 Capital Producers

As in Christiano, Motto, and Rostagno (2004), the physical stock of capital, $\widetilde{k}_t$ (where the t subscript indicates when capital is actually used), is produced by a continuum of competitive firms indexed by j. Households own these firms and receive any profits or losses as lump-sum transfers. However, while Christiano, Motto, and Rostagno (2004) assume there to be a cost of changing the flow of investment, I follow the more standard literature on investment adjustment costs, and assume there to exist increasingly marginal adjustment costs in the production of capital: investment expenditures, i_t^j, deliver $\Phi\left(\frac{i_t^j}{\widetilde{k}_t^j}\right)\widetilde{k}_t^j$ new capitals goods. Following BGG, I also assume investment decisions to be determined one period in advance. This assumption helps to account for a gradual response of investment to shocks affecting the real interest rate, a feature observed in the data. Capital producers solve the following problem:

$$\max_{i_{t+1}^j} E_t \left[q_{t+1} \Phi\left(\frac{i_{t+1}^j}{\widetilde{k}_{t+1}^j}\right) \widetilde{k}_{t+1}^j - i_{t+1}^j \right],$$

where q_{t+1} is the relative price of capital, and near the steady state $\Phi > 0$, $\Phi'(.) > 0$, $\Phi''(.) < 0$. I also assume that in steady state, the relative price of capital is one.

The law of motion of the aggregate capital stock is:

$$\widetilde{k}_{t+1} = \Phi\left(\frac{i_t}{\widetilde{k}_t}\right)\widetilde{k}_t + (1-\delta(u_t))\widetilde{k}_t,$$

where u_t is the rate of capital utilization[3], $\delta(u_t) \in (0,1)$ is a convex depreciation function with $\delta'(.) > 0$, and $\delta''(.) > 0$ around the steady state. I choose the function $\delta(u_t)$ such that $\delta(0) = 0$, $\delta(\infty) = 1$ and in steady state $\delta(1) = \delta$.[4]

2.5 Entrepreneurs and Financial Intermediaries

Entrepreneurs own the physical stock of capital, $\widetilde{k}_t$, and provide capital services, k_t. They finance capital purchases both with their own net worth and debt. Capital services are related to the physical stock of capital by:

$$k_t = u_t\widetilde{k}_t.$$

Entrepreneurs are risk neutral and have finite horizons, being γ the probability of survival to the next period. This assumption rules out the possibility of entrepreneurs accumulating enough wealth to be fully self-financed: part of their capital must be financed through bank loans with a standard debt contract.

At the end of period t, entrepreneurs decide how much to borrow. Then, at the beginning of period $t+1$, after observing all the shocks, they choose how intensely to use their capital.

2.5.1 Optimal Contract

As in BGG, the return on capital depends on both aggregate and idiosyncratic shocks. The ex post return on capital for entrepreneur i is $\omega^i_{t+1} r^k_{t+1}$, where ω^i is an *i.i.d.* lognormal random variable with pdf $F(\omega)$ and mean one.[5] The riskiness of entrepreneurs is determined by the variance of the idiosyncratic shock, σ_ω. The average return of capital in the economy is:

$$r^k_{t+1} = \frac{u_{t+1}z_{t+1} + (1-\delta(u_{t+1}))q_{t+1}}{q_t}.$$

[3] u_t can take any value ≥ 0, where values greater than one mean that there exists over utilization of capital.

[4] One example of this kind of function can be $\delta(u_t) = 1 - \frac{1+p}{p+\exp^{\varepsilon u_t}}$ with $p, \varepsilon > 0$. In this case, $\delta(0) = 0$, $\delta(\infty) = 1$, $\delta(1) = 1 - \frac{1+p}{p+\exp^{\varepsilon}} = \delta$. However, I focus on a more general case of functional forms and I estimate $\delta''_{ss}/\ \delta'_{ss}$.

[5] As in Christiano, Motto, and Rostagno (2004), I assume that after entrepreneurs purchase capital, they draw an idiosyncratic shock which changes $\widetilde{k}^i_{t+1}$ to $\omega^i_{t+1}\widetilde{k}^i_{t+1}$.

Entrepreneurs finance their capital stock at the end of period t with their own net worth at the end of the period, n^i_{t+1}, and banks loans, b^i_{t+1}:[6]

$$q_t \widetilde{k}^i_{t+1} = n^i_{t+1} + b^i_{t+1}.$$

The entrepreneur borrows from a financial intermediary that obtains its funds from households, with an opportunity cost equal to the riskless gross rate of return, r_t. In equilibrium, the intermediary holds a pooled, and perfectly safe, portfolio and the entrepreneurs absorb any aggregate risk.

Following a "costly state verification" problem of the type analyzed by Townsend (1979), in which lenders must pay a fixed auditing cost to observe an individual borrower's realized return, BGG assume monitoring costs to be a proportion μ of the realized gross payoff to the firms' capital[7], i.e., monitoring costs equals $\mu\omega^i_{t+1} r^k_{t+1} q_t \widetilde{k}^i_{t+1}$[8]. When $\mu = 0$, we are in the special case of frictionless financial markets.

The optimal contract will be incentive compatible, characterized by a schedule of state contingent threshold values of the idiosyncratic shock ϖ^i_{t+1}, such that for values of the idiosyncratic shock greater than the threshold, the entrepreneur is able to repay the lender, and for values below the threshold, the entrepreneur declares default and the lender obtains $(1-\mu)\,\omega^i_{t+1} r^k_{t+1} q_t \widetilde{k}^i_{t+1}$. Only one-period contracts between borrowers and entrepreneurs are feasible.

Under these assumptions, the optimal contract is chosen to maximize expected entrepreneurial utility, conditional on the expected return of the lender, for each possible realization of r^k_{t+1}, being equal to the riskless rate, r_t. In Appendix A, it is shown that the following two first-order conditions must hold in the optimal contract between entrepreneurs and banks[9]:

$$E_t \left\{ \left(1 - \Gamma(\varpi^i_{t+1})\right) \frac{r^k_{t+1}}{r_t} + \lambda(\varpi^i_{t+1}) \left[\left(\Gamma(\varpi^i_{t+1}) - \mu G(\varpi^i_{t+1})\right) \frac{r^k_{t+1}}{r_t} - 1 \right] \right\} = 0$$

and

$$\left[\Gamma(\varpi^i_{t+1}) - \mu G(\varpi^i_{t+1})\right] r^k_{t+1} q_t \widetilde{k}^i_{t+1} = r_t \left[q_t \widetilde{k}^i_{t+1} - n^i_{t+1} \right],$$

where $\mu G(\varpi^i_{t+1}) = \mu \int_0^{\varpi^i_{t+1}} \omega dF(\omega)$ is expected monitoring costs, $\Gamma(\varpi^i_{t+1}) = \left(1 - F(\varpi^i_{t+1})\right)\varpi^i_{t+1} + G(\varpi^i_{t+1})$ is the expected gross share of profits going to the lender, and $\lambda(\varpi^i_{t+1}) = \frac{\Gamma'(\varpi^i_{t+1})}{\Gamma'(\varpi^i_{t+1}) - \mu G'(\varpi^i_{t+1})}$.

---

[6] The relevant price of capital at the end of period t is q_t.

[7] Levin, Natalucci, and Zakrajsek (2004) estimate μ to be time varying.

[8] The relevant price here is q_t since capital price gains are included in r^k_{t+1}.

[9] For more details, see BGG (1999).

From this first first-order condition, we see that when financial markets are frictionless, $\mu = 0$, $\lambda(\varpi_{t+1}^{i}) = 1$ and $E_t r_{t+1}^{k} = r_t$: the ex-ante return on capital equals the risk free rate when there are no monitoring costs. The second first-order condition is related to the fact that the financial intermediary receives an expected return equal to the opportunity cost of its funds. In this case, the lender's expected return can simply be expressed as a function of the average cutoff value of the firm's idiosyncratic shock, ϖ_{t+1}.

Since the entrepreneur is risk neutral, he only cares about the mean return on his wealth. He guarantees the lender a return that is free of any systematic risk: conditional on r_{t+1}^{k}, he offers a state-contingent contract that guarantees the lender a return equal in expected value to the riskless rate.

From these two equations, aggregation is straightforward and it can be shown that capital expenditures by each entrepreneur i are proportional to his net worth. Aggregate entrepreneurial net worth (in consumption units) at the end of period t, n_{t+1} is given by:

$$n_{t+1} = \gamma \left\{ r_t^k q_{t-1} \widetilde{k}_t - \left[r_{t-1} \left(q_{t-1} \widetilde{k}_t - n_t \right) + \mu \int_0^{\varpi_t} \omega dF(\omega) r_t^k q_{t-1} \widetilde{k}_t \right] \right\} + w^e,$$

where γ is the fraction of entrepreneurs surviving to the next period, and w^e are net transfers to entrepreneurs. At each period, a fraction $(1 - \gamma)$ of new entrepreneurs enters the market receiving some transfers and the wealth of the fraction that did not survive is given to the government.

2.5.2 Optimal Capital Utilization Decision

After observing the shocks at the beginning of period $t+1$, entrepreneurs decide how intensively to use their capital. Higher capital utilization is costly because of higher depreciation rates.[10] This is an important assumption because it allows for variable capital utilization, a relevant feature in the data. Entrepreneurs choose capital utilization, u_{t+1} to solve

$$\max_{u_{t+1}} \left[\frac{u_{t+1} z_{t+1} + (1 - \delta(u_{t+1})) q_{t+1}}{q_t} \right].$$

2.6 Government

Government consumption expenditures, g_t, follow a first order autoregressive process. The government finances its expenditures by lump sum taxes, t_t, and nominal bonds, nb_{t+1}.

[10] This approach has been used by Baxter and Farr (2001), among others.

2.7 Competitive Equilibrium

In a competitive equilibrium all the above optimality conditions are satisfied. In addition, markets clear. The aggregate resource constraint is

$$y_t = c_t + i_t + g_t + \mu \int_0^{\overline{\omega}_t} \omega dF(\omega) r_t^k q_{t-1} \widetilde{k}_t,$$

Final goods are allocated to consumption, investment, government expenditure and monitoring costs[11]. Furthermore, credit markets clear and $b_t = d_t$.

Finally, the monetary authority conducts monetary policy by controlling the gross nominal interest rate, r_t^n. For convenience, I assume a cashless economy, but the monetary authority can set the interest rate directly in the interbank market. The Central Bank follows a Taylor type rule of the form

$$r_t^n = H(r_{t-1}^n; E_t(\pi_{t+1}); y_t; \varepsilon_t^r),$$

where ε_t^r is a monetary policy shock and π_{t+1} is inflation in $t+1$.

2.8 The log-linearized model

To solve the model, I loglinearize the equilibrium conditions around their steady state values. The model can then be written in terms of three blocks of linear equations where letters with a hat represent log deviations from the steady state at time t, and letters without a subscript represent the steady state values of the variables.

2.8.1 Equilibrium conditions

The loglinearized versions of aggregate demand and supply are:

$$\widehat{y}_t = \frac{c}{y}\widehat{c}_t + \delta\frac{\widetilde{k}}{y}\widehat{i}_t + \frac{g}{y}\widehat{g}_t + \frac{\mu G(\varpi) r^k \widetilde{k}}{y}(\widehat{r}_t^k + \widehat{q}_{t-1} + \widehat{\widetilde{k}}_t) + \frac{\mu r^k G'(\varpi)\widetilde{k}\varpi}{y}\widehat{\varpi}_t \quad (2.1)$$

and

$$\widehat{y}_t = \widehat{a}_t + \alpha\widehat{k}_t + (1-\alpha)\widehat{l}_t, \quad (2.2)$$

where δ is the steady state capital depreciation.

Next, I write the consumption Euler equation, equation (2.3); the arbitrage condition for nominal bonds, equation (2.4); and the law of motion of real wages, equation (2.5)[12]:

$$\widehat{c}_t = \frac{(1-h)}{\sigma(1+h)}(\widehat{\nu}_t - E_t\widehat{\nu}_{t+1}) + \frac{h}{(1+h)}\widehat{c}_{t-1} - \frac{(1-h)}{\sigma(1+h)}\widehat{r}_t + \frac{E_t\widehat{c}_{t+1}}{(1+h)}, \quad (2.3)$$

[11] The last term is the loss in monitoring costs associated with defaulting entrepreneurs.

[12] This is the same notation as in Christiano, Eichenbaum, and Evans (2005) but a wage mark up has been introduced and the mark up is in net terms.

$$\widehat{r}_t^n = \widehat{r}_t + E_t\widehat{\pi}_{t+1}, \tag{2.4}$$

$$E_t\left\{\eta_0\widehat{w}_{t-1}^r + \eta_1\widehat{w}_t^r + \eta_2\widehat{w}_{t+1}^r + \eta_3\hat{\pi}_{t-1} + \eta_4\hat{\pi}_t + \eta_5\hat{\pi}_{t+1} + \eta_6\widehat{l}_t + \eta_7\left(\widehat{c}_t - h\widehat{c}_{t-1}\right) + \eta_8\widehat{\xi}_t + \eta_9\widehat{\tau}_t\right\} = 0, \tag{2.5}$$

where $b_w = [(\tau+1)+\tau] / [(1-\vartheta)(1-\beta\vartheta)]$ and

$$\eta = \begin{pmatrix} b_w\vartheta \\ -b_w\left(1+\beta\vartheta^2\right)+(\tau+1) \\ \beta\vartheta b_w \\ b_w\vartheta \\ -\vartheta b_w(1+\beta) \\ b_w\beta\vartheta \\ \tau \\ \tau\sigma(1-h)^{-1} \\ \tau \\ \tau\frac{\tau}{\tau+1} \end{pmatrix} = \begin{pmatrix} \eta_0 \\ \eta_1 \\ \eta_2 \\ \eta_3 \\ \eta_4 \\ \eta_5 \\ \eta_6 \\ \eta_7 \\ \eta_8 \\ \eta_9 \end{pmatrix}.$$

These three equations are derived from the households' first-order conditions. τ is the net wage mark up in steady state; $\widehat{\nu}_t$ is the preference shock, and $\widehat{\xi}_t$ is the labor supply shock.

The demand for labor and capital in the wholesale sector, where factor prices are equal to marginal productivity plus real marginal cost, $\widehat{s}_t$, are given by:

$$\widehat{y}_t - \widehat{l}_t + \widehat{s}_t = \widehat{w}_t^r \tag{2.6}$$

and

$$\widehat{s}_t + \widehat{y}_t - \widehat{k}_t = \widehat{z}_t. \tag{2.7}$$

A Phillips curve can be derived from the wholesale sector optimization problem for prices, where $(1-\theta)$ is the probability of adjusting prices and λ is the net price mark up in steady state:

$$\widehat{\pi}_t = \frac{\widehat{\pi}_{t-1}}{(1+\beta)} + \frac{\beta}{(1+\beta)}E_t\widehat{\pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{(1+\beta)\theta}\widehat{s}_t + \frac{(1-\theta)(1-\beta\theta)}{(1+\beta)\theta}\frac{\lambda}{(\lambda+1)}\widehat{\lambda}_t. \tag{2.8}$$

Capital producers' optimality condition is:

$$E_t\widehat{q}_{t+1} + \varphi\left[\widehat{i}_{t+1} - \widehat{\widehat{k}}_{t+1}\right] = 0. \tag{2.9}$$

This equation links asset prices and investment, where $\varphi = \Phi''\left(\frac{i}{k}\right)\left(\frac{i}{k}\right)$ is the elasticity of the price of capital with respect to the investment-capital ratio.

