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The role of financial frictions in the 2007-2008 crisis: an estimated DSGE model

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The role of financial frictions in the 2007-2008 crisis: an estimated DSGE model*

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Abstract

After the banking crises experienced by many countries in the 1990s and in 2008, financial market conditions have turned out to be a relevant factor for economic fluctuations. The purpose of this paper is to determine whether frictions in financial markets are important for business cycles, and whether the recent 2007-2008 crisis has enhanced (or reduced) the size of some shocks and the role played by financial factors in driving economic fluctuations.

The analysis is based on both versions of the Smets and Wouters DSGE model (2003, 2007), which are estimated using Bayesian techniques. The two versions differ because the Smets and Wouters (2007) version entails a risk premium shock, which captures that interest rate faced by firms and households might be different from the policy rate because of some unmodelled frictions. Both versions are augmented to include an endogenous financial accelerator mechanism as in Bernanke, Gertler and Gilchrist (1999), which arises from information asymmetries between lenders and borrowers that create inefficiencies in financial markets. The analysis is based on the same data-set as in the Smets and Wouters model, but extended to 2010.

One first set of results suggests that the recent crisis has amplified the relevance of financial factors, as well as unmodelled frictions. Overall, this paper proves that the Smets and Wouters model augmented with a financial accelerator mechanism is suitable to capture much of the historical developments in U.S. financial markets that led to the financial crisis in 2007-2008. In particular, the concomitance of a peak in leverage ratio and the deepening of the recession supports the argument that leverage and credit have an important role to play in shaping the business cycle, in particular the intensity of recessions.

JEL classification: C11, E32, E44.

Keywords: Business cycle, financial frictions, Bayesian estimation.

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Contents

1 Introduction **1**

2 Model presentation **4**

3 Methodology for estimation and model evaluation **9**

4 Estimation results **11**

5 What were the main driving forces behind the financial recession in 2007-2008? **16**

5.1 Variance decomposition 16

5.2 Historical decomposition 18

6 Conclusions and policy implications **20**

1 Introduction

After the banking crises experienced by many countries in the 1990s and in 2008, financial market conditions have turned out to be a relevant factor for economic fluctuations. As a consequence, a good understanding of the business cycle dynamics requires adding financial market frictions in macroeconomic models.

A first strand of the empirical literature, following the so-called financial accelerator approach initially introduce by Bernanke, Gertler and Gilchrist (1999) disregards the potential role of financial factor as a source of shocks itself and assumes that financial frictions work as a mechanism of transmission of macroeconomic shocks. Based on this modelling framework, these studies conclude that financial market frictions are relevant for the U.S. and the euro area (Levin, Natalucci and Zakrajšek (2004); Christensen and Dib (2008); De Graeve (2008); Queijo (2009)).

More recently, after that the 2007-2008 crisis has featured a significant disruption of financial intermediation, a second strand of literature has emphasized the role of financial sector as a source of shocks and not only as a mechanism of propagation. This more recent literature is unanimous in concluding that banking sector shocks and investors' sentiment explain the largest share of the contraction in the economic activity in the euro area during the 2007-2008 crisis (Gerali, Neri, Sessa and Signoretti (2010); Martin and Ventura (2010); Kollmann, Enders and Müller (2011)) and the quick and strong propagation of the crisis (Gertler and Kiyotaki (2009)).

However, results reached by the more recent strand of the literature are not at odds with those stated by the first strand of literature based on the original approach proposed by Bernanke, Gertler and Gilchrist (1999). The more recent strand of the literature developed in the aftermath of the crisis concludes that financial shocks (namely, shocks that either push up the cost of loans or decrease the demand of credit) explain a large share of contraction in the euro area economic activity. The so-called net-worth shock in Bernanke, Gertler and Gilchrist (1999), by affecting entrepreneur's net worth, also affects borrowing needs and therefore might have similar effects as a financial shock that affects the demand of credit.

This paper follows the approach of the first strand of the literature and attempts to quantify the role of such frictions in business cycle fluctuations by estimating a DSGE model with the financial accelerator mechanism à la Bernanke, Gertler and Gilchrist (1996, 1999) using a Bayesian maximum likelihood approach. To this purpose, I extend the Smets and Wouters model (hereafter, SW) by adding financial frictions. I consider two alternative versions of the Smets and Wouters model. The first version (denoted as SW 2007[1]) includes a so-called risk premium shock, which represents a spread between the interest rate controlled by the central bank and the interest rate faced by households and firms. A positive shock to this spread increases the required return on assets hold by households and hence reduces current consumption. At the same time, it also increases the cost of capital and hence reduces the value of capital and investment. The risk premium shock reveals the presence of unmodelled frictions, which are lacking in a previous version of the SW model (denoted as SW 2003[2]), where the risk premium shock is replaced by a preference shock, which affects only the intertemporal consumption Euler equation.

Starting from both versions of the SW model, I introduce an endogenous financial accelerator mechanism following the pioneer paper of Bernanke, Gertler and Gilchrist (1996, 1999) (henceforth, BGG). This endogenous mechanism is based on information asymmetries between lenders and entrepreneurs that create inefficiencies in financial markets, affect the supply of credit and amplify business cycles. Specifically, during booms (recessions), an increase (fall) in borrowers' net worth decreases (increases) their cost of obtaining external funds, further stimulating (reducing) investment and amplifying the effects of the initial shock[3].

Then dynamics is driven by a large number of shocks, including a risk premium shock, a preference shock, three shocks arising from technology and preferences (a productivity shock, a shock to the investment adjustment cost function, and a government consumption shock); two "cost-push" shocks (modelled as shocks to the mark-up in the goods and labour markets) and a monetary policy shock. To estimate the parameters of the model and the

[1] Smets and Wouters (2007), published in the *American Economic Review*, American Economic Association, Vol. 97, No. 3, pp. 586-606, June.

[2] Smets and Wouter (2003) published in the *Journal of the European Economic Association,* MIT Press, Vol. 1, No. 5, pages 1123-1175. See also Smets and Wouters (2005) published in the *Journal of Applied Econometrics*, Vol. 20, No. 2, pp. 161-183

[3] This approach has also been adopted by Carlstrom and Fuerst (1997) and Christiano, Motto and Rostagno (2010). In a different approach, the financial accelerator mechanism arises from the reduction of asset price used as collateral. Therefore, borrowers that use these assets as collateral are limited in their ability to borrow, and hence to invest, as the market value of collateral has been reduced. A partial list of works in this strand of literature includes Kiyotaki and Moore (1997), Christiano, Gust and Roldos (2002), Iacoviello (2005), Iacoviello and Neri (2009), Aoki, Benigno and Kiyotaki (2009) and Mendoza (2008).

stochastic processes governing the structural shocks, I use the same seven key macroeconomic time series for the U.S. economy used in the SW model: real GDP, consumption, investment, the GDP deflator, the real wage, employment and the nominal short-term interest rate. I estimate the model on U.S. quarterly data from 1947 to 2010 using Bayesian methods.

The aim of this paper is to investigate whether frictions in financial markets have become more important for business cycles especially during the recent financial crisis, even if realistic frictions in goods and labour markets are added to a model with frictions in financial markets. The paper contributes to the debate on the sources of business cycle fluctuations during the recession in three respects. First, it assesses the influence of the great recession on estimates results. For this purpose, the standard Smets and Wouters models is re-estimated over the whole sample up to 2010, so to include the effects of the crisis. The comparison between these estimates with those based on the sample up to 2004, originally used in the SW model, proves that the recent crisis has amplified the role of financial factors. Second, the paper assesses the relevance of the financial accelerator mechanism. For this purpose, once included the crisis times 2007-2010 the original model is augmented with the financial accelerator mechanism à la BGG. Estimation results conclude that financial factors have enhanced the relevance of financial-type shocks in driving economic fluctuations. Third, the paper identifies the shocks that are responsible for the financial crisis and are accounted as the key sources of economic fluctuations. In this respect, the analysis concludes that leverage and credit have played an important role in shaping the business cycle. Moreover, results in this paper help interpreting movements in the premium in relation to shocks driving the business cycle and are in line with the events that started with the subprime crisis in the summer 2007 and triggered the financial crisis.

A similar analysis has recently been proposed by Gilchrist, Ortiz and Zakrajšek (2009). This paper complements their analysis in two respects. First, the conclusion in favour of the presence of a financial accelerator mechanism is supported by marginal likelihood. Second, this paper finds stronger evidence in favour of the presence of financial frictions, as proved by the higher estimate of the elasticity of the external premium.

The rest of the paper is structured as follows. Section 2 presents the model. Section 3 shortly discusses the estimation methodology. Section 4 presents estimation results. Section 5 discusses the contribution of each shock to the developments in U.S. economy and the historical relevance of disturbances for macroeconomic performance, with a particular focus on the most recent financial crisis. Finally, Section 6 summarizes the main conclusions. Data are described in the Appendix.

2 Model presentation

To assess the role played by financial factors, the analysis based on two alternative versions of the SW model (Smets and Wouters (2003) and Smets and Wouters (2007))[4]. Both versions are augmented to include the endogenous financial accelerator mechanism à la Bernanke, Gertler and Gilchrist (1999). The model framework closely follows Smets and Wouters (2007), except in the presence of financial frictions[5]. Therefore, for an exhaustive description of the model, I refer the reader to the original paper (Smets and Wouters (2007)). However, to make the paper self-contained, in this section I shortly present directly the log-linearized version of the model and I concentrate the discussion on the aspects related to financial frictions. All variables are log-linearized around their steady-state and variables not indexed by time denote steady-state values.

Output (y_t) is composed by consumption (c_t), investment (i_t), capital-utilization costs that are a function of the capital utilization rate (z_t^k), and exogenous spending (g_t). I assume that exogenous spending follows an $AR(1)$ process with an IID-Normal error term and is also affected by the productivity shock[6] as follows: $g_t = \rho_g g_{t-1} + \eta_t^g + \rho_{ga}\eta_t^a$

$$y_t = \frac{c}{y}c_t + \frac{i}{y}i_t + g_t + [f-(1-\delta)]\left(\frac{k}{y}\right)z_t^k + \left(\frac{k}{y}\right)f\left(1-\frac{r}{f}\right)\left(1-\frac{1}{lev}\right)\left(r_t + p_t^k + k_t\right) \quad (1)$$

where $\frac{c}{y} = 1 - \frac{g}{y} - \frac{i}{y}, \frac{i}{y} = [\gamma - (1-\delta)]\frac{k}{y}$ and the term $[f-(1-\delta)]\left(\frac{k}{y}\right)z_t^k$ measures the cost

[4] The main difference between the two versions of the Smets and Wouters model is that in the Smets and Wouters (2007) the preference shock is replaced by the risk premium shock. In contrast to the preference shock, the risk premium shock affects in the same direction both consumption and investment, while the preference shock affects only consumption. Therefore, the risk premium shock helps to explain the comovement of consumption and investment.

[5] For the general description, I refer mainly at Smets and Wouters (2007) published in the *American Economic Review*, American Economic Association, Vol. 97, No. 3, pages 586-606, June.

[6] The latter is empirically motivated by the fact that, in estimation, exogenous spending also includes net exports, which may be affected by domestic productivity developments.

associated with variable capital utilization. The term $\left(\frac{k}{y}\right) f \left(1 - \frac{r}{f}\right)\left(1 - \frac{1}{lev}\right)\left(r_t + p_t^k + k_t\right)$ measures the bankruptcy costs, where $lev = \frac{p^k k}{n}$ is the steady-state value of the leverage ratio, that is the ratio of capital to net worth.

Households maximize a non-separable[7] utility function with two arguments (goods and labour effort) over an infinite life horizon. Aggregate consumption evolves according to

$$c_t = c_1 c_{t-1} + c_2 E_t c_{t+1} + c_3 \left(l_t - E_t l_{t+1}\right) - c_4 \left(r_t - E_t \pi_{t+1} + \varepsilon_t^b + \varepsilon_t^\beta\right) \tag{2}$$

$$c_1 = \left(\frac{\frac{h}{\gamma}}{1 + \frac{h}{\gamma}}\right); c_2 = \left(\frac{1}{1 + \frac{h}{\gamma}}\right);$$

$$c_3 = \frac{\sigma - 1}{\sigma\left(1 + \frac{h}{\gamma}\right)\lambda_w} \frac{(1-\alpha)}{\alpha} \frac{r^k \frac{k}{y}}{\frac{c}{y}}; c_4 = \left[\frac{1 - \frac{h}{\gamma}}{\sigma\left(1 + \frac{h}{\gamma}\right)}\right]$$

where the parameter h introduces habit in consumption, γ is the steady state growth and σ represents the inverse of elasticity of intertemporal substitution. Equation (3) states that current consumption (c_t) depends on a weighted average of past and expected future consumption and on expected growth in hours worked ($l_t - E_t l_{t+1}$), the ex-ante real interest rate ($r_t - E_t \pi_{t+1}$), and the disturbance terms ε_t^b and ε_t^β. The disturbance terms are assumed to follow an $AR(1)$ process with an IID-Normal error term: $\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b$ and $\varepsilon_t^\beta = \rho_\beta \varepsilon_{t-1}^\beta + \eta_t^\beta$. A first version of the model, denoted as SW(2003), features only the preference shock ε_t^β, which affects the discount rate that determines the intertemporal substitution decisions of households. A second version of the model, denoted as SW (2007), features only the risk premium shock ε_t^b, which represents a wedge between the interest rate controlled by the central bank and the return on assets held by households. A positive shock to this wedge increases the required return on assets and reduces current consumption.

Investment dynamics are

$$i_t = \frac{1}{1 + \beta\gamma}\left[i_{t-1} + \beta\gamma E_t i_{t+1} + \frac{1}{\gamma^2 \varphi} p_t^k\right] + \varepsilon_t^i \tag{3}$$

where p_t^k is the current value of capital stock, φ is the steady-state elasticity of the capital

[7] The non-separability of the utility function implies that consumption will also depend on expected employment growth. Therefore, when the elasticity of the intertemporal substitution is smaller than one ($\sigma > 1$), consumption and labour supply are complements.

adjustment cost function, and β is the discount factor applied by households. The disturbance to the investment-specific technology process is assumed to follow an $AR(1)$ process with an IID-Normal error term: $\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i$.

The corresponding arbitrage equation for the value of capital is given by

$$p_t^k = -(f_t + \varepsilon_t^b) + \frac{r^k}{r^k + (1-\delta)} r_{t+1}^k + \frac{(1-\delta)}{r^k + (1-\delta)} p_{t+1}^k \tag{4}$$

where f_t is the external cost of funding and r_t^k is the rental cost of capital. This equation states that the current value of the capital stock depends positively on its expected future value and the expected real rental rate on capital and negatively on the ex-ante cost of external funding and the risk premium disturbance. As showed in equation (2), the risk premium disturbance introduces a wedge between the policy rate and the return on assets hold by households. At the same time, it also increases the cost of capital and reduces the value of capital and investment. This shock has similar effects as so-called net-worth shocks in Bernanke, Gertler and Gilchrist (1999) and Christiano, Motto and Rostagno (2010).