The equilibrium conditions of the entrepreneurs are:

$$E_t \widehat{r}^k_{t+1} - \widehat{r}_t = E_t \widehat{\varpi}_{t+1} \varpi \frac{r^k}{r} \left(1 - \Gamma(\varpi)\right) \left[\frac{\Gamma''(\varpi)}{\lambda(\varpi)\Gamma'(\varpi)} - \frac{\Gamma''(\varpi)}{\Gamma'(\varpi)} + \frac{\mu G''(\varpi)}{\Gamma'(\varpi)} \right], \tag{2.10}$$

$$\left[(1 - F(\varpi)) - \mu G'(\varpi)\right] \frac{\widetilde{k}}{n} \frac{r^k}{r} \varpi \widehat{\varpi}_{t+1} + \left[\frac{\widetilde{k} - n}{n} \right] (\widehat{r}^k_{t+1} - \widehat{r}_t) = \widehat{\widetilde{k}}_{t+1} + \widehat{q}_t - \widehat{n}_{t+1}, \tag{2.11}$$

$$\widehat{k}_t = \widehat{u}_t + \widehat{\widetilde{k}}_t, \tag{2.12}$$

and

$$\widehat{z}_{t+1} = \frac{\delta''(1)}{\delta'(1)} \widehat{u}_{t+1} + \widehat{q}_{t+1}. \tag{2.13}$$

Equations (2.10) and (2.11) are the first-order conditions of the optimal lending contract derived in Appendix A.[13] Equation (2.12) relates capital services to the capital stock, while equation (2.13) is the optimality condition for capital utilization.

The loglinearized return on capital is:

$$\widehat{r}^k_{t+1} = \frac{z}{r^k} \widehat{z}_{t+1} + \frac{(1-\delta)}{r^k} \widehat{q}_{t+1} - \widehat{q}_t. \tag{2.14}$$

Equations (2.15) and (2.16) are the law of motion of net worth and capital respectively:

$$\widehat{n}_{t+1} = \gamma \left\{ \begin{array}{c} \left(\frac{\widetilde{k} - \mu G(\varpi)\widetilde{k}}{n}\right) r^k \widehat{r}^k_t + \left(\frac{r^k \widetilde{k} - \widetilde{k} r - \mu G(\varpi) r^k \widetilde{k}}{n}\right) \widehat{q}_{t-1} + \left(\frac{r^k - r - \mu G(\varpi) r^k}{n}\right) \widetilde{k} \widehat{\widetilde{k}}_t \\ - \left(\frac{\widetilde{k} - n}{n}\right) r \widehat{r}_{t-1} + r \widehat{n}_t - \left(\frac{\mu r^k G_w \widetilde{k}}{n}\right) \varpi \widehat{\varpi}_t \end{array} \right\} \tag{2.15}$$

and

$$\widetilde{k}_{t+1} = \delta \widehat{i}_t + (1-\delta) \widetilde{k}_t - \delta'(1) \widehat{u}_t. \tag{2.16}$$

2.8.2 Monetary policy rule

The loglinearized monetary policy rule is:

$$\widehat{r}^n_t = \rho^r \widehat{r}^n_{t-1} + (1-\rho^r)(\gamma^\pi E \widehat{\pi}_{t+1}) + (1-\rho^r)(\gamma^y \widehat{y}_t)/4 + \widehat{\varepsilon}^r_t. \tag{2.17}$$

[13] In the model without financial frictions, $\mu = 0$, and these equations and the law of motion of net worth are:

$$E_t \widehat{r}^k_{t+1} = \widehat{r}_t,$$

$$\left[(1 - F(\varpi))\right] \frac{\widetilde{K}}{N} \varpi \widehat{\varpi}_{t+1} + \left[\frac{\widetilde{K} - N}{N} \right] (\widehat{r}^k_{t+1} - \widehat{r}_t) = \widehat{\widetilde{k}}_{t+1} + \widehat{q}_t - \widehat{n}_{t+1},$$

and

$$\widehat{n}_{t+1} = \gamma R \left\{ \left(\frac{\widetilde{K}}{N}\right) \widehat{r}^k_t - \left(\frac{\widetilde{K} - N}{N}\right) \widehat{r}_{t-1} + \widehat{n}_t \right\}.$$

The first equation shows that without monitoring costs, the ex-ante risk premium is zero.

2.8.3 Shock Process

There exist seven shocks in the model:

$$\widehat{\varepsilon}_t^r = \varepsilon_t^r, \tag{2.18}$$

$$\widehat{\lambda}_t = \varepsilon_t^\lambda, \tag{2.19}$$

$$\widehat{\tau}_t = \varepsilon_t^\tau, \tag{2.20}$$

$$\widehat{\xi}_t = \rho^\xi \widehat{\xi}_{t-1} + \varepsilon_t^\xi, \tag{2.21}$$

$$\widehat{\nu}_t = \rho^\nu \widehat{\nu}_{t-1} + \varepsilon_t^\nu, \tag{2.22}$$

$$\widehat{g}_t = \rho^g \widehat{g}_{t-1} + \varepsilon_t^g, \tag{2.23}$$

and

$$\widehat{a}_t = \rho^a \widehat{a}_{t-1} + \varepsilon_t^a, \tag{2.24}$$

where ε_t^i are white noise shocks affecting the economy.

Equations (2.18)-(2.20) are the monetary policy, price mark up and wage mark up shocks. I specify these shocks as white noise shocks. The rest of the shocks in the model, to labor supply, preferences, government spending and technology follow a first-order autoregressive process. I choose this specification for the shocks to avoid identification problems.

2.8.4 Solution Method

To solve the model, I use the method described in Sims (2000) and his matlab code gensys.m. The loglinearized model can be written as

$$\Gamma_0 X_t = \Gamma_1 X_{t-1} + \Psi V_t + \Pi \eta_t,$$

where V_t is a vector of exogenous random disturbances, and η_t is a vector of expectational errors with mean zero.

2.9 The Standard BGG Model

When estimating the model, I start out with the standard BGG model and then add four frictions not present in that model: price indexation to past inflation, sticky wages, external habit formation in consumption and variable capital utilization. I add these frictions cumulatively, one by one. Once all four frictions have been added, I obtain the benchmark model described earlier in this section. For each of the five versions, I estimate the model both with and without monitoring costs.

The intention of this exercise is to check the robustness of the results when other commonly used frictions are included. Moreover, we want to see which frictions are more relevant to fit the data.

To fix ideas, I will next describe the four main differences between the benchmark model described in this section and the standard BGG model.[14]

First, in the standard BGG model, firms that are not allowed to reoptimize prices do not index their prices to past inflation. Equation (2.8) becomes:

$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{(1+\beta)\theta}\widehat{s}_t + \frac{(1-\theta)(1-\beta\theta)}{(1+\beta)\theta}\frac{\lambda}{(\lambda+1)}\widehat{\lambda}_t,$$

where inflation does not depend on past inflation as in the benchmark model and I have added a price mark up shock. I include price indexation in the benchmark model since this introduces a lagged inflation term component in inflation which generates inflation inertia, an aspect observed in the data.

Second, in the standard BGG model, wages are flexible, and equation (2.5) becomes the standard consumer first-order condition with respect to labor:

$$\widehat{w}_t^r - \sigma(1-h)^{-1}(\widehat{c}_t - h\widehat{c}_{t-1}) = \widehat{\xi}_t + \widehat{l}_t + \frac{\tau}{\tau+1}\widehat{\tau}_t,$$

where I have added the existence of wage mark up shocks.

Third, households do not exhibit external consumption habits, $h = 0$ and equation (2.3) becomes the standard Euler equation plus a preference shock:

$$\widehat{c}_t = \frac{1}{\sigma}(\widehat{\nu}_t - E_t\widehat{\nu}_{t+1}) - \frac{1}{\sigma}\widehat{r}_t + E_t\widehat{c}_{t+1}.$$

The introduction of consumption habits mainly helps to account for the gradual and hump-shaped response of consumption observed in the data.

Fourth, since there is not variable capital utilization, equation (2.13) is replaced by $\widehat{u}_t = 0$ and the depreciation rate is constant. Introducing variable capital utilization helps to offset the fluctuations in labor productivity and affects the marginal cost, which is reflected in a more gradual response of prices.

The rest of the equations are those presented in Section 2.8.

3 Methodology for Estimation and Model Evaluation

The model has a total of 30 free parameters. Seven of these are calibrated to their steady state values, as they cannot be identified from the detrended data.

[14] Another difference is that in the original BGG model, there are only three shocks affecting the economy: monetary policy, government and technology shocks. Moreover, the interest rate rule only responds to past inflation.

The steady state rate of depreciation of capital δ is set equal to 0.025, which corresponds to an annual rate of depreciation of ten percent. The discount factor β is set at 0.99, which corresponds to an annual real rate in steady state of four percent. The steady state share of government spending was set equal to 19.5 percent[15]. The parameter of the Cobb-Douglas function, α, was set equal to 0.33, while the steady state price mark up, λ, was set at 20 percent. These values imply steady state consumption and investment ratios of 60.9 and 19.6 percent in models without financial frictions[16]. Moreover, the steady state wage mark up, τ, was set equal to five percent, and the steady state probability of default, $F(\varpi)$, equal to three percent per year, the same value as BGG.

The remaining 23 parameters are estimated using Bayesian procedures. The advantage of Bayesian estimation relative to maximum likelihood (the only realistic alternative), is that the solution of the model implies many restrictions and boundary values for the parameters which are difficult to impose using maximum likelihood. Besides, using Bayesian methods also makes it possible to formally incorporate our beliefs about the parameters.

I start by solving the model for an initial set of parameters. Then, the Kalman Filter is used to calculate the likelihood function of the data (for given parameters). Combining prior distributions with the likelihood of the data gives the posterior kernel which is proportional to the posterior density. Since the posterior distribution is unknown, we use Markov Chain Monte Carlo (MCMC) simulation methods to conduct inference about the parameters. Some of these aspects are discussed in the rest of this section.

3.1 Data

The data used for the estimation corresponds to seven variables of the model: real output, real consumption, real investment, hours worked, nominal interest rate, inflation and real wages.[17] In all the cases, I use quarterly detrended data. For the U.S., the data covers the period 1980Q1-2004Q1[18], while

[15] Since this number does not include transfers, we can assume the same value for the U.S. and the Euro area.

[16] In models with a financial accelerator, these ratios will also depend on the risk premium.

[17] I do not include any financial variables since to compare the model with and the one without financial frictions, the first will present a natural advantage in the case when these variables are included.

[18] U.S. data was taken from the Bureau of Economic Analysis of the U.S. Department of Commerce (BEA), the IMF database and the Bureau of Labor Statistics (BLS). Real output is measured by real GDP converted into per capita terms dividing by the population aged above sixteen (P16). Real consumption is real personal consumption expenditures divided by P16. Real investment is real gross private domestic investment also in per capita terms. Hours worked are measured by the product of average weekly hours in the private sector times

for the Euro area, it covers the period 1980Q1-2002Q4[19].

3.2 Prior Distribution

All prior distributions of the parameters were selected from the normal, beta, gamma and uniform distributions, depending on the different supports and characteristics of the parameters. The prior distributions are the same for the U.S. and the Euro area and are shown in Table 1.

Many of the priors are standard and follow the literature (Smets and Wouters (2004), Adolfson, Lasén, Lindé, and Villani (2004)). The relative risk aversion coefficient, σ, has a normal distribution with mode one; the habit persistence parameter, h, has a beta distribution with mode 0.70. The parameters determining prices and wages follow a beta distribution. The modes of the Calvo parameters θ and ϑ, the probability of not adjusting prices and wages, were set equal to 0.70, so that, on average, prices and wages adjust every ten months.

Some of the parameters are particular to the way I capture some frictions in the model. This is the case of the elasticity of the price of capital with respect to the investment-capital ratio, φ. There is no consensus about this parameter: BGG set it equal to -0.25 while King and Wolman (1996) use a value of -2 based on estimations of Chirinko (1993). Since there is not enough information about this parameter, I use a uniform prior distribution between -1 and 0. The prior for δ''/δ' is a gamma distribution with mode equal to one, following the calibrations of Baxter and Farr (2001).

Other non standard parameters in the model are those related to the fi-

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the population aged above twenty. The nominal interest rate is the Federal Funds Rate, and inflation is calculated as the difference of the GDP deflator. Real wages are measured by the average hourly earnings of production workers in real terms. All series were detrended with a linear trend and in the case of the interest rate, I used the same trend as inflation.

[19] European data was taken from the AWM database of the ECB. Real output is measured by real GDP converted into per capita terms dividing by the labor force. Real consumption is real consumption divided by the labor force. Real investment is real gross investment also in per capita terms. To calculate hours worked, I use data on total employment, and transform it into hours worked using the same criterion as Smets and Wouters (2003). They assume that in any period, only a constant fraction of firms, ξ_e, is able to adjust employment to its desired total labor input. This results in the following equation for employment:

$$\widehat{e}_t = \beta \widehat{e}_{t+1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{\xi_e}(\widehat{l}_t - \widehat{e}_t),$$

where $\widehat{e}_t$ is total employment. In contrast to them, I do not estimate ξ_e, but following their results and the results in Adolfson, Lasén, Lindé, and Villani (2004), I fix it equal to 0.70. The nominal interest rate is the quarterly short-term interest rate, and inflation is calculated as the difference of the GDP deflator. Real wages are measured by the wage rate deflated by the GDP deflator. All series were detrended with a linear trend and in the case of the interest rate, I used the same trend as inflation.

nancial frictions. Following BGG, the prior for monitoring costs, μ, was assumed to be beta distributed with mode equal to 0.12. The fraction of entrepreneurs surviving to the next period, γ, has a beta distribution with mode 0.975 which implies that on average, entrepreneurs live ten years. Finally, the prior for the steady state external risk premium (the difference between the cost of funds raised externally and the opportunity cost of funds), $r^k - r$, was set gamma distributed with a mode 0.005, which corresponds to an annual two percent risk premium as in BGG.

The priors for the parameters of the monetary policy rule are based on the estimates of Clarida, Gali, and Gertler (2000) for the post-82 period. The long run coefficients on inflation and output, γ^{π} and γ^{y}, are normally distributed with mode 1.5 and 0.5 respectively. The interest rate smoothing parameter, ρ_r, follows a beta distribution with mode 0.85.

Regarding the shocks affecting the economy, the autoregressive coefficients have a beta distribution with mode 0.85, while the standard deviations for the shocks follow a gamma distribution with mode 0.01 for the monetary, technology and government shocks, and 0.10 for the other shocks.

3.3 Posterior Distribution

I first estimate the mode of the posterior distribution maximizing the posterior density $p(\Omega \mid Y)$ with respect to the vector of parameters Ω and given the data Y. The objective is to maximize:

$$\log p(\Omega \mid Y) = \log p(Y \mid \Omega) + \log p(\Omega) - \log p(Y),$$

where $p(Y \mid \Omega)$ is the sample density or likelihood function, $p(\Omega)$ is the prior density of the parameters and $p(Y)$ is the marginal likelihood.