Following BGG (1998), I assume the existence of an agency problem that makes external finance more expensive than internal funds. The entrepreneurs costless observe their output which is subject to a random outcome. External lenders incur an auditing cost to observe an entrepreneur's output. After observing her project outcome, an entrepreneur decides whether to repay her debt or to default. If she defaults, lenders audit the loan and recover the project outcome less monitoring costs. Accordingly, the marginal external financing cost is equal to a gross premium for external funds over the gross real opportunity costs equivalent to the riskless interest rate. Thus, the demand for capital should satisfy the following optimality condition which states that the real expected return on capital is equal to the real cost on external funds:

$$E_t f_{t+1} = (r_t - E_t \pi_{t+1}) + \omega(p_t^k + k_{t+1} - n_{t+1}) \tag{5}$$

The gross external finance premium ($prem$) depends on the borrowers leverage ratio ($p_t^k + k_t - n_t$) and the elasticity of the premium with respect to the leverage ratio (ω):

$$prem_t = E_t f_{t+1} - (r_t - E_t \pi_{t+1}) = \omega(p_t^k + k_{t+1} - n_{t+1}) \tag{6}$$

To ensure that entrepreneurs' net worth will never be sufficient to fully finance the new capital acquisition, I assume that entrepreneurs have a limited life span and the probability that entrepreneurs will survive until next period is ν. The entrepreneur's net worth is defined as

$$\frac{1}{\nu f} n_{t+1} = (lev) f_t - \omega(lev-1)(p^k_{t-1} + k_t) - (lev-1)(r_{t-1} - \pi_t) + [\omega(lev-1)+1] n_t \quad (7)$$

As the leverage ratio rises, the risk premium also rises. The higher risk premium will increase the cost of borrowing and, on the other hand, the lower price of capital will decrease the return on capital. Then, the entrepreneurial net worth will decrease at the end of the period and, other things being equal, the leverage ratio will be higher. This mechanism amplifies the recession.

Output is produced using capital (k_t) and labour services (l_t).

$$y_t = \Phi_P \left[\alpha k_t + (1-\alpha) l_t + \varepsilon^a_t\right] \quad (8)$$

The parameter α captures the share of capital in production, and the parameter Φ_P is one plus the share of fixed costs in production, reflecting the presence of fixed costs in production. Disturbances in total factor productivity are captured by the term $\varepsilon^a_t = \rho_a \varepsilon^a_{t-1} + \eta^a_t$ which follows an $AR(1)$ process with an IID-Normal error term.

The current capital services depend on capital installed in the previous period (k^p_{t-1}) and the degree of capital utilization (z_t)

$$k_t = k^p_{t-1} + z_t \quad (9)$$

where the accumulation of installed capital (k^p_t) is a function of the flow of investment and of the relative efficiency of these investment expenditures as captured by the investment specific technology disturbance:

$$k^p_t = \frac{(1-\delta)}{\gamma} k^p_{t-1} + \frac{\delta}{\gamma} i_t + \delta \gamma^2 \varphi \varepsilon^i_t \quad (10)$$

and the degree of capital utilization is a positive function of the rental rate of capital:

$$z_t = \frac{1-z^k}{z^k} r^k_t \quad (11)$$

where z^k determines the elasticity of utilization costs with respect to capital inputs. The rental rate of capital is derived by cost minimization

$$r_t^k = w_t + l_t - k_t \tag{12}$$

Price and wage setting follow a Calvo-price adjustment mechanism with partial indexation. Due to price stickiness and partial indexation, prices and wages adjust sluggishly to their desired mark-up. Price mark-up (μ_t^p) is determined, under monopolistic competition, as the difference between the marginal product of labour (mpl_t) and the real wage (w_t):

$$\mu_t^p = mpl_t - w_t = \alpha r_t^k + (1-\alpha) w_t + \varepsilon_t^a \tag{13}$$

Similarly the wage mark-up is determined as the difference between the real wage and the marginal rate of substitution between working and consuming:

$$\mu_t^w = w_t - mrs_t = w_t - \left[w_t \sigma_l l_t + \frac{1}{1-\frac{h}{\gamma}} c_t + \frac{\frac{h}{\gamma}}{1-\frac{h}{\gamma}} c_{t-1} \right] \tag{14}$$

where σ_l is the elasticity of labour supply with respect to the real wage and h is the habit parameter in consumption.

Profit maximization by price-setting firms gives rise to the following New-Keynesian Phillips curve:

$$\pi_t = \frac{1}{1+\beta\gamma\iota_p} \{\beta\gamma E_t \pi_{t+1} + \iota_p \pi_{t-1} + \pi_{mk} \mu_t^p\} + \varepsilon_t^p \tag{15}$$

where $\pi_{mk} = \dfrac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p[(\Phi_P - 1)\varkappa_p + 1]}$. Inflation ($\pi_t$) depends positively on past and expected future inflation, negatively on the current price mark-up, and positively on a price mark-up disturbance (ε_t^p). The price mark-up disturbance is assumed to follow an $ARMA(1,1)$ process with an IID-Normal error term: $\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p$. The inclusion of the MA term is designed to capture the high-frequency fluctuations in inflation. The speed of adjustment to the desired mark-up depends, among others, on the degree of price stickiness (ξ_p), the degree of indexation to past inflation (ι_p), the curvature of the Kimball goods market aggregator ($\varkappa_p$), and the steady-state mark-up, which in equilibrium is itself related to the share of fixed costs in production (Φ_P) through a zero-profit condition.

Similarly, Calvo-style wage setting implies

$$w_t = \frac{1}{1+\beta\gamma}\left\{\beta\gamma E_t\pi_{t+1} + w_{t-1} + \iota_w\pi_{t-1} - (1+\beta\gamma\iota_w)\pi_t + \beta\gamma E_t\pi_{t+1} + w_{mk}\mu_t^w\right\} + \varepsilon_t^w \quad (16)$$

where $w_{mk} = \dfrac{(1-\xi_w)(1-\beta\gamma\xi_w)}{\xi_w[(\Phi_w - 1)\varkappa_w + 1]}$. The real wage is a function of expected and past real wages, expected, current, and past inflation, the wage mark-up, and a wage mark-up disturbance (ε_t^w). The wage mark-up disturbance is assumed to follow an $ARMA(1,1)$ process with an IID-Normal error term: $\varepsilon_t^w = \rho_w\varepsilon_{t-1}^w + \eta_t^w - \mu_w\eta_{t-1}^w$. As in the case of the price mark-up shock, the inclusion of a MA term allows us to pick up some of the high-frequency fluctuations in wages. The speed of adjustment to the desired wage mark-up depends on the degree of wage stickiness (ξ_w), the degree of wage indexation (ι_w) and the demand elasticity for labour, which itself is a function of the steady-state labour market mark-up ($\Phi_w - 1$) and the curvature of the Kimball labour market aggregator ($\varkappa_w$).