However, since $p(Y)$ does not depend on Ω, the posterior mode can be obtained maximizing (Hamilton (1994))[20]:

$$\log p(\Omega, Y) = \log p(Y \mid \Omega) + \log p(\Omega).$$

Markov Chain Monte Carlo (MCMC) simulation methods are used to obtain the posterior distribution. This is necessary since it is not possible to sample the parameters directly from the posterior distribution. The idea behind MCMC is to draw values of the parameters from an approximate distribution and then correct these draws to better approximate the posterior distribution. Starting from an initial arbitrary value of the parameters, the samples are drawn sequentially, such that each draw will depend on the previous value. The approximate distribution of the parameters is improved at each step of the simulation

[20] The RHS was maximized using Sims' code csminwel.

until it converges to the posterior. The posterior output can then be used to compute any posterior function of the parameters: impulse responses, moments, etc.

To perform the simulations, I used the so-called Metropolis-Hasting algorithm, which uses an acceptance/rejection rule to converge to the posterior distribution. The algorithm samples a proposal vector of parameters Ω from a jumping distribution $q(\Omega^{l+1} \mid \Omega^{l})$ and accepts the draw with probability $\kappa = \min\left\{\frac{p(\Omega^{l+1}|Y)/q(\Omega^{l+1}|\Omega^{l})}{p(\Omega^{l}|Y)/q(\Omega^{l}|\Omega^{l+1})}, 1\right\}$. If the new value of the parameters is rejected, then $\Omega^{l+1} = \Omega^{l}$. A random walk around the parameter space was used as the jumping function. In particular, I set $q(\Omega^{l+1} \mid \Omega^{l}) = N(\Omega^{l}, c^2\Sigma)$ where Σ is the inverse of the Hessian computed at the joint posterior mode, and c is a scale factor set to obtain efficient algorithms[21]. After the first round of simulations, the exercise was instead repeated setting Σ equal to the estimated covariance matrix. The purpose when choosing the scale factor was to tune the acceptance rate around 25 percent as suggested by Gelman, Carlin, Stern, and Rubin (2004).

To check convergence, I run different chains starting from dispersed points. Each set of estimates is based on two different chains starting from the mode of the posterior plus-minus two standard deviations, with a total of 100 000 draws in each simulation. Convergence was monitored by comparing the parameters variation between and within simulated sequences until 'within' variation approximates 'between' variation. The idea is that only when the distribution of each sequence is close to that of all sequences mixed together, all draws can be considered as coming from the same posterior distribution.

To be more specific, consider the between (B) and within (W) sequence variance of each parameter given by:

$$B = \frac{N}{S-1}\sum_{j=1}^{S}(\widehat{\Omega}_{\cdot j} - \widehat{\Omega}_{\cdot\cdot})^2, \text{ where } \widehat{\Omega}_{\cdot j} = \frac{1}{N}\sum_{i=1}^{N}\Omega_{ij} \text{ and } \widehat{\Omega}_{\cdot\cdot} = \frac{1}{S}\sum_{j=1}^{S}\widehat{\Omega}_{\cdot j}\ ,$$

and

$$W = \frac{1}{S}\sum_{j=1}^{S}{s_j}^2, \text{ where } {s_j}^2 = \frac{1}{N-1}\sum_{i=1}^{N}\ (\Omega_{ij} - \widehat{\Omega}_{\cdot j})^2,$$

where S is the number of sequences and N the number of draws in each sequence. The marginal posterior variance of each parameter will be a weighted average of W and B :

$$\widehat{var}(\Omega|Y) = \frac{N-1}{S}W + \frac{1}{N}B.$$

[21] Gelman, Carlin, Stern, and Rubin (2004) argue that within this class of jumping rules, the most efficient one has the scale coefficient $c \approx 2.4\sqrt{d}$, where d is the number of parameters to be estimated.

One way of checking convergence is to calculate the potential scale reduction:

$$\widehat{R} = \sqrt{\frac{\widehat{var}(\Omega|Y)}{W}}, \tag{3.1}$$

which declines to 1 as $N \to \infty$. If the potential scale reduction is high, one should proceed with further simulations to improve inference. This ratio was computed for all parameters.

Moreover, to avoid the effect of the starting points and given that eventually the distribution converges to the posterior, the first half of each sequence was ignored.

3.4 Model Comparison

To compare the performance of different models, their marginal data density must be calculated. Let us label a model with financial frictions by M_f and an alternative specification of the model without financial frictions by M_n. The marginal data density for each model will be:

$$p(Y \mid M_i) = \int p(Y \mid \Omega_i, M_i) p(\Omega_i \mid M_i) d\Omega_i,$$

where Ω_i is a vector of parameters of model i, $p(Y \mid \Omega_i, M_i)$ is the sample density of model i and $p(\Omega_i \mid M_i)$ is the prior density of the parameters for model i. The posterior probability for each model will be:

$$p(M_i \mid Y) = \frac{p(Y \mid M_i) p(M_i)}{\sum_i p(Y \mid M_i) p(M_i)}.$$

Bayesian model selection is done pairwise, comparing the models in terms of the posterior odds ratio:

$$PO_{i,j} = \frac{p(M_i \mid Y)}{p(M_j \mid Y)} = \frac{p(Y \mid M_i) p(M_i)}{p(Y \mid M_j) p(M_j)},$$

where the prior odds $\frac{p(M_i)}{p(M_j)}$ are updated by the Bayes factor, $B_{ij} = \frac{p(Y|M_i)}{p(Y|M_j)}$. Jeffreys (1961) suggested rules of thumb to interpret the Bayes factor as follows:

$B_{ij} < 1$	support for M_j
$1 < B_{ij} < 3$	very slight evidence against M_j
$3 < B_{ij} < 10$	slight evidence against M_j
$10 < B_{ij} < 100$	strong evidence against M_j
$B_{ij} > 100$	decisive evidence against M_j

One problem with this approach is how to compute the marginal likelihood, which is obtained by integrating the sample density with respect to the prior distribution. Following Geweke (1999), I use the modified harmonic mean to approximate the marginal likelihood. Gelfand and Dey (1994) show that for any pdf $f(\Omega)$ whose support Θ_m is contained in the parameter space, we have:

$$
\begin{aligned}
& E\left[\frac{f(\Omega_i)}{p(Y \mid \Omega_i, M_i)p(\Omega_i \mid M_i)} \mid Y, M_i\right] \\
= & \int_{\Theta_m} \frac{f(\Omega_i)}{p(Y \mid \Omega_i, M_i)p(\Omega_i \mid M_i)} p(\Omega_i \mid Y, M_i) d\Omega_i = p(Y \mid M_i)^{-1}.
\end{aligned}
$$

Based on this result, one can use the sample posterior mean of $\left[\frac{f(\Omega_i)}{p(Y|\Omega_i,M_i)p(\Omega_i|M_i)}\right]$ as an approximation for the inverse of the marginal density. Following Geweke (1999), I choose f multivariate normal with mean $\overline{\Omega} = N^{-1}\sum_{g=1}^{N}\Omega_g$ (estimated posterior mean) and variance $\widehat{\Sigma} = N^{-1}\sum_{g=1}^{N}(\Omega_g - \overline{\Omega})(\Omega_g - \overline{\Omega})'$. Moreover, to ensure that the domain of f is contained in the parameter space, the distribution is truncated to the region $\Theta_p = \left\{\Omega : (\Omega - \overline{\Omega})'\widehat{\Sigma}^{-1}(\Omega - \overline{\Omega}) \leq \chi^2_{1-p}(d)\right\}$, where d is the number of estimated parameters and all parameters subject to restrictions have been appropriately transformed.

4 Results

I first present the results for the U.S. and then for the Euro area. To check the relevance of the financial accelerator mechanism, I start estimating the standard BGG model. Then, I add, one at a time, price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. I reestimate the parameters of each alternative model with and without financial frictions.

4.1 U.S.

4.1.1 Frictions in the U.S.

In Table 2, I report the posterior mean of the parameters and the marginal data density for alternative models using U.S. data. In all specifications of the model, the Bayes factor is greater than 100, which is decisive evidence against the model without a financial accelerator. This extends the findings by Christensen and Dib (2004) who only estimate the standard BGG model with maximum likelihood and provide evidence in favor of a financial accelerator. In particular, the table shows that the estimated mean of monitoring costs in the benchmark case is twelve percent. This result is in line with the results of Levin, Natalucci, and Zakrajsek (2004). Using microdata for 900 U.S. firms over the period 1997Q1 to 2003Q3, they estimate that time varying monitoring cost moved between eight and sixteen percent between 1997 and 1999. When they smooth through a spike in 1998Q4, the average monitoring costs during this period is close to twelve percent. After the fall of the stock market in 2000, monitoring costs went up to reach values as high as forty percent, and then declined again in 2003.

Table 2 also indicates that the size of monitoring costs decreases once we introduce other frictions to the standard BGG model. In the standard BGG case, monitoring costs are almost twice as large as in the benchmark model. The intuition is that high monitoring costs are necessary for the standard BGG model to capture the dynamics of the data. Once other frictions are introduced, however, the data does not require such large financial frictions.

It is important to mention than when we add price indexation and sticky wages, the data marginal density decreases. This is probably due to the fact that in both cases I am imposing full indexation to past inflation. Smets and Wouters (2004) estimate that for the U.S., the mean degree of price and wage indexation is 0.34 and 0.75 respectively. In the model, I am constraining these parameters to be equal to unity in order to reduce the number of parameters to estimate.

4.1.2 Parameter Estimates for the U.S.

I will now only focus on the benchmark model, which includes all the frictions. Table 1 reports the mean, median and the 5th and 95th percentile of the posterior distribution of the benchmark model for U.S. data. Plotting the path of the different parameters along the chain, as well as the value of the posterior likelihood function, we see convergence to a stationary distribution. Moreover, when I calculate the potential scale reduction as in equation (3.1), this idea is confirmed by the results. The only parameter which presents some doubts is the variance of the wage mark up shocks, σ^{τ}. However, relatively small changes in the value of this parameter does not affect the properties of the model since it is multiplied by a very small number in the solution.

The estimated posterior mean of the risk premium in steady state, $rk-r$, implies an annual premium of 2.4 percent, which is in line with the value used by BGG and Christiano, Motto, and Rostagno (2004). Together with other parameters, this value implies that the investment and consumption output ratio in steady state are 17 and 63 percent respectively. Moreover, the fraction of GDP used in bankruptcy costs is around 0.4 percent, and the mean for the fraction of entrepreneurs who survive, γ, is 0.99, implying an average duration of entrepreneurs of 27 years.[22]

Table 1 indicates that the four autoregressive shocks affecting the economy present a high persistence, compared to the priors.

The coefficients describing consumer preferences do not differ substantially from the priors. The mean of risk aversion is 1.1 rather than one as the prior, and the habit persistence parameter has a posterior mean of 0.60 as compared to the prior mean of 0.70.

The posterior mean of θ implies that prices adjust on average once every fourteen months. This result implies more flexible prices than Smets and Wouters (2004). The same occurs with wages, where the average duration of contracts if estimated at only four months. Both the elasticity of capital price with respect to the investment capital ratio, φ, and the variable depreciation parameter, δ''/δ', have a similar posterior mean as the prior: -0.47 and 1.02 respectively.

Concerning the coefficients in the Central Bank instrument rule, all coefficients differ from the estimates of Clarida, Gali, and Gertler (2000). The coefficient on future inflation, γ^{π}, is higher while the coefficient on output, γ^{y}, and the interest rate smoothing parameter, ρ_r, are lower.

In the case of the same model but without monitoring costs (no financial accelerator), the estimation is robust for most of the parameters. However, the estimates of two parameters differ considerably. This is the case of the elasticity of the price of capital, φ, and the entrepreneurs' rate of survival, γ. Both these parameters are higher in the model with financial frictions. A possible explanation is that in a model with financial accelerator investment reacts more to shocks, which requires higher adjustment costs to match the dynamics of investment in the data. This implies that monitoring costs are not relevant because the model cannot explain investment behavior, but because monitoring costs help to explain other variables. Moreover, to ensure that self-financing never occurs, estimates of the probability of survival are lower in a frictionless credit market model.

To assess the model fit, Figure 5 shows the actual and one-side Kalman filter fitted data evaluated at the posterior mean for the benchmark model with and without monitoring costs. The model with financial frictions seems to better fit the data, which is in accordance to the Bayes factor criterion. Moreover, plotting the two-side Kalman filter estimated shocks in figure 6, we see that the model without financial accelerator has a weaker propagation mechanism: com-

[22] These values imply a elasticity of the external finance premium with respect to the leverage ratio of 0.055, which is in line with the value estimated by Christensen and Dib (2004)

pared to the model with monitoring costs, larger shocks are needed to explain the dynamics of the data.

4.2 Euro Area

4.2.1 Frictions in the Euro Area

In Table 3, I report the posterior mean and the marginal data density for alternative models using European data. Also for European data, the Bayes factor is greater than 100 in all five different specifications, which clearly favors a model with monitoring costs. In the benchmark case, the posterior mean of monitoring costs is 18 percent, fifty percent higher than the cost estimated for the U.S. This number is higher in almost all other specifications of the model, reaching values as high as 52 percent in the model with price indexation and sticky wages. Moreover, for each model, the estimated mean of monitoring costs is higher than in the U.S.

Considering the other frictions in the model, price indexation and variable capital utilization seem to be the most important ones.[23]

4.2.2 Parameter Estimates for the Euro Area

Table 1 also reports the mean, median and the 5th and 95th percentile of the posterior distribution of the benchmark model for European data. The value of the potential scale reduction indicates some convergence problems for the parameters governing variable capital depreciation and preference shocks. However, small changes in the value of these parameters do not affect the properties of the model when the impulse response functions are plotted.

The posterior distribution of the parameters using European data is in general very similar to that of the U.S. This indicates that the shocks driving the economy and the transmission mechanisms in the two areas are not too different. However, some parameters display more distinct differences.

The fact that monitoring costs are larger in the Euro area drives up the external risk premium: in the Euro area, the posterior mean of the annual risk premium is 3.6 percent in steady state. This implies that in steady state, the investment and consumption ratio to output are 15.6 and 64.3 percent, respectively, and that the fraction of GDP used in bankruptcy cost is 0.6 percent.

Concerning the size of the shocks affecting both economies, monetary shocks are smaller in the Euro area: the estimated mean value of monetary

[23] In the case of models without financial frictions, introducing variable capital utilization decreases the marginal data density. This result is in line with Adolfson, Lasén, Lindé, and Villani (2004), who find that a model without variable capital utilization delivers a higher marginal density for European data.

shocks is 145 basic points (annual) in the U.S., but only 92 basic points in the Euro area. This difference in monetary policy shocks among the U.S. and the Euro area have also been documented in Angeloni, Kashyap, Mojon, and Terlizzese (2003), Peerman and Smets (2001) and Smets and Wouters (2004). Another difference is that preference shocks are larger in the Euro area, while wage mark up shocks are smaller. When it comes to persistence, while technology shocks are slightly more persistent in the Euro area, government spending shocks are less persistent.

The mean of risk aversion in the Euro area is 1.2, which is higher than in the U.S. On the other hand, the parameter of consumption habit formation is smaller in the Euro area, and around 0.50.

Concerning price stickiness, prices adjust every six quarters on average. This implies that prices are more sticky in the Euro area, consistent with Peerman and Smets (2001), who find that the impact on prices after a monetary shock is faster in the U.S. Moreover, wage behavior is very similar to the U.S.: wages change every four months on average.

The elasticity of the price of capital with respect to the investment capital ratio, φ, is larger in Europe, with a mean value of -0.97. Given larger monitoring costs in the Euro area, the model requires higher adjustment costs in investment to dampen the response of investment after a shock. In the model, these two effects offset each other and investment responds similarly in the U.S. and the Euro area.

The coefficients in the monetary rule are similar in both areas, and different from the prior, suggesting that both areas have responded in a similar way to expected inflation and output in the last twenty years.

In Figure 7, I plot the actual and one-side Kalman filter fitted data of the benchmark model with and without monitoring costs. The figure shows that the model with a financial accelerator slightly better represents the actual data.

5 Discussion

The results show that frictions in financial markets are important in the U.S. and the Euro area. Moreover, the size of these frictions is larger in the case of the Euro area. This is in line with independent observations suggesting that financial markets are more developed and integrated in the U.S., and that the institutional and legal framework in the two areas differ. For example, Danthine, Giavazzi, Vives, and von Thadden (1999) argue that the legal differences among European countries, and the lack of a 'European corporate law', constitute an additional factor of market segmentation. These authors claim that the

European financial framework is not harmonized when it comes to law, taxation, and supervisory and regulatory institutions. Evidently, such discrepancies can easily translate into a less efficient credit market.

Moreover, the U.S. has a more fragmented banking sector than the Euro area and a larger number of publicly listed firms 'per capita', which may also imply a more transparent and competitive market.

A number of studies have documented these kinds of differences in financial markets on the two sides of the Atlantic. Table 4 shows the Thomson rating to be lower in the U.S., meaning a more efficient banking system. Moreover, while the return on assets is higher in the U.S., loan losses are lower, which is consistent with the results obtained in my estimation. Table 8 shows loan losses to be 0.10 and 0.32 percent in the U.S. and the Euro area, respectively. In the model, these numbers are identified by monitoring costs: the posterior mean of monitoring costs is 12 percent in the U.S. and 18 percent in the Euro area for the benchmark model.

The financial market structure can play an important role in the transmission mechanism of shocks and the decisions of firms. The fact that the Euro area presents more frictions in credit markets than the U.S. might generate different dynamics of investment. For example, with the rest of the parameters being equal, a model with larger monitoring costs has a greater response in investment to a monetary policy shock.

Figure 9 and 10 plot the impulse response function to a one standard deviation monetary shock of the benchmark model, with and without monitoring costs, in each of the two areas. In the absence of monitoring costs, both inflation and investment react much less to the shock. To facilitate comparison, Figure 11 shows the impulse response functions to a monetary policy shock of equal size in both economies, evaluated at the posterior mean for the benchmark model. Even though monitoring costs are larger in the Euro area, the response of investment is similar in both economies. In the model, this is due to higher investment adjustment costs in the Euro area, which offset the larger credit frictions. In that sense, frictions in credit markets are not a good explanation for the 'output composition puzzle' described in Angeloni, Kashyap, Mojon, and Terlizzese (2003). These authors find that while the response patterns to a monetary policy shock are similar in the U.S. and the Euro area, there is a noticeable difference in the composition of output changes. In the U.S., consumption is the predominant driver of output changes after a monetary shock, while in the Euro area it is investment. Figure 11 shows that even though there exist higher financial frictions in the Euro area, this does not imply a different response of output, investment or consumption after a monetary policy shock.

Figure 11 also shows that higher monitoring costs imply a different propagation mechanism of inflation, real wages and the external risk premium. To check that this is not caused by other parameters in the model, I perform a counterfactual analysis. In Figure 12, I plot the impulse response function to a monetary policy shock of the estimated model for the U.S. (evaluated at the mean of the posterior) and the same exercise only changing the value of three parameters: monitoring costs, steady state risk premium and investment adjustment costs. I set these three parameters equal to their mean estimates for the Euro area. The figure suggests that larger monitoring costs in Europe are not related to a different transmission mechanism of investment. Moreover, the existence of higher monitoring costs implies a higher response of the costs of funds in the Euro area.

6 Conclusions

I study an extended version of the BGG model augmented with other frictions, such as price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. This model is estimated using Bayesian techniques for both the U.S. and the Euro area.

The results indicate that financial frictions are relevant in both areas, but quantitative more important in the Euro area. This suggests that the financial market structure can play an important role in the transmission mechanism of shocks and the decisions of firms. The fact that the Euro area presents more frictions in credit markets might be considered to generate different dynamics in investment as compared to the U.S. In actual fact, however, the response of investment is similar in both economies. In the model, this is due to higher investment adjustment costs in the Euro area, which offset the larger credit frictions. Higher financial frictions in the Euro area do generate different responses of prices, wages and the external risk premium, though.

Future research should investigate the robustness of these results to alternative ways of specifying financial frictions. The financial accelerator mechanism is certainly a popular device to account for informational frictions in financial markets, but not the only one.

7 Bibliography

Adolfson, M., S. Lasén, J. Lindé, and M. Villani (2004): "Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through," *Working Paper.*

Aghion, P., P. Bacchetta, and A. Banerjee (2004): "Financial Development and the Instability of Open Economies," *Journal of Monetary Economics*, 51(6), 1077–1106.

Aghion, P., P. Howitt, and D. Mayer-Foulkes (2003): "The Effect of Financial Development on convergence: Theory and Evidence," *Unpublished Manuscritp.*

Angeloni, I., A. Kashyap, B. Mojon, and D. Terlizzese (2003): "The Output Composition Puzzle: A Difference in the Monetary Transmission Mechanism in the Euro Area and U.S.," *European Central Bank, Working Paper N. 268.*

Baxter, M., and D. Farr (2001): "Variable Factor Utilization and International Business Cycles," *National Bureau of Economic Research Working Paper 8392.*

Bernanke, B., and M. Gertler (1989): "Agency Costs, Net Worth and Business Fluctuations," *American Economic Review*, 79(1), 14–31.

Bernanke, B., M. Gertler, and S. Gilchrist (1996): "The Financial Accelerator and the Flight to Quality," *Review of Economic Studies*, 78(1), 1–15.

——— (1999): "The Financial Accelerator in a Quantitative Business Cycle Framework," *Handbook of Macroeconomics*, 1, 1341–1393.

Carlstrom, C. T., and T. S. Fuerst (1997): "Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis," *American Economic Review*, 87(5), 893–910.

Chirinko, R. (1993): "Business fixed investment spending: A Critical Survey of Modelling Strategies, Empirical Results and Policy Implications," *Journal of Economic Literature*, 31, 1875–1911.

Christensen, I., and A. Dib (2004): "Monetary Policy in an Estimated DSGE Model with a Financial Accelerator," *Unpublished manuscript.*

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113(1), 1–45.

Christiano, L. J., R. Motto, and M. Rostagno (2004): "The Great Depression and the Friedman-Schwartz Hypothesis," *Working Paper.*

Clarida, R., J. Gali, and M. Gertler (2000): "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *Quarterly Journal of Economics*, 115(1), 147–80.

Danthine, J.-P., G. Giavazzi, X. Vives, and E.-L. von Thadden (1999): "The Future of European Banking," *London, Centre for Economic Policy Research*.

Erceg, C. J., D. Henderson, and A. T. Levin (2000): "Optimal Monetary Policy with Staggered Wage and Price Contracts," *Journal of Monetary Economics*, 46, 281–313.

Faia, E. (2002): "Monetary policy in a World with Different Financial Systems," *Working Paper*.

Gelfand, A., and D. Dey (1994): "Bayesian Model Choice: Asymptotics and Exact Calculations," *Journal of the Royal Statistical Society. Series B (Methodological), volume = 56, number = 3, pages = 501-514,*.

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin (2004): *Bayesian Data Analysis*. Chapman and Hall/CRC, second edn.

Gertler, M., S. Gilchrist, and F. M. Natalucci (2003): "External Constraints on Monetary Policy and The Financial Accelerator," *BIS Working Paper 139*.

Geweke, J. (1999): "Using Simulation Methods for Bayesian Econometric Models: Inference, Development and Communication," *Econometric Reviews*, 18, 1–126.

Gilchrist, S., J.-O. Hairault, and H. Kempf (2002): "Monetary Policy and the Financial Accelerator in a Monetary Union," *European Central Bank Working Paper 175*.

Greenwald, B., and J. Stiglitz (1993): "Financial Market Imperfections and Business Cycles," *The Quarterly Journal of Economics*, 108(1), 77–114.

Hamilton, J. (1994): "Time Series Analysis," *Princeton: Princeton University*.

King, R., and A. L. Wolman (1996): "Inflation Targeting in a St. Luis model of the 21st Century," *National Bureau of Economic Research Working Paper: 5507*.

Kiyotaki, N., and J. Moore (1997): "Credit Cycles," *Journal of Political Economy*, 105(2), 211–248.

Levin, A. T., F. M. Natalucci, and E. Zakrajsek (2004): "The Magnitude and Cyclical Behavior of Financial Market Frictions," *Finance and Economics Discussion Series, Federal Reserve Board, Washington DC.*

Meier, A., and G. Muller (2005): "Fleshing our the Monetary Transmission Mechanism: Output Composition and the Role of Financial Frictions," *Working Paper.*

Peerman, G., and F. Smets (2001): "The Monetary Transmission Mechanism in the Euro Area: More Evidence from VAR Analysis," *ECB, Working Paper.*

Sims, C. A. (2000): "Solving Linear Rational Expectations Models," *Unpublish manuscript.*

Smets, F., and R. Wouters (2003): "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association*, 1(5), 1123–1175.

——— (2004): "Comparing Shocks and Frictions in US and Euro Area Business Cycles: A Bayesian Approach," *European Central Bank Working Paper 391.*

A Optimal Contract

As in BGG, the return on capital depends both on aggregate and idiosyncratic shocks. The ex post return on capital in state s of the economy is $\omega^i_{t+1} r^k_{s,t+1}$, where ω^i is an *i.i.d.* lognormal random variable with pdf $F(\omega)$ and mean one.

Entrepreneurs finance their capital stock at the end of period t with their own net worth at the end of the period and bank loans:

$$q_t \widetilde{k}^i_{t+1} = n^i_{t+1} + b^i_{t+1},$$

where q_t is the relative price of capital at the end of the period. As in BGG, the entrepreneur borrows from a financial intermediary that obtains its funds from households, with an opportunity cost equal to the riskless gross rate of return, r_t. Following a "costly state verification" problem of the type analyzed by Townsend (1979), lenders must pay a fixed "auditing cost" to observe an individual borrower's realized return. BGG assume monitoring costs to be a proportion μ of the realized gross payoff to the firms' capital, i.e., the monitoring cost equals $\mu \omega^i_{t+1} r^k_{s,t+1} q_t \widetilde{k}^i_{t+1}$.

The optimal contract will be characterized by a schedule of state contingent threshold values of the idiosyncratic shock $\varpi^i_{s,t+1}$, such that for values of the idiosyncratic shock greater than the threshold, the entrepreneur can repay the lender, and for values below, the entrepreneur declares default and the lender gets $(1-\mu)\,\omega^i_{t+1} r^k_{s,t+1} q_t \widetilde{k}^i_{t+1}$. Because the entrepreneur is risk neutral, he is willing to guarantee the lender a return free of any aggregate risk.

Under these assumptions, the optimal contract is chosen to maximize expected entrepreneurial utility conditional on the return of the lender, for each possible realization of r^k_{t+1}, being equal in expected value to the riskless rate, r_t. The problem to solve is:

$$\max_{\left\{\varpi^i_{s,t+1}\right\}_s, \widetilde{k}^i_{t+1}} \sum_s \Pi_s \left(1 - \Gamma(\varpi^i_{s,t+1})\right) r^k_{s,t+1} q_t \widetilde{k}^i_{t+1}$$

subject to

$$\left[\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1})\right] r^k_{s,t+1} q_t \widetilde{k}^i_{t+1} = r_t \left[q_t \widetilde{k}^i_{t+1} - n^i_{t+1}\right] \qquad \forall s,$$

where Π_s is the probability of reaching state s, $\mu G(\varpi^i_{s,t+1}) = \mu \int_0^{\varpi^i_{s,t+1}} \omega dF(\omega)$ is the expected monitoring costs and $\Gamma(\varpi^i_{s,t+1}) = \left(1 - F(\varpi^i_{s,t+1})\right)\varpi^i_{s,t+1} + G(\varpi^i_{s,t+1})$ is the expected gross share of profits going to the lender given state s of the economy. Associating a multiplier $\Pi_s \lambda_s$ for each constraint, the FOC are:

$$\Gamma'(\varpi^i_{s,t+1}) r^k_{s,t+1} q_t \widetilde{k}^i_{t+1} + \lambda_s \left[\left[\Gamma'(\varpi^i_{s,t+1}) - \mu G'(\varpi^i_{s,t+1}) \right] r^k_{s,t+1} q_t \widetilde{k}^i_{t+1} \right] = 0,$$

$$\sum_s \Pi_s \left(1 - \Gamma(\varpi^i_{s,t+1})\right) r^k_{s,t+1} q_t + \sum_s \Pi_s \lambda_s \left[\left(\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1}) \right) r^k_{s,t+1} - r_t \right] = 0,$$

and

$$\left[\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1}) \right] r^k_{s,t+1} q_t \widetilde{k}^i_{t+1} = r_t \left[q_t \widetilde{k}^i_{t+1} - n^i_{t+1} \right] \qquad \forall s.$$

Rearranging, we get

$$\lambda_s(\varpi^i_{s,t+1}) = \frac{\Gamma'(\varpi^i_{s,t+1})}{\Gamma'(\varpi^i_{s,t+1}) - \mu G'(\varpi^i_{s,t+1})} \qquad \forall s,$$

$$E_t \left\{ \left(1 - \Gamma(\varpi^i_{t+1})\right) r^k_{t+1} + \lambda(\varpi^i_{t+1}) \left[\left(\Gamma(\varpi^i_{t+1}) - \mu G(\varpi^i_{t+1}) \right) r^k_{t+1} - r_t \right] \right\} = 0$$

and

$$\left[\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1}) \right] r^k_{s,t+1} q_t \widetilde{k}^i_{t+1} = r_t \left[q_t \widetilde{k}^i_{t+1} - n^i_{t+1} \right] \qquad \forall s.$$

Since all entrepreneurs have the same distribution of the idiosyncratic risk, $\varpi^i_{s,t+1} = \varpi_{s,t+1}$ and $\lambda_s(\varpi^i_{s,t+1}) = \lambda_s(\varpi_{s,t+1})$. From the third FOC, this implies that $\frac{n^i_{t+1}}{\widetilde{k}^i_{t+1}}$ will also be the same across entrepreneurs.

From the second FOC, we see that when $\mu = 0, \lambda(\varpi_{t+1}) = 1$ and $E_t r^k_{t+1} = r_t$. The third FOC is related to the fact that bank profits are zero ex post. In this case, the lender's expected return can simply be expressed as a function of the average cutoff value of the firm's idiosyncratic shock, ϖ_{t+1}.

BGG show the capital to wealth ratio to be an increasing function of the ex ante premium on external funds.