Finally, the monetary authority follows a generalized Taylor rule in setting the short-term interest rate (r_t) in response to the lagged interest rate, current inflation, the current level and the current change in the output gap and an exogenous disturbance term $\varepsilon_t^r = \rho_r\varepsilon_{t-1}^r + \eta_t^r$ that is assumed to follow an $AR(1)$ process with an IID-Normal error term

$$r_t = \rho r_{t-1} + \rho_\pi(1-\rho)\pi_t + \rho_y(1-\rho)(y_t - y_t^P) + \rho_{dy}\left[(y_t - y_{t-1}) - (y_t^P - y_{t-1}^P)\right] + \varepsilon_t^r \quad (17)$$

To obtain the original model without financial frictions, it is sufficient to set the elasticity of the risk premium to the leverage ratio $\omega = 0$ and the steady-state of the leverage ratio $lev = 1$.

3 Methodology for estimation and model evaluation

The model presented in the previous section is estimated with Bayesian estimation techniques using seven key macroeconomic quarterly U.S. time series as observable variables: the log difference of real GDP, real consumption, real investment the log difference of the

GDP deflator, the real wage, log hours worked, and the federal funds rate[8]. The data sample is 1966-2010, at quarterly frequency[9]. The corresponding measurement equation is:

$$Y_t = \begin{bmatrix} d\log GDP_t \\ d\log CONS_t \\ d\log INV_t \\ d\log W_t \\ \log HOURS_t \\ d\log P_t \\ FEDFUNDS_t \end{bmatrix} = \begin{bmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{l} \\ \bar{\pi} \\ \bar{r} \end{bmatrix} + \begin{bmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ i_t - i_{t-1} \\ w_t - w_{t-1} \\ l_t \\ \pi_t \\ r_t \end{bmatrix} \tag{18}$$

where $\bar{\gamma} = 100(\gamma - 1)$ is the common quarterly trend growth rate to real GDP, consumption, investment and wages; $\bar{\pi} = 100\pi$ is the quarterly steady-state inflation rate and $\bar{r} = 100(\beta^{-1}\gamma^{\sigma}\bar{\pi})$ is the steady-state nominal interest rate; $\bar{l}$ is steady-state hours worked, which is normalized to be equal to zero.

Bayesian methods combine prior information on parameters from existing evidence with sample information as captured by the likelihood of data[10].

In specifying most of the prior distributions of parameters, I follow SW 2007. Therefore, for an exhaustive discussion of prior elicitation and estimation methodology, I refer the reader to Smets and Wouters (2003, 2007). Hereby, I discuss only the priors of parameters describing the entrepreneurial sector and related to the endogenous financial accelerator mechanism (hereafter, FA), which is lacking in the original setting. The steady-state of the external cost of financing is calibrated to $1/\beta$ =1.01; the elasticity of leverage with respect to premium is normally distributed with a mean 0.05 and a standard error 0.02

[8] The first four variables are provided by the U.S. Department of Commerce of the Bureau of Economic Analysis; wage and hours worked are provided by the U.S. Department of Labor, Bureau of Labor Statistics, interest rate is provided by the Board of Governors of the Federal Reserve System. A more detailed description of data is reported in the appendix.

[9] The dataset starts in 1947. As in the original Smets and Wouters (2003), I decided to shorten the sample to 1957:Q1-2010:Q1 by dropping the first 10 years, as they results not to be representative of the rest of the sample. In addition the first 10 years are used as a training sample for calculate the marginal likelihood of unconstrained VARs. Finally, the first 4 observation are skipped in order to evaluate the likelihood, so that the sample starts in 1967:Q1.

[10] Bayesian estimation methods of DSGE models have been initially proposed by Smets and Wouters (2003), Schorfheide and An (2005) and Del Negro et al. (2005). Smets and Wouters (2003) have applied full-information Bayesian methods to estimate a micro-founded macroeconometric model with rigidities and found that the model is competitive with an unrestricted Bayesian VAR, both in terms of goodness-of-fit and in terms of out-of-sample forecasting performance.

as in Carlstrom, Fuerst, Ortiz and Paustian (2012). The steady-state of the leverage ratio is also normally distributed in the range $[1, 3.5]$ with a mean 2 and a standard deviation 0.25. Finally, the probability of default, which varies in the range $[0, 1]$, is described by a beta distribution with mean 0.97 and standard deviation 0.02.

Bayesian model comparison is done pairwise by computing the Bayes factor which is the ration of the marginal likelihood[11] of two alternative models:

$$B_{ij} = \frac{p(Y \mid M_i)}{p(Y \mid M_j)} \tag{19}$$

4 Estimation results

In this section, I start presenting estimation results[12] for four alternative specifications of the SW models, summarized in Chart 1. As a first step, I consider two alternative versions of the SW model. The first version, defined as SW (2007) entails a risk premium shock which captures that interest rate faced by firms and households might be different from the policy rate because of some unmodelled frictions. This shock has similar effects as the so called net-worth shock in Bernanke, Gertler and Gilchrist (1999). On the contrary, the second version of the SW model, defined as SW (2003), does not feature the risk premium shock. Each of these two models is considered both in the original set-up and in an alternative set-up entailing a FA mechanism à la BGG (1999). Thereby, the number of model specifications rises to four. Finally, each of the four specifications is estimated both on the sample 1966:Q1-2010:Q1 and on a shorter sample up to 2004:Q4, in order to assess whether the recent global crisis has affected the main forces driving economic fluctuations. The basic idea is to assess whether the introduction of the FA mechanism emphasizes or (partially) invalidates the unmodelled frictions introduced through the risk premium shock. Moreover, the estimation results might help interpreting the recent economic developments and understanding whether or not the recent financial crisis has emphasized the role of fi-

[11] The most commonly used method to calculate the marginal likelihood is the modified harmonic mean because it works for all sampling methods and it is not sensitive to the step size. As an alternative, it is possible to use the Laplace approximation that assumes that the posterior distribution is close to a normal distribution. The advantage of using the Laplace approximation is that it can generate an approximation of the marginal likelihood very quickly, given the normality assumption and the estimated mode. The Laplace approximation results to work very well in practice and it is often very close to the modified harmonic mean.

[12] All estimations are done with Dynare, version 4.3 (www.dynare.org).

nancial factors. To this purpose, I first start comparing the alternative model specifications in term of their performance, and then I proceed to estimate model parameters.

Table 1 reports the log likelihood for each of the four specifications of the model over the two samples. The model comparison based on the maximum likelihood and Bayes factors outlines some important results. First, the risk premium shock plays a key role, especially during the recent crisis, as proved by the better performance of the SW (2007) model compared to the SW (2003) model. The intuition is that the risk premium shock in the SW (2007) model introduces some unmodelled frictions that are completely neglected in the SW (2003) model. Second, the performance of both the SW (2003) and SW (2007) model improves when the endogenous FA mechanism à la BGG is included. However, the relative improvement of the endogenous FA mechanism is slightly lower if the estimation is carried over the sample up to 2010. Third, when the last crisis is included in the estimation sample, the advantages of the SW (2007) model, compared to the SW (2003) model, are amplified, as provided by the log Bayes factor becoming larger than 10. To summarize, results suggest that financial factors turn to have played a key role.

Results derived from the model comparison are corroborated by the estimation results reported in Table 2. When the FA mechanism is operative, the risk premium shock results to be substantially more persistent, albeit less volatile. Opposite conclusions hold for the investment shock: the FA mechanism increases the volatility of the investment shock, but reduces its persistence. In addition, the analysis of the impulse response functions (hereafter, IRFs) based on the estimated parameters from the SW(2007) model reaches the same conclusions. Figure 1 and Figure 2 depict the IRFs of output and its components to the risk premium shock and the investment shock. The line marked by circle is from the original SW(2007) model without the FA mechanism, while the line marked by triangles is from the SW(2007) augmented with financial frictions. The IRFs prove that the FA mechanism emphasizes the negative effect of the risk premium shock on investment decisions and hence on output, while it reduces the impact of the investment shock. These results prove that the financial accelerator mechanism has emphasized – and not replaced – the role played by the risk premium shock.