B Tables and Figures

Table 1-A: Prior and Posterior Distribution of the Parameters

Parameter	Prior			U.S. Posterior					Euro Area Posterior				
	Type	Mode	St. Error	5%	Median	Mean	95%	$\widehat{R}$	5%	Median	Mean	95%	$\widehat{R}$
σ_r Std. dev. monetary shock	Gamma	0.01	0.005	0.003	0.004	0.004	0.004	1.002	0.002	0.002	0.002	0.003	1.035
σ_a Std. dev. technology shock	Gamma	0.01	0.005	0.006	0.007	0.007	0.008	1.002	0.007	0.008	0.008	0.009	1.000
σ_g Std. dev. gov. spending shock	Gamma	0.01	0.005	0.015	0.017	0.017	0.019	1.000	0.015	0.017	0.017	0.019	1.001
σ_ν Std. dev. preferences shock	Gamma	0.10	0.05	0.089	0.126	0.126	0.165	1.024	0.082	0.164	0.155	0.218	1.793
σ_ξ Std. dev. labor supply shock	Gamma	0.10	0.05	0.026	0.031	0.031	0.037	1.014	0.027	0.032	0.032	0.037	1.001
σ_λ Std. dev. price mark up shock	Gamma	0.10	0.05	0.271	0.327	0.329	0.397	1.021	0.272	0.318	0.320	0.376	1.019
σ_τ Std. dev. wage mark up shock	Gamma	0.10	0.05	1.877	2.142	2.143	2.414	1.295	1.514	1.814	1.807	2.061	1.138
ρ^r Smooth coef. in instrument rule	Beta	0.85	0.10	0.354	0.431	0.430	0.500	1.014	0.428	0.500	0.499	0.564	1.038
ρ^a Autocor. coef. technology shock	Beta	0.85	0.10	0.953	0.977	0.976	0.993	1.000	0.965	0.987	0.985	0.996	1.006
ρ^g Autocor. coef. gov. spend. shock	Beta	0.85	0.10	0.868	0.922	0.920	0.963	1.010	0.739	0.841	0.841	0.948	1.011
ρ^ν Autocor. coef. preferences shock	Beta	0.85	0.10	0.991	0.994	0.993	0.996	1.008	0.993	0.997	0.996	0.998	1.572
ρ^ξ Autocor. coef. labor supply shock	Beta	0.85	0.10	0.985	0.993	0.992	0.998	1.002	0.99	0.996	0.995	0.999	1.000

Note: Benchmark model with financial accelerator (FA).

Table 1-B: Prior and Posterior Distribution of the Parameters

Parameter	Prior			U.S. Posterior					Euro Area Posterior				
	Type	Mode	St. Error	5%	Median	Mean	95%	$\widehat{R}$	5%	Median	Mean	95%	$\widehat{R}$
γ^{π} coef. inflation in monetary rule	Normal	1.50	0.05	1.542	1.614	1.614	1.687	1.001	1.482	1.555	1.556	1.631	1.013
γ^{y} coef. output in monetary rule	Normal	0.50	0.05	0.157	0.240	0.240	0.322	1.001	0.146	0.227	0.227	0.307	1.015
σ risk aversion	Normal	1.00	0.10	0.984	1.112	1.110	1.227	1.034	1.052	1.208	1.211	1.373	1.155
θ prob. of not adj. prices	Beta	0.70	0.05	0.758	0.782	0.782	0.804	1.013	0.812	0.833	0.832	0.852	1.007
φ elasticity of capital price wrt I/K	Uniform	-0.5*	0.29	-0.578	-0.471	-0.475	-0.386	1.001	-0.999	-0.980	-0.973	-0.92	1.000
γ entrepreneurs' rate of survival	Beta	.975	0.01	0.985	0.991	0.991	0.995	1.000	0.991	0.994	0.994	0.997	1.007
μ monitoring costs	Beta	0.12	0.05	0.083	0.118	0.119	0.158	1.000	0.117	0.184	0.182	0.245	1.005
$r^k - r$ steady state risk premium	Gamma	0.005	0.002	0.004	0.006	0.006	0.008	1.000	0.006	0.009	0.009	0.012	1.005
ϑ prob. of not adj. wages	Beta	0.70	0.05	0.174	0.207	0.208	0.243	1.171	0.236	0.274	0.274	0.311	1.058
h habit formation	Beta	0.70	0.05	0.548	0.605	0.604	0.659	1.004	0.458	0.516	0.516	0.574	1.068
δ''/δ' variable dep. parameter	Gamma	1.00	0.05	0.939	1.018	1.020	1.106	1.098	0.913	0.996	0.997	1.087	1.301

Note: Benchmark model with financial accelerator (FA).

* Mean

Table 2-A: Robustness and Different Models Performance - Mean of the Posterior distribution for U.S. Data

Parameter	BGG Model		Pr. Indexation		Sticky Wages		Cons. Habits		Benchmark	
	FA	no FA	FA	no FA	FA	no FA	FA	no FA	FA	No FA
σ_r Std. dev. monetary shock	0.003	0.007	0.004	0.006	0.004	0.004	0.004	0.004	0.004	0.004
σ_a Std. dev. technology shock	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.006
σ_g Std. dev. gov. spending shock	0.015	0.019	0.016	0.019	0.016	0.019	0.016	0.019	0.017	0.019
σ_ν Std. dev. preferences shock	0.009	0.107	0.075	0.077	0.123	0.117	0.135	0.147	0.126	0.145
σ_ξ Std. dev. labor supply shock	0.011	0.023	0.020	0.027	0.027	0.033	0.037	0.046	0.031	0.040
σ_λ Std. dev. price mark up shock	0.245	0.148	0.175	0.151	0.289	0.219	0.335	0.236	0.329	0.260
σ_τ Std. dev. wage mark up shock	0.487	0.679	0.583	0.762	1.850	2.112	1.995	2.262	2.143	2.438
ρ^r Smooth coef. in instrument rule	0.193	0.135	0.218	0.101	0.359	0.279	0.409	0.345	0.430	0.395
ρ^a Autocor. coef. technology shock	0.822	0.807	0.993	0.978	0.971	0.889	0.981	0.971	0.976	0.923
ρ^g Autocor. coef. gov. spend. shock	0.909	0.951	0.916	0.933	0.931	0.958	0.944	0.968	0.920	0.966
ρ^ν Autocor. coef. preferences shock	0.898	0.996	0.993	0.995	0.995	0.995	0.993	0.993	0.993	0.994
ρ^ξ Autocor. coef. labor supply shock	0.947	0.955	0.960	0.932	0.967	0.947	0.991	0.987	0.992	0.989

Note: The first two columns represent the standard BGG model with and without financial accelerator. In the next columns, I cumulatively add price indexation, sticky wages, consumption habits and variable capital utilization. This last model corresponds to the benchmark model. In all these cases, I estimate the model with (FA) and without financial accelerator (no FA).

Table 2-B: Robustness and Different Models Performance - Mean of the Posterior distribution for U.S. Data

Parameter	BGG Model		Pr. Indexation		Sticky Wages		Cons. Habits		Benchmark	
	FA	no FA	FA	no FA	FA	no FA	FA	no FA	FA	No FA
γ^{π} coef. inflation in monetary rule	1.287	1.719	1.502	1.636	1.607	1.615	1.623	1.631	1.614	1.637
γ^{y} coef. output in monetary rule	0.140	0.061	0.275	0.221	0.231	0.180	0.220	0.221	0.240	0.198
σ risk aversion	1.134	1.227	1.330	1.288	1.322	1.312	1.144	1.158	1.110	1.100
θ prob. of not adj. prices	0.700	0.710	0.637	0.675	0.757	0.732	0.779	0.747	0.782	0.759
φ elasticity of capital price wrt I/K	-0.100	-0.078	-0.142	-0.060	-0.361	-0.139	-0.370	-0.217	-0.475	-0.220
γ entrepreneurs' rate of survival	0.989	0.972	0.992	0.971	0.992	0.972	0.989	0.971	0.991	0.971
μ monitoring costs	0.222	-	0.191	-	0.121	-	0.099	-	0.119	-
$r^k - r$ steady state risk premium	0.012	-	0.010	-	0.006	-	0.005	-	0.006	-
ϑ prob. of not adj. wages	-	-	-	-	0.181	0.162	0.218	0.191	0.208	0.186
h habit formation	-	-	-	-	-	-	0.601	0.653	0.604	0.661
δ''/δ' variable dep. parameter	-	-	-	-	-	-	-	-	1.020	1.005
Log Marginal Data Density	1941.2	1819.9	1927.9	1860.9	1858.7	1803.6	1876.9	1827.5	1880.2	1829.8
Log Bayes Factor	0	121.3	0	67.0	0	55.1	0	49.3	0	50.5
Bayes Factor	1	1e+52	1	1e+29	1	1e+23	1	1e+21	1	1e+21

Note: The first two columns represent the standard BGG model with and without financial accelerator. In the next columns, I cumulatively add price indexation, sticky wages, consumption habits and variable capital utilization. This last model corresponds to the benchmark model. In all these cases, I estimate the model with (FA) and without financial accelerator (no FA).

Table 3-A: Robustness and Different Models Performance - Mean of the Posterior distribution for European Data

Parameter	BGG Model		Pr. Indexation		Sticky Wages		Cons. Habits		Benchmark	
	FA	no FA	FA	no FA	FA	no FA	FA	no FA	FA	no FA
σ_r Std. dev. monetary shock	0.002	0.006	0.002	0.004	0.002	0.003	0.002	0.003	0.002	0.003
σ_a Std. dev. technology shock	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.008	0.008
σ_g Std. dev. gov. spending shock	0.017	0.016	0.016	0.016	0.017	0.016	0.017	0.016	0.017	0.016
σ_ν Std. dev. preferences shock	0.012	0.101	0.039	0.08	0.060	0.100	0.078	0.133	0.155	0.104
σ_ξ Std. dev. labor supply shock	0.022	0.022	0.022	0.025	0.017	0.022	0.031	0.037	0.032	0.033
σ_λ Std. dev. price mark up shock	0.347	0.285	0.203	0.166	0.301	0.245	0.314	0.223	0.320	0.252
σ_τ Std. dev. wage mark up shock	0.298	0.510	0.368	0.547	1.660	2.166	1.713	2.116	1.807	2.369
ρ^r Smooth coef. in instrument rule	0.371	0.146	0.342	0.169	0.530	0.331	0.468	0.384	0.499	0.395
ρ^a Autocor. coef. technology shock	0.975	0.93	0.989	0.994	0.896	0.831	0.987	0.939	0.985	0.842
ρ^g Autocor. coef. gov. spend. shock	0.903	0.967	0.899	0.967	0.828	0.958	0.937	0.969	0.841	0.965
ρ^ν Autocor. coef. preferences shock	0.943	0.996	0.983	0.997	0.988	0.995	0.992	0.995	0.996	0.994
ρ^ξ Autocor. coef. labor supply shock	0.981	0.973	0.984	0.974	0.992	0.977	0.995	0.992	0.995	0.994

Note: The first two columns represent the standard BGG model with and without financial accelerator. In the next columns, I cumulatively add price indexation, sticky wages, consumption habits and variable capital utilization. This last model corresponds to the benchmark model. In all these cases, I estimate the model with (FA) and without financial accelerator (no FA).

Table 3-B: Robustness and Different Models Performance - Mean of the Posterior distribution for European Data

Parameter	BGG Model		Pr. Indexation		Sticky Wages		Cons. Habits		Benchmark	
	FA	no FA	FA	no FA	FA	no FA	FA	no FA	FA	no FA
γ^{π} coef. inflation in monetary rule	1.501	1.713	1.565	1.639	1.506	1.539	1.558	1.617	1.556	1.568
γ^{y} coef. output in monetary rule	0.285	0.146	0.309	0.239	0.261	0.120	0.217	0.191	0.227	0.152
σ risk aversion	1.264	1.279	1.317	1.310	1.157	1.223	1.180	1.135	1.211	1.093
θ prob. of not adj. prices	0.772	0.768	0.736	0.757	0.806	0.839	0.826	0.827	0.832	0.843
φ elasticity of capital price wrt I/K	-0.469	-0.331	-0.317	-0.171	-0.806	-0.275	-0.619	-0.461	-0.973	-0.347
γ entrepreneurs' rate of survival	0.995	0.972	0.994	0.972	0.997	0.972	0.994	0.972	0.994	0.971
μ monitoring costs	0.243	-	0.314	-	0.520	-	0.129	-	0.182	-
$r^k - r$ steady state risk premium	0.011	-	0.014	-	0.023	-	0.006	-	0.009	-
ϑ prob. of not adj. wages	-	-	-	-	0.271	0.240	0.254	0.236	0.274	0.245
h habit formation	-	-	-	-	-	-	0.495	0.573	0.516	0.569
δ''/δ' variable dep. parameter	-	-	-	-	-	-	-	-	0.997	1.013
Log Marginal Data Density	1898.0	1773.9	1927.6	1904.9	1920.8	1882.0	1902.6	1891.3	1921.0	1881.1
Log Bayes Factor	0	124.1	0	22.6	0	38.9	0	11.2	0	39.9
Bayes Factor	1	1e+53	1	1e+9	1	1e+16	1	1e+4	1	1e+17

Note: The first two columns represent the standard BGG model with and without financial accelerator. In the next columns, I cumulatively add price indexation, sticky wages, consumption habits and variable capital utilization. This last model corresponds to the benchmark model. In all these cases, I estimate the model with (FA) and without financial accelerator (no FA).

Table 4: Bank Industry Health and Importance of External Finance

	U.S.	Euro Area
Return on Assets	1.42	0.50
Loan Loss	0.10	0.32
Ext Fin as % of GDP	64.0	40.8
Thomson Rating	1.73	2.16
Corporate Debt Security	31.2	7.4

Note: Data taken from Faia (2002)

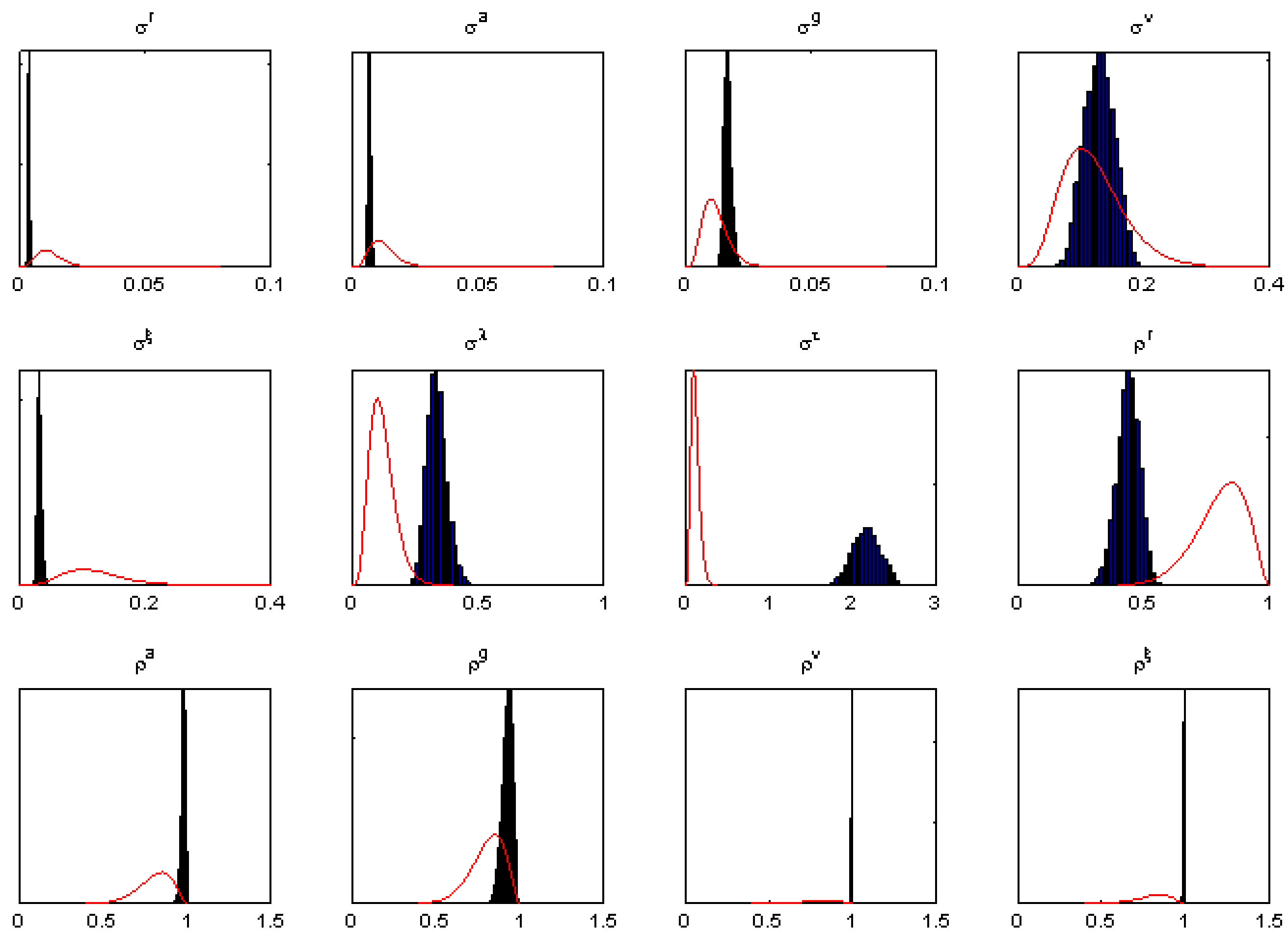

Figure 1: Prior and posterior distribution of the benchmark model with financial frictions for U.S. data.

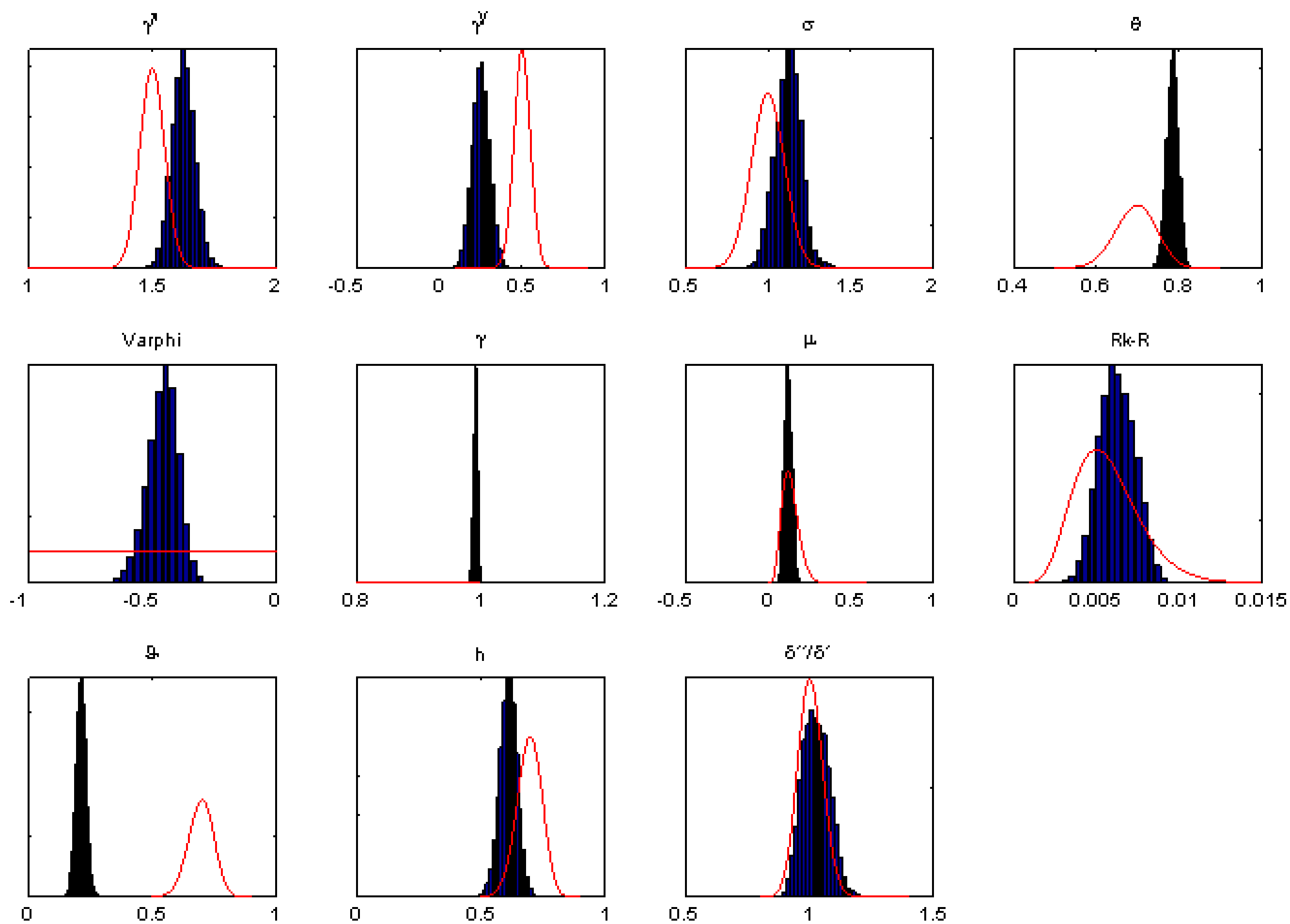

Figure 2: Prior and posterior distribution of the benchmark model with financial frictions for U.S. data.

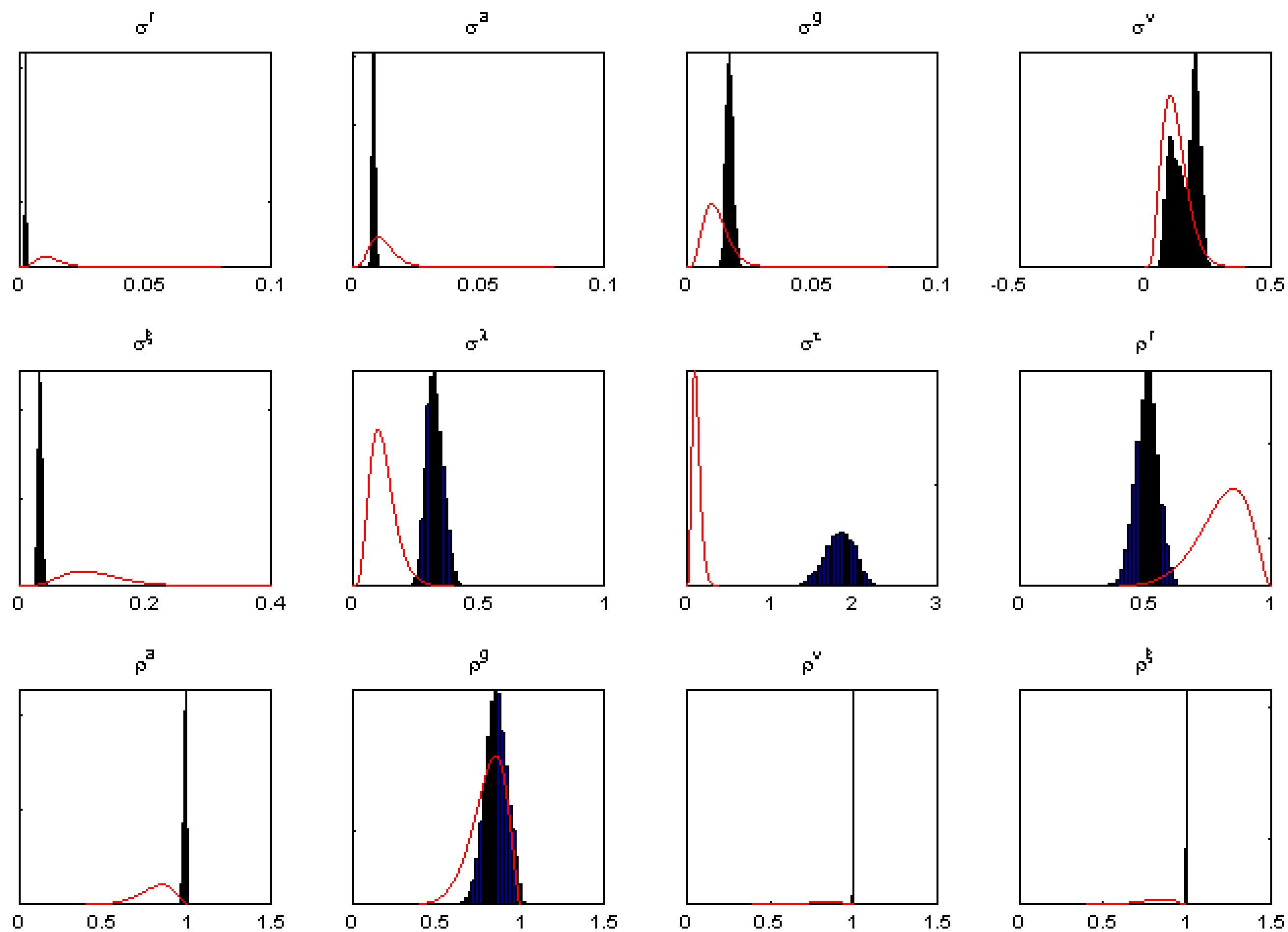

Figure 3: Prior and posterior distribution of the benchmark model with financial frictions for Euro data.

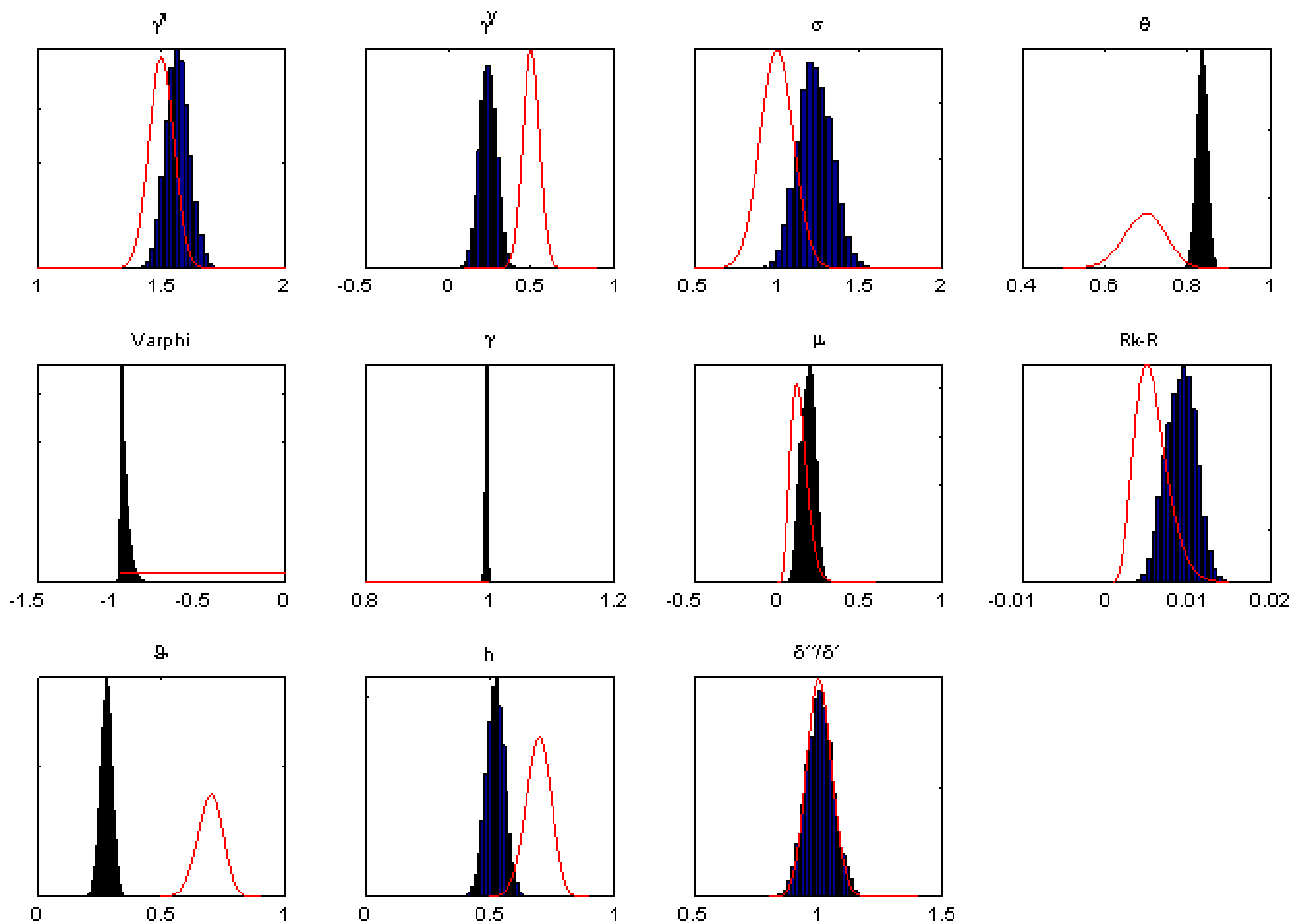

Figure 4: Prior and posterior distribution of the benchmark model with financial frictions for Euro data.