The estimates of the parameters linked to the financial accelerator mechanism – namely the leverage ratio and the elasticity of the finance premium – prove that firms' balance sheets have slightly deteriorated during the recession. Surprisingly, the estimate of the elasticity of the external finance risk premium over the longer sample including the crisis period is lower than that one estimated on the pre-crisis sample. However, the elasticity in this work results to be relatively high compared to other papers. For instance, Gilchrist, Ortiz and Zakrajšek (2009) estimate the elasticity of the external finance risk premium equal to 0.01, while in this work the estimate is equal to 0.025. Moreover, the leverage ratio results to be very volatile in the more recent period, especially from 2006Q1 onwards[13]. Therefore, the relatively high value of the estimate of the elasticity of the external finance risk premium combined with the high volatility of the leverage ratio in the more recent period gives a high external finance risk premium, even though the elasticity results to be lower than that one estimated over the sample excluding the crisis period. More generally, the recent recession has increased the volatility of the U.S. economy. This is reflected in the higher variance of the variables, once recent data are included (Table 3). Concerning the U.S. corporate leverage ratio, in this paper the estimate is higher than the value estimated in Queijo (2009) over the sample up to 2007:Q4. This result confirms that during 2008-2009 corporate sector has been more leveraged.

Turning to structural parameters, once the endogenous FA mechanism operates and the crisis period is included into the estimation sample, monetary policy results to be less reactive to inflation. This result is in line with the view sometimes expressed by policy-makers aiming to avoid a worsening of market sentiment (*e.g.*, Bini Smaghi, 2008). The prospect of hitting the ZLB in 2008-2009 calls the FED to cut interest rates less aggressively than what they it would have done before 2005:Q1. An aggressive interest rate cut may be taken as a sign that policy-makers have a more pessimistic view of the economic outlook than market participants[14]. As a counterfactual, I have performed a conditional forecast of the interest rate starting in 2008Q2. The conditional forecast assumes that *(i)* the conditional path for the shocks over the horizon 2008Q2-2010Q1 imposes that shocks are exactly those produced by the model over the whole estimation sample; *(ii)* the conditional path for

[13] The series of the leverage ratio is not shown in this paper. However, data and figure are available up to request.

[14] An opposite recommendation is prescribed by a strand of literature on monetary policy in the vicinity of the zero bound. Among these authors, Adam and Billi (2006) argue that at low interest rates, forward looking agents anticipate the possibility that future shocks might push the interest rate down to the ZLB. As a result, output and inflation are lowered today. To counteract this amplification mechanism, the central bank must therefore cut rates pre-emptively in order to raise expectations of future inflation and output. Furthermore, using dynamic programming techniques, Orphanides and Wieland (2000) find that the policy rate becomes increasingly sensitive to inflation as it falls and the likelihood that the ZLB will be reached rises.

the monetary policy shock imposes that the monetary shock is zero. The latter assumption for the conditional forecast implies that the monetary authority exactly implements its regular Taylor rule and the ZLB constraint is not binding; *(iii)* the FED implements either the pre-crisis Taylor rule or the Taylor rule estimated over the whole sample. The conditional forecast shown in Figure 3 suggests some important results. First, if the ZLB were not binding, the FED should have cut the interest rate more aggressively than what it has effectively done. Of course, the FED cut the interest rate (mainly in 2008Q2 and 2008Q4, as proved by the observed series), but it was not allowed to further decrease the effective interest rate below the ZLB. Second, if the ZLB were not binding – as stated in the assumption *(ii)* – the Taylor rule estimated over the whole sample would respond more aggressively than the pre-crisis Taylor rule. If the ZLB were not binding, the interest rate would have been negative both before and during the crisis. However, in the case of the Taylor rule estimated over the whole sample, the interest rate decreases more than in the case of the pre-crisis Taylor rule. Finally, in 2008Q2, the FED has decreased the interest rate more aggressively than she would have done if she had no faced any monetary shock. This implies that in 2008Q2, the monetary shock to the Taylor rule was negative. This result points out that the FED has decreased interest rate pre-emptively, before the ZLB was hit. This result is in line with the evidence for the euro area found in Gerlach and Lewis (2010) who argue that after the autumn 2008, the ECB, in response to worsening economic conditions, has cut interest rates more rapidly than the regular reaction function would have predicted.

The estimation results help interpreting movements in the premium in relation to shocks driving the business cycle. Figure 4 plots impulse response functions (IRFs) for the external risk premium, based on estimated parameters. The analysis proves that the premium is not necessarily countercyclical. The external risk premium becomes procyclical after three periods, conditional on a productivity shock. This finding is consistent with De Graeve (2008), while it contrasts with Bernanke, Gertler and Gilchrist (1999) and Queijo (2009), in which favourable productivity shocks reduce the premium and therefore boost investment. As explained in De Graeve (2008), the primary reason for the different responses lies in the form of adjustment costs. This paper features investment adjustment costs, while Bernanke, Gertler and Gilchrist (1999) features capital adjustment costs. In the case of investment adjustment costs, if investment is positive today, it will be positive for a prolonged period, in order to minimize costs associated with changing its flow. This implies that, in case of the productivity shock, the capital stock outgrows net worth, thereby increasing borrowing needs and the external finance premium. The same conclusion holds for the risk premium shock: a positive[15] risk premium shock increases the cost of capital and hence reduces investment. As the capital stock is much lower than net worth, borrowing needs and hence the external finance risk premium decrease, as well as investment and total output. The investment shock also leads to a procyclical external premium, by implying a reduction in the price of capital and hence a decrease in net worth. As entrepreneurial borrowing needs increase, the external premium results to be procyclical. The government consumption shock, by crowding out private investments, reduces the price of capital and hence net worth. Borrowing needs increase and hence the external premium results countercyclical. The analysis proves that the positive effect on output of the productivity shock, the risk premium shock, the investment specific shock and the government spending shock are not overturned by the increase in the external risk premium. Therefore, the IRFs analysis proves how economic expansions may occur in the wake of increasing external finance premium. A price mark-up shock is associated with lower production and lower external premium: with higher market power, firms have an incentive to reduce production to maximize profits and are less limited in borrowing. Finally, the external finance premium is countercyclical conditional on a monetary policy shock. This finding is in line with those of Bernanke, Gertler and Gilchrist (1999) and De Graeve (2008): an exogenous rise in the interest rate lowers asset prices and net worth. Since firms are leveraged, net worth falls more than asset prices, leading to an increase in firms' borrowing needs and in the external finance risk premium.