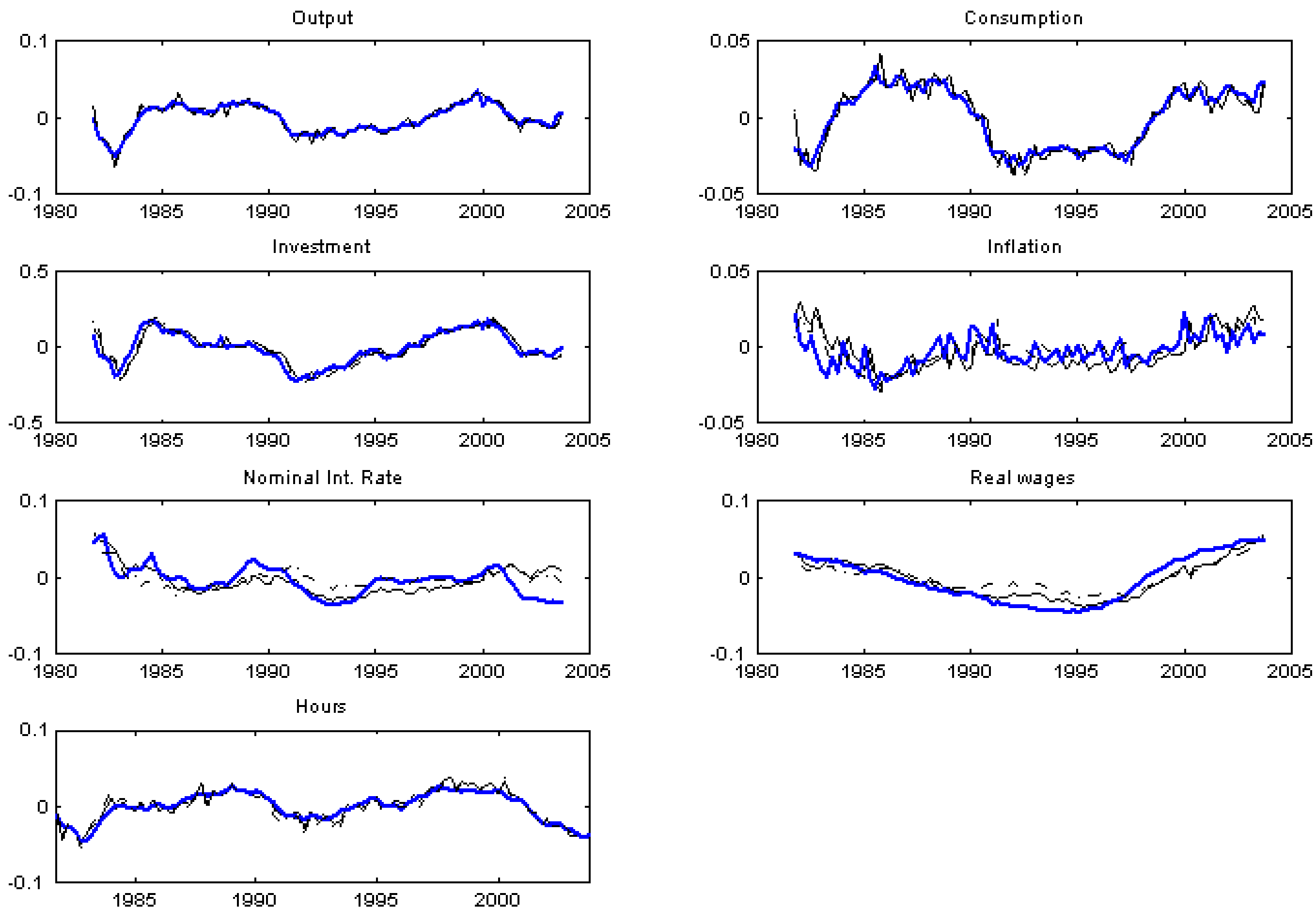

Figure 5: U.S. actual and one-side Kalman filter fitted data evaluated at the mean of the posterior. Thin solid line - benchmark model with financial accelerator. Dashed line - benchmark model without financial accelerator. Thick solid line - Actual data.

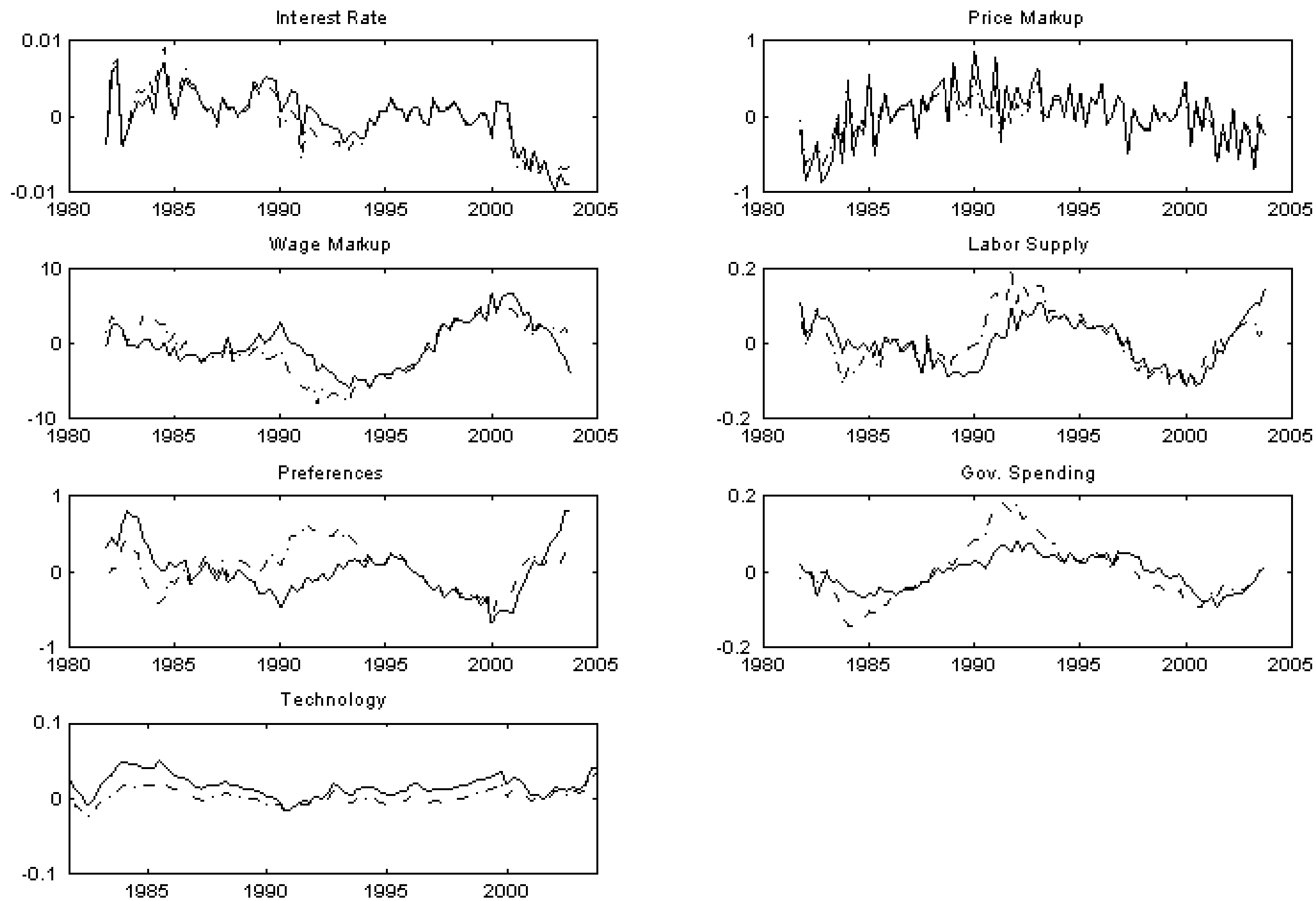

Figure 6: U.S. two-side Kalman Filter estimated shocks (at the mean of the posterior). Dashed line - benchmark model with financial accelerator. Dotted line - benchmark model without financial accelerator.

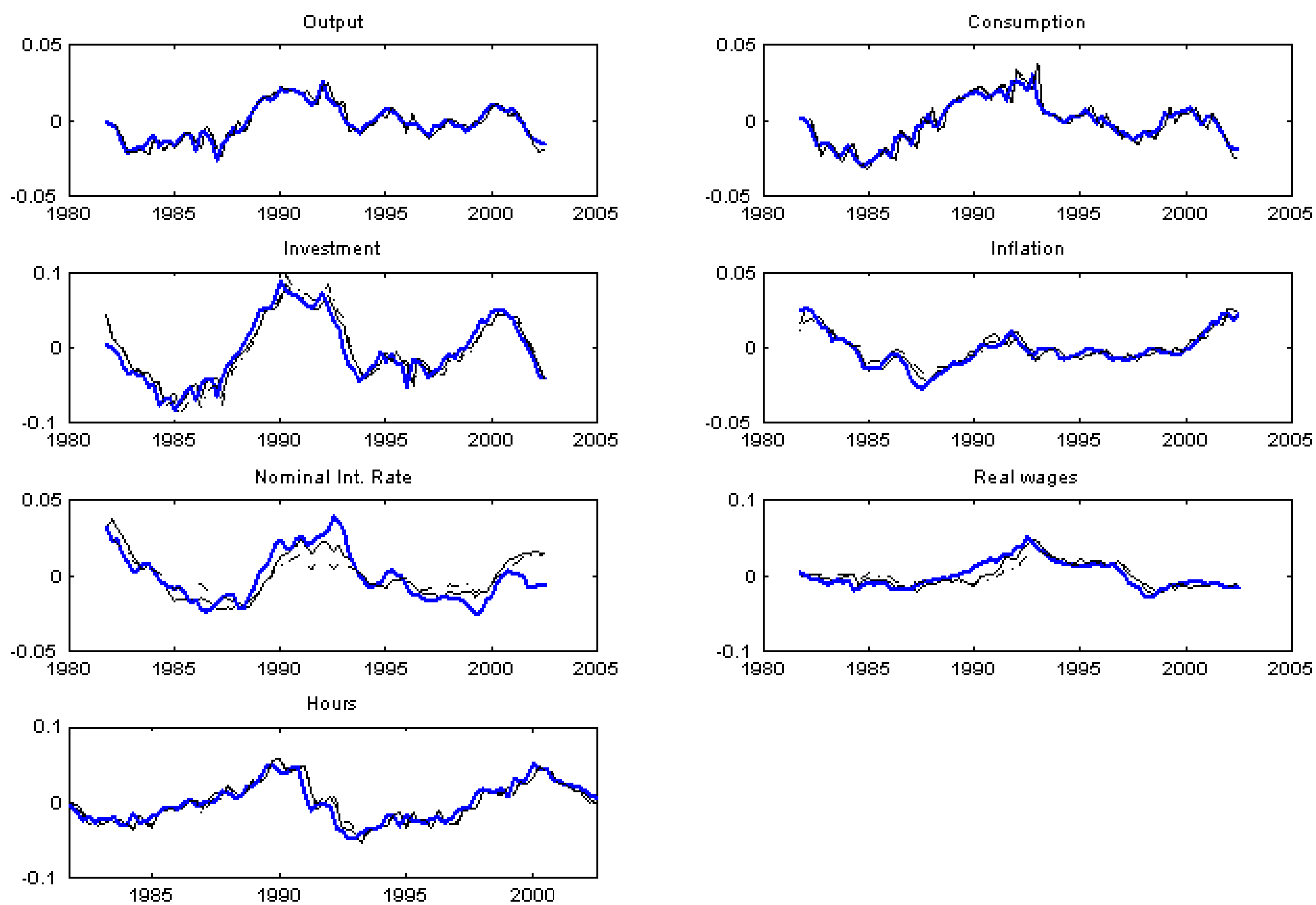

Figure 7: European actual and one-side Kalman filter fitted data evaluated at the mean of the posterior. Thin solid line - benchmark model with financial accelerator. Dashed line - benchmark model without financial accelerator. Thick solid line - Actual data.

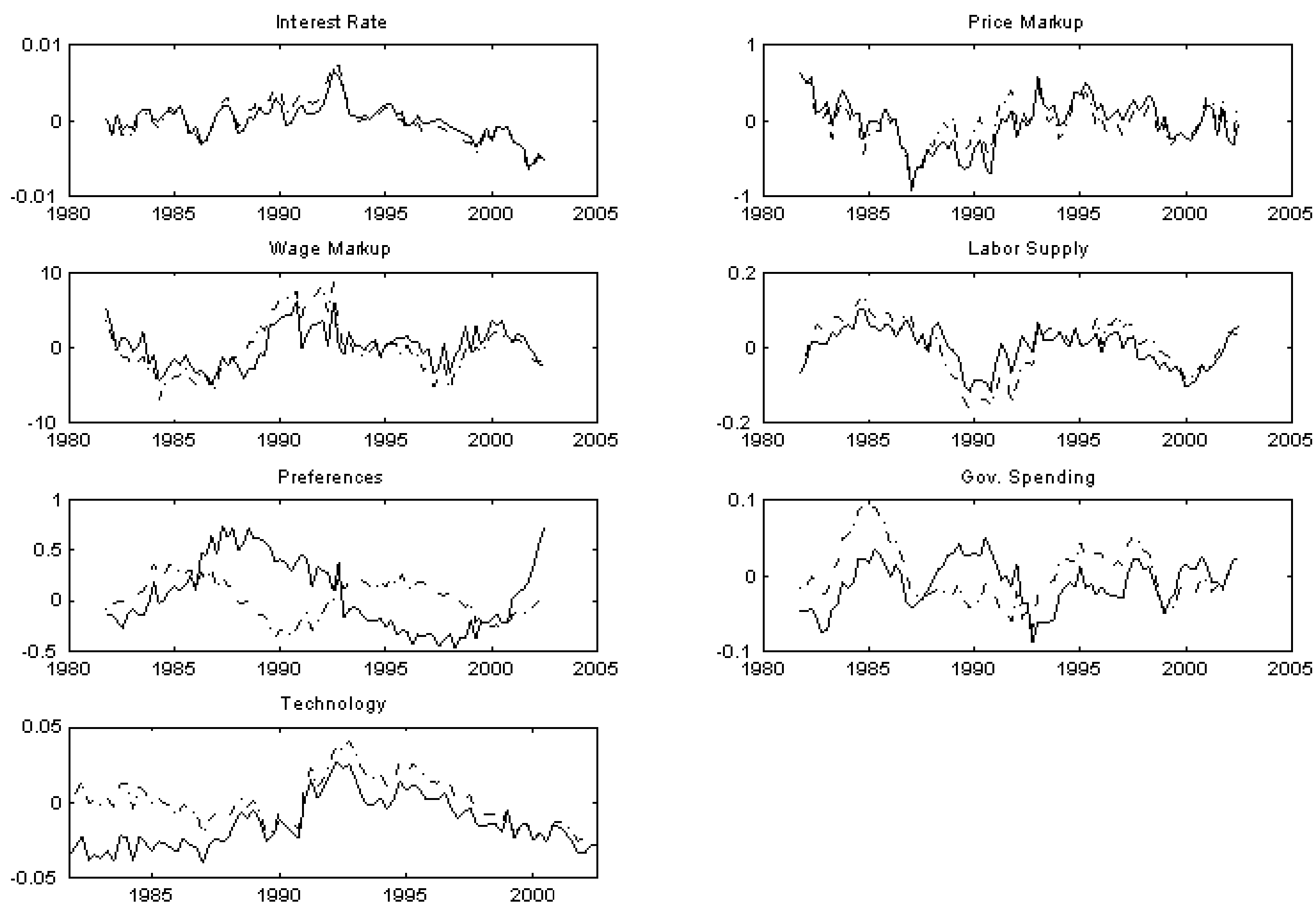

Figure 8: European two-side Kalman Filter estimated shocks (at the mean of the posterior). Dashed line - benchmark model with financial accelerator. Dotted line - benchmark model without financial accelerator.