To conclude, estimation results prove that during the crisis financial frictions not only have become more relevant, but they have also emphasized the effect of the risk premium shock. An argument that might be raised to this analysis is that this work attempts to estimate this financial-type shock without including any financial variable (*e.g.* interest rate spreads) among observables. In this respect, I refer to Gilchrist, Ortiz and Zakrajšek (2009). They also estimate the Smets and Wouters (2007) model, augmented with a financial accelerator mechanism and extended to 2009:Q1. Their analysis differs in the number of shocks and

[15] Here positive refers to the fact that the risk premium is increasing, and not to the effects of the risk premium shock on output. A positive risk premium shock increases both the require return on assets and the cost of capital, and thereby it reduces both output components, that is consumption and investment.

selected variables: they include two financial shocks (namely, an external finance premium shock and a net-worth shock) and then they add to the set of observables two financial series, the logarithm of the leverage ratio and the credit spread. I point out that, even without adding additional financial shocks and financial series, the estimates obtained in this work are very close to those in Gilchrist, Ortiz and Zakrajšek (2009). Moreover, they calibrate the steady-state leverage ratio at $lev = 1.7$, the value that corresponds to the average leverage ratio in the U.S. non-financial corporate sector over the sample period. Then, they estimate only the elasticity of the external finance premium and they conclude in favour of the presence of a financial accelerator mechanism even though they obtained a low estimate of the elasticity of the external premium. Hereby, compared to Gilchrist, Ortiz and Zakrajšek (2009), the estimate of the elasticity of the external premium results to be higher and the estimate of the leverage ratio is extremely close to their calibrated value. These findings provide a stronger support in favour of the presence of an operative financial accelerator mechanism in the U.S. economy.

5 What were the main driving forces behind the financial recession in 2007-2008?

5.1 Variance decomposition

Table 4 reports the contribution of each shock to the variance of the observed macroeconomic variables of both the model with financial frictions and the model without financial frictions. This decomposition provides insight into the main forces driving economic fluctuations. The contribution of each of the structural shocks to variance of the observed variables is reported on impact and at various horizons (2.5 years and 10 years). For the sake of simplicity, I focus the analysis only on the SW (2007) with endogenous financial frictions, given that it yields the best performance in terms of likelihood, as proved in section 4.

The dominant forces behind short-term developments in the output are the productivity shock, the risk premium shock and the government shock. If the recession is introduced in conjunction with endogenous financial frictions, the risk premium becomes the dominant source of output fluctuations in the model entailing the recession. Confirming the large identified VAR literature on the role of monetary policy shocks (*e.g.* Christiano, Eichenbaum and Evans (2000)), monetary policy shocks contribute only a small fraction of the variance of output at all horizons.

Looking at the determinant of consumption, regardless of the presence of endogenous financial frictions, at any horizon a big part of the variations is explained by the risk premium shock, especially before the occurrence of the crisis.

Not surprisingly, the investment shock explains the largest part of investment at any horizon. In the presence of endogenous financial frictions, the monetary policy shock causes a great deal of movements in the premium and partially replaces the investment shock in explaining variations in investment, especially during the occurrence of the crisis when financial frictions have played a determinant role. Therefore, the relevance of the investment shock is muted. Although the risk premium shock affects both components of output, it has a larger impact on consumption than investment, and the main source behind fluctuations in investment remains the investment shock.

By affecting output, the risk premium also affects hours worked and therefore proves to be the main source of short-run fluctuations also in hours worked. Similarly to output and consumption, the concomitance of the recession and the presence of endogenous financial frictions strengthens the role played by the risk premium shock. However, in the long-run, the wage mark-up shock becomes the dominant factor behind movements in hours worked.

Turning to the determinants of inflation, variations in the short-term inflation are mainly driven by the price mark-up shock. In the model without financial frictions, in the long-run, the wage mark-up shock dominates the price mark-up shock. This outcome remains valid also in the model entailing financial frictions estimated up to 2004. However, once the sample is extended up to 2010, the recession emphasizes the role played by the price mark-up shock, which remains the dominant source of inflation variations both in the short-run and in the long-run. Monetary policy shock accounts only for a small fraction of inflation volatility. At the short and medium-term horizon, most of variations in the nominal interest rate are due to the various demand and productivity shocks. Once the estimation sample is extended to include the recession, the monetary policy is less aggressive due to the binding zero lower bound constraint. In this case, the price mark-up shock accounts for an even smaller fraction of inflation volatility.

Finally, wage developments are mostly explained by wage mark-up shock at any horizon.

To some extent, this finding is not very surprising as wages are estimated to be highly sticky. It is therefore not very surprising that one needs quantitatively important shocks to account for the behaviour of wages.

To summarize, the variance decomposition confirms that the FA mechanism emphasizes the role of the risk premium shock in driving the economic activity, especially during the recession in 2007-2008, while it reduces the overall relevance of the investment shock, especially in the long-run.

5.2 Historical decomposition

Figures 6-8 summarize the historical contribution of the various structural shocks to output developments and credit conditions in the U.S. from 2000 onwards, with a particular focus on the recent crisis. This decomposition is based on the best estimates of the various shocks in the SW (2007) model with the endogenous FA mechanism. While obviously such decomposition must be treated with caution, it helps in understanding how the estimated model interprets specific movements in the observed data and therefore can shed some light on its plausibility.

Focusing on the decomposition of output, the risk premium shock and the investment shock account for a significant portion of drop in output from 2007 onwards (Figure 6). This result accords well with the considerable damage that the recent financial crisis and recession have inflicted on the economy between the middle of 2007 and early 2009, notably a significant tightening of credit. Moreover, the financial crisis has raised the cost of capital and hence discouraged investment. On the opposite side, fiscal policy has contributed quite significantly to the surge in output during the crisis. The stimulus package passed in early 2009 has successfully supported employment and output. However, in some quarters, much of the fiscal stimulus has been offset by consolidation measures at state and local level. Furthermore, accordingly to OECD data[16], productivity has increased strongly in the U.S. during the recession, and hence the fall in output has been moderate compared to other countries. Going backward, monetary policy and price mark-up shock also account for a portion of output variation between 2001 and 2006. In January 2001, as the economy weakened rapidly following the collapse of the dotcom bubble, the FED started to loosen monetary policy. The loose monetary policy contributed to the surge in output between

[16] OECD (2010), *Economic Survey of the United States*, OECD, Paris.

2001 and 2004. Then, starting in June 2004, the FOMC increased interest rates gradually until June 2006. The unexpected hike in interest rates accounts for a portion of drop in output between 2005 and 2007. Then, when the crisis was acute, the transmission mechanism of the monetary policy stimulus through its traditional instrument – the nominal interest rate – was less effective. With policy rates near to the lower bound, the FED was forced to use unconventional monetary policy measures to support activity in capital markets and the impaired banking system.

Similar conclusions are drawn for the decomposition of output components, that is consumption and investment[17]. According to national data, credit conditions tightened significantly and consumer and business expenditures fell 6% between the second quarter of 2008 and the second quarter of 2009. Concerning consumption, the risk premium shock, as a proxy of tightening credit conditions, explains the sharp increase during the crisis in the desire of households to save – for precautionary reasons – rather than spend. Concerning investments, the risk premium shock has limited lending opportunities to business and hence has depressed investments.

The analysis points out that the risk premium shock, by introducing unmodelled frictions, play an important role in business cycle. The direction of the risk premium shock has reversed course sharply in 2007—that is, from having a significantly expansionary effect on output (as well as on its components, consumption and investment) during the period 2004-2006 to having a negative influence on investment spending by the middle of 2007. This result supports the idea that financial crisis recessions tend to go hand in hand with slowdown in credit growth. One possible interpretation of the risk premium shock is that it behaves as a proxy of the health condition of the financial system. To corroborate this intuition, Figure 5 proves the existence of a correlation of the smoothed risk premium shock and the OECD Financial Condition index[18]. This index proves a tightening of financial conditions in the U.S. starting from the second half of 2008. Hereby the risk premium shock plays a similar role as the net-worth shock in Bernanke, Gertler and Gilchrist (1999)[19]. The

[17] Figures with historical decomposition of consumption and investment are available upon request.

[18] A increase (decline) in the index implies an easing (tightening) of financial conditions, while a positive (negative) risk premium shock implies a contraction (expansion) in both consumption and investment and hence in output..

[19] Similarly, Justiniano, Primiceri and Tambarlotti (2011) demonstrate that a marginal-efficiency investment shock, that is a shock that affects the transformation of investment goods into productive capital, results to be the most important source of macro fluctuations. This specific investment shock plays a similar economic role to that of net worth in Carlstrom and Fuerst (1997). As a counterfactual, they re-estimate the model including the spread among the observables, but the interpretation of the marginal-efficiency

important difference is the risk premium shock is just an exogenous disturbance, while net worth is a key endogenous variable in the agency cost model.

Figure 7 depicts historical fluctuations of the leverage ratio based on the estimation results. The historical decomposition shows that the leverage ratio has peaked in the third quarter of 2008. More precisely, following the period of relatively low external financing costs, the leverage ratio has experienced a rise peaking in the third quarter of 2008. Then after 2008, leverage ratio has started to decrease, because households and companies seek to reduce leverage, so that spending and investment are primarily constrained by balance-sheet repair, not by the availability of credit[20]. The gradual decline in the leverage ratio reflects the contraction in firms' need for external financing due to lower level of economic activity and weaker capital formation. The concomitance of a peak in leverage ratio and the deepening of the recession supports the argument that leverage and credit play a relevant role in shaping the business cycle, in particular the intensity of recessions. The underlying idea is that financial accelerator effects are also likely to be stronger when balance sheets are larger and thus more vulnerable to weakening.

6 Conclusions and policy implications

This paper provides evidence in support of the notion that financial frictions play an important role in the U.S. cyclical fluctuations. Based on the likelihood of alternative models, one first set of results suggests that the recent crisis has amplified the relevance of financial factors. Moreover, both estimates and the variance decomposition prove that the introduction of an endogenous FA mechanism has increased the role played by the risk premium shock, especially during the recession in 2007-2008, while it has decreased the relevance of the investment shock, especially in the long-run. The historical decomposition shows that the model entailing financial frictions is suitable to capture much of the historical developments in financial markets that led to episodes of financial crisis in 2007-2008. In addition, the concomitance of a peak in the leverage ratio and the deepening of the recession supports the argument that leverage and credit have an important role to play in shaping the business cycle, in particular the intensity of recessions.

investment shock as a proxy for the efficiency of the financial system remains valid.

[20] For instance, Mian and Sufi (2011) study economic developments in individual U.S. counties during the Great Recession. They find that higher income leverage going into the crisis is associated with much weaker spending growth after crisis.

The model also explains the gradual decline in the leverage ratio starting in the second quarter of 2009. On the demand side, lower levels of economic activity and weaker capital formation have contributed to reduce firms' need for external financing. On the supply side, the tighter credit standards applied by banks have contributed to firms' deleveraging by curtailing the growth of bank loans to the non-financial corporate sector. Even though this framework does not feature credit-supply factors, results are consistent with the argument that the tighter credit standards applied by banks have contributed to firms' deleveraging by curtailing the growth of bank loans to the non-financial corporate sector[21].This set of results supports the argument that financial market frictions arising from asymmetric information and moral hazard play an important macroeconomic role as an amplification mechanism for disturbances in the economy.

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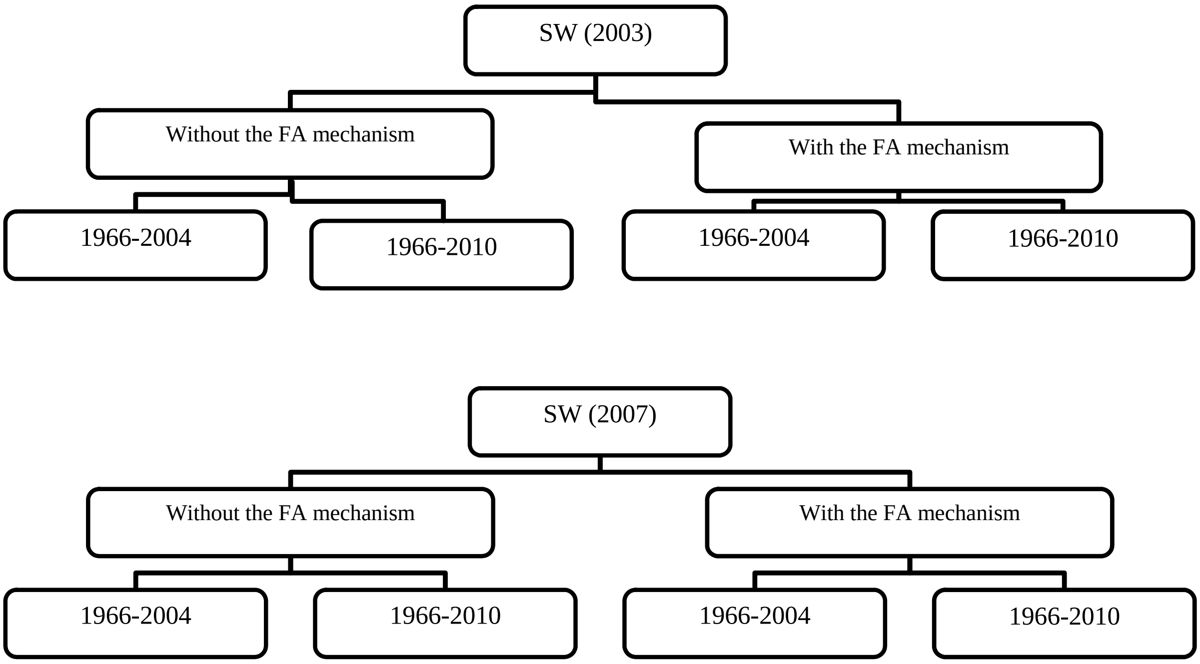

Chart 1: Flow-chart of alternative specifications of the model

	Without financial accelerator		With financial accelerator	
Estimation sample	SW (2007)	SW (2003)	SW (2007)	SW (2003)
1966-2004	-930	-939	-915	-924
1966-2010	-1074	-1086	-1060	-1072

Table 1: Comparison of the marginal likelihood (Laplace approximation) of alternative model specifications over alternative samples.