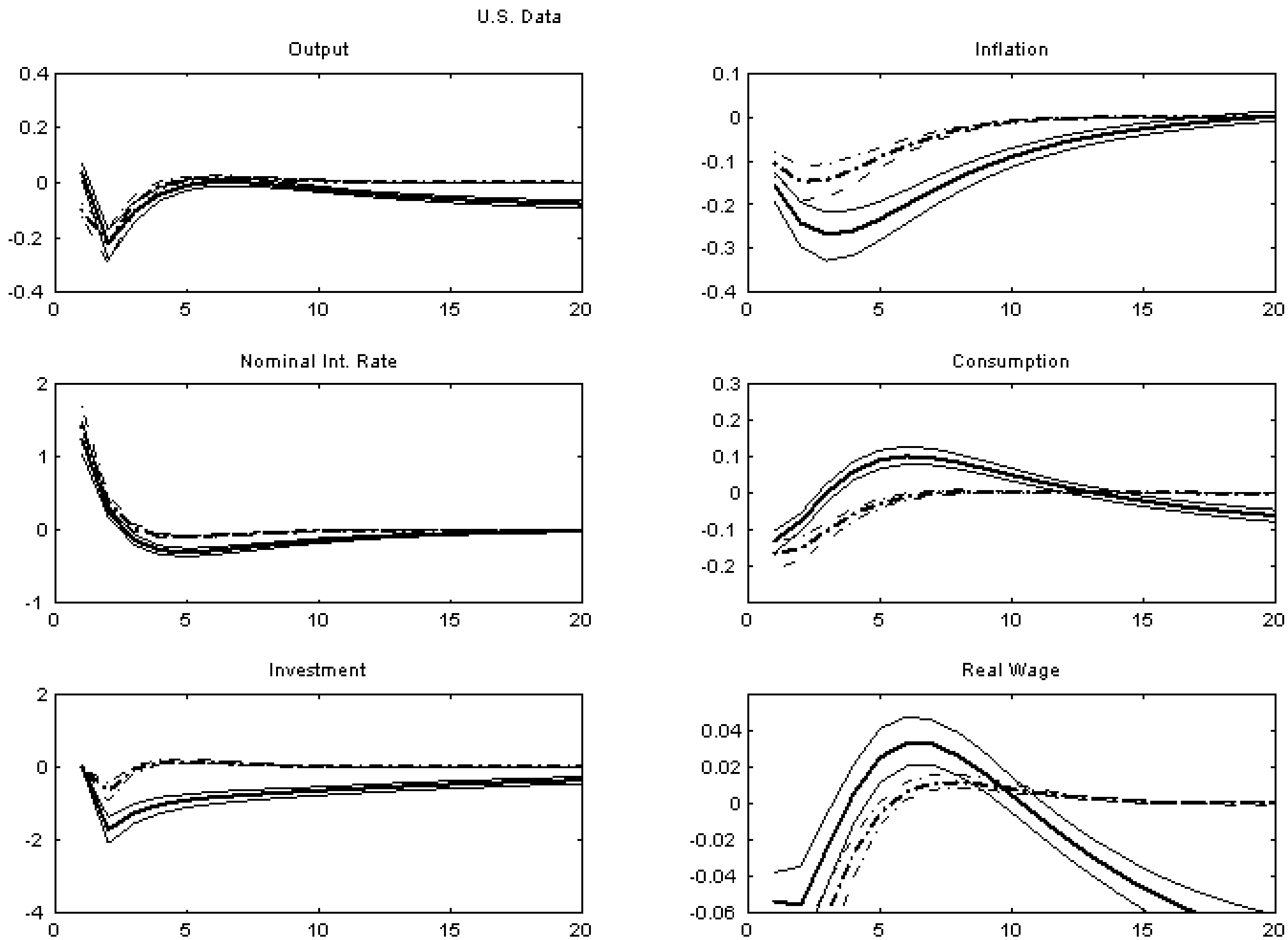

Figure 9: Impulse Response Function to a one standard deviation monetary policy shock (mean, 5 and 95 percentiles). Solid line: benchmark financial accelerator model. Dashed line: benchmark model without financial accelerator.

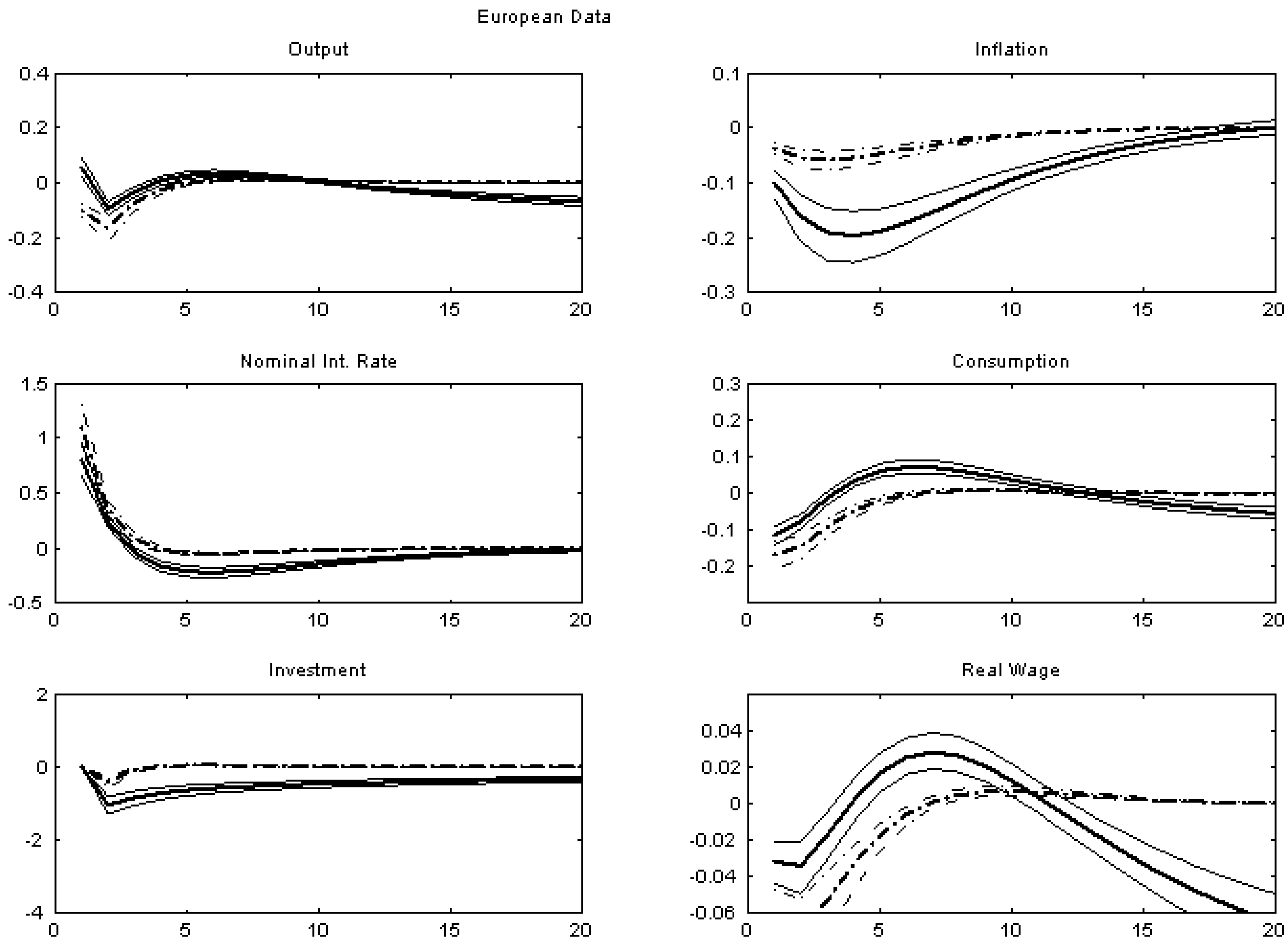

Figure 10: Impulse Response Function to a one standard deviation monetary policy shock (mean, 5 and 95 percentiles). Solid line: benchmark financial accelerator model. Dashed line: benchmark model without financial accelerator.

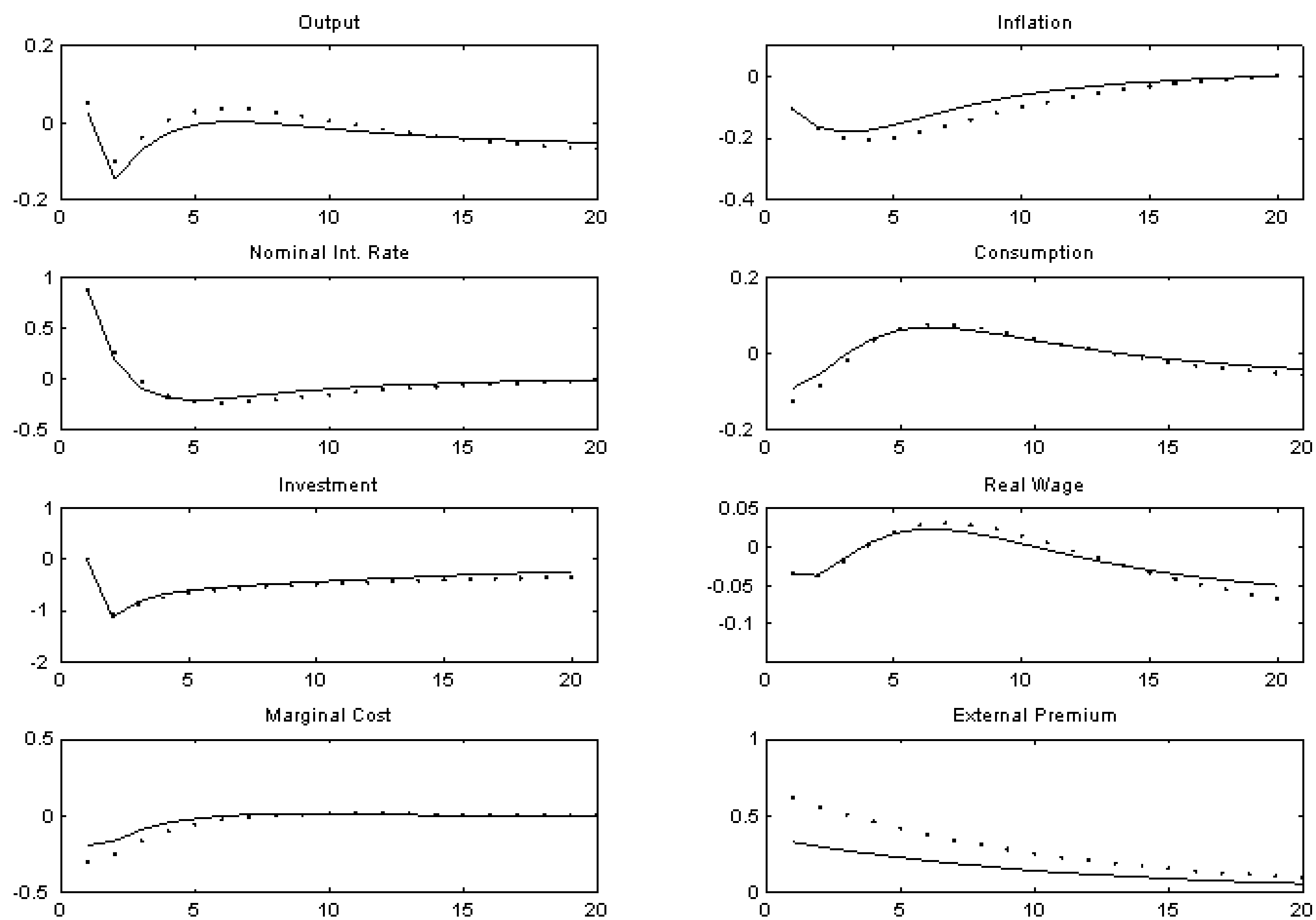

Figure 11: Impulse Response functions to a one percent shock to the nominal interest rate (annual) for the benchmark model with monitoring costs. Solid line: U.S. data. Doted line: European data

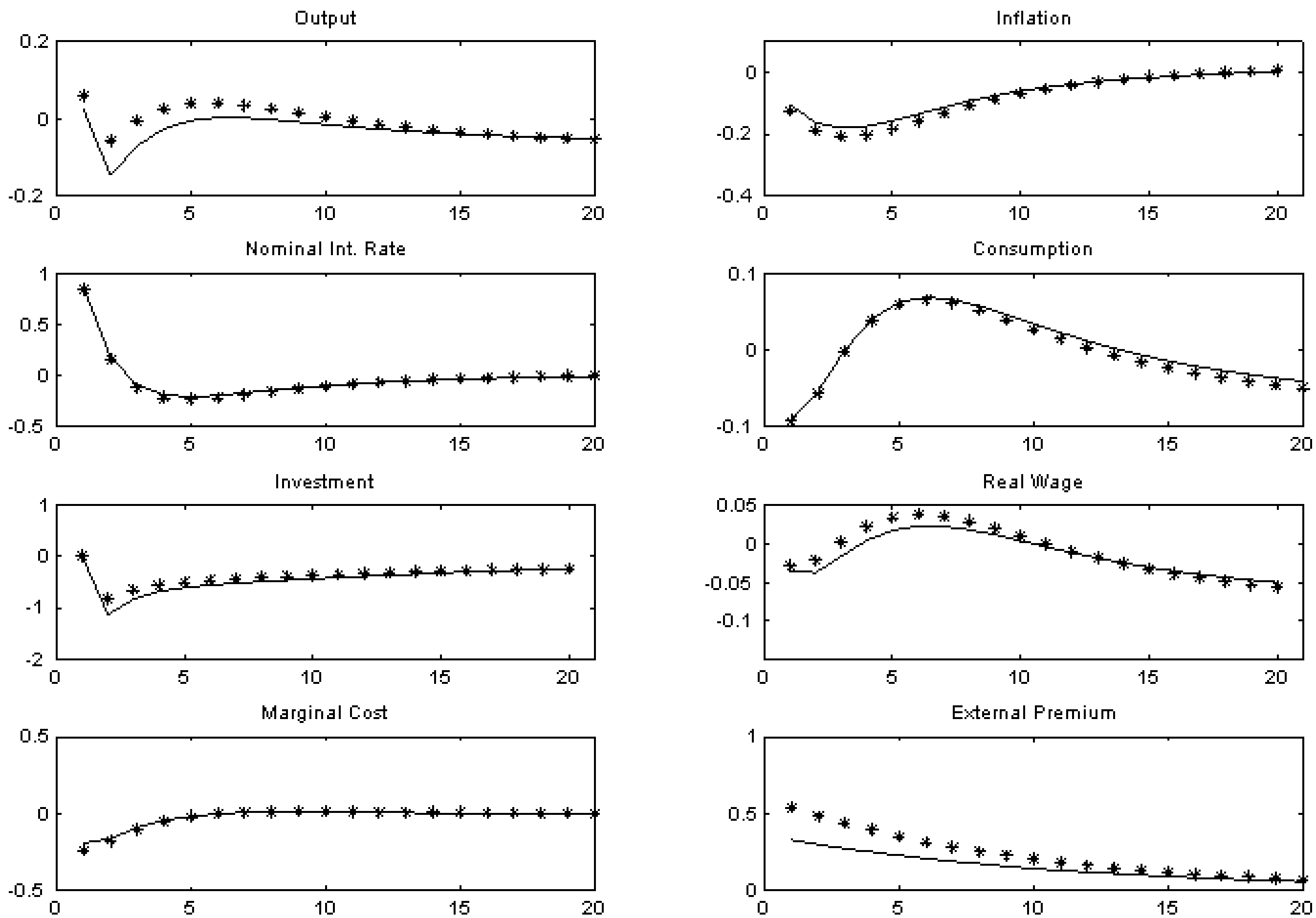

Figure 12: Counterfactual: Impulse Response functions to a one percent shock to the nominal interest rate (annual) for the benchmark model with monitoring costs. Solid line: U.S. data. Star line: U.S. data using credit market frictions and investment adjustment costs as in the Euro area.

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