Estimation sample 1966-2010				Without financial accelerator				With financial accelerator			
parameters		Prior		Posterior SW (2007)		Posterior SW (2003)		Posterior SW (2007)		Posterior SW (2003)	
		Mean	s.d.	post. mode	post. s.d.	post. mode	post. s.d.	post. mode	post. s.d.	post. mode	post. s.d.
ρa	AR term in productivity shock	0.5	0.2	0.965	0.009	0.965	0.008	0.963	0.013	0.960	0.009
$\rho\beta$	AR term in preference shock	0.5	0.2	-	-	0.314	0.089	-	-	0.370	0.114
ρb	AR term in risk premium shock	0.5	0.2	0.408	0.109	-	-	0.736	0.069	-	-
ρg	AR term in gov. spending shock	0.5	0.2	0.965	0.008	0.965	0.008	0.970	0.010	0.977	0.008
ρi	AR term in investment shock	0.5	0.2	0.808	0.047	0.749	0.047	0.668	0.071	0.730	0.056
ρr	AR term in interest rate shock	0.5	0.2	0.191	0.070	0.207	0.073	0.160	0.067	0.263	0.078
ρp	AR term in inflation shock	0.5	0.2	0.910	0.041	0.915	0.038	0.893	0.042	0.908	0.039
ρw	AR term in wage shock	0.5	0.2	0.971	0.013	0.968	0.015	0.933	0.026	0.905	0.038
μp	MA term in price shock	0.5	0.2	0.785	0.073	0.792	0.070	0.775	0.076	0.787	0.074
μw	MA term in wage shock	0.5	0.2	0.944	0.024	0.944	0.024	0.895	0.038	0.862	0.052
φ	investment adjustment costs	4	1.5	4.310	1.001	5.468	1.182	3.197	0.769	5.471	1.112
σ	σ consumption	1.5	0.375	1.483	0.181	1.496	0.197	1.165	0.241	1.399	0.176
h	habit in consumption	0.7	0.1	0.628	0.065	0.641	0.063	0.587	0.081	0.626	0.064
ξw	wage Calvo adjustment	0.5	0.1	0.828	0.046	0.838	0.046	0.829	0.040	0.854	0.034
σL	σ labour supply	2	0.75	1.544	0.617	1.414	0.641	1.934	0.539	2.080	0.555
ξp	price Calvo adjustment	0.5	0.1	0.741	0.046	0.737	0.045	0.772	0.040	0.753	0.038
ιw	wage indexation	0.5	0.15	0.594	0.129	0.585	0.129	0.578	0.132	0.590	0.129
ιp	price indexation	0.5	0.15	0.218	0.086	0.225	0.088	0.235	0.091	0.224	0.089
zk	steady-state capital utilization rate	0.5	0.15	0.757	0.103	0.752	0.102	0.634	0.130	0.692	0.103
Φp	Fixed cost in production	1.25	0.125	1.666	0.075	1.714	0.077	1.482	0.084	1.584	0.075
$\rho\pi$	T.R. coefficient on inflation	1.5	0.25	1.746	0.166	1.590	0.165	1.629	0.161	1.387	0.116
ρ	T.R. interest rate smoothing	0.75	0.1	0.798	0.028	0.774	0.034	0.793	0.029	0.716	0.044
ρy	T.R. coefficient on output	0.125	0.05	0.051	0.018	0.038	0.017	0.065	0.022	0.027	0.016
ρdy	T.R. coefficient on d(output)	0.125	0.05	0.220	0.026	0.214	0.028	0.229	0.025	0.220	0.027
π	steady-state inflation rate	0.625	0.1	0.679	0.066	0.669	0.063	0.796	0.086	0.765	0.109
$100[(1/\beta)-1]$	steady-state nominal interest rate	0.25	0.1	0.210	0.091	0.210	0.091	0.171	0.074	0.119	0.050
l	steady-state hours worked	0	2	-0.623	1.106	-0.758	1.186	-0.854	0.829	-1.295	0.981
$trend$	trend growth rate	0.4	0.1	0.434	0.017	0.437	0.017	0.409	0.016	0.411	0.012
ηga	response of gov.spending to prod. shock	0.5	0.25	0.614	0.085	0.618	0.086	0.542	0.076	0.542	0.079
α	capital share in production	0.3	0.05	0.205	0.039	0.226	0.040	0.163	0.018	0.178	0.015
lev	leverage ratio	2	0.5	-	-	-	-	1.692	0.295	1.871	0.328
v	surviving rate	0.97	0.02	-	-	-	-	0.992	0.005	0.975	0.010
ω	elasticity external risk premium	0.05	0.02	-	-	-	-	0.025	0.009	0.033	0.013
σa	σ productivity shock	0.1	2	0.457	0.026	0.452	0.026	0.488	0.029	0.474	0.027
$\sigma\beta$	σ preference shock	0.1	2	-	-	0.219	0.027	-	-	0.199	0.031
σb	σ risk premium shock	0.1	2	0.198	0.029	-	-	0.124	0.019	-	-
σg	σ government spending shock	0.1	2	0.530	0.028	0.531	0.028	0.501	0.027	0.509	0.027
σi	σ investment shock	0.1	2	0.435	0.041	0.465	0.049	0.529	0.050	0.507	0.053
σr	σ interest rate shock	0.1	2	0.234	0.014	0.234	0.014	0.233	0.014	0.240	0.015
σp	σ inflation shock	0.1	2	0.134	0.015	0.132	0.015	0.137	0.015	0.132	0.015
σw	σ wage shock	0.1	2	0.284	0.021	0.282	0.021	0.275	0.021	0.270	0.021

Table 2-panel A: Estimation results (sample: 1966-2010)

Estimation sample 1966-2004				Without financial accelerator				With financial accelerator			
parameters		Prior		Posterior SW (2007)		Posterior SW (2003)		Posterior SW (2007)		Posterior SW (2003)	
		Mean	s.d.	post. mode	post. s.d.	post. mode	post. s.d.	post. mode	post. s.d.	post. mode	post. s.d.
ρ_a	AR term in productivity shock	0.5	0.2	0.957	0.012	0.959	0.010	0.940	0.017	0.942	0.015
ρ_β	AR term in preference shock	0.5	0.2	-	-	0.162	0.077	-	-	0.217	0.092
ρ_b	AR term in risk premium shock	0.5	0.2	0.197	0.085	-	-	0.293	0.121	-	-
ρ_g	AR term in gov. spending shock	0.5	0.2	0.964	0.009	0.963	0.009	0.974	0.010	0.976	0.009
ρ_i	AR term in investment shock	0.5	0.2	0.744	0.068	0.661	0.061	0.602	0.068	0.580	0.063
ρ_r	AR term in interest rate shock	0.5	0.2	0.127	0.066	0.126	0.065	0.116	0.063	0.119	0.065
ρ_p	AR term in inflation shock	0.5	0.2	0.922	0.046	0.923	0.046	0.890	0.051	0.887	0.051
ρ_w	AR term in wage shock	0.5	0.2	0.973	0.014	0.976	0.012	0.918	0.029	0.913	0.032
μ_p	MA term in price shock	0.5	0.2	0.773	0.093	0.777	0.093	0.732	0.105	0.726	0.107
μ_w	MA term in wage shock	0.5	0.2	0.916	0.050	0.927	0.043	0.836	0.057	0.834	0.060
φ	investment adjustment costs	4	1.5	5.167	1.070	6.114	1.165	4.840	1.005	5.956	1.104
σ	σ consumption	1.5	0.375	1.463	0.149	1.528	0.148	1.326	0.156	1.485	0.147
h	habit in consumption	0.7	0.1	0.688	0.047	0.677	0.045	0.688	0.054	0.658	0.047
ξ_w	wage Calvo adjustment	0.5	0.1	0.768	0.068	0.776	0.063	0.797	0.053	0.808	0.051
σ_L	σ labour supply	2	0.75	1.753	0.636	1.699	0.637	2.326	0.555	2.332	0.551
ξ_p	price Calvo adjustment	0.5	0.1	0.665	0.063	0.668	0.068	0.703	0.050	0.698	0.050
ι_w	wage indexation	0.5	0.15	0.551	0.145	0.541	0.146	0.544	0.143	0.543	0.142
ι_p	price indexation	0.5	0.15	0.295	0.113	0.302	0.117	0.287	0.109	0.294	0.112
zk	steady-state capital utilization rate	0.5	0.15	0.537	0.122	0.562	0.121	0.456	0.119	0.516	0.133
Φ_p	Fixed cost in production	1.25	0.125	1.713	0.076	1.729	0.078	1.576	0.078	1.592	0.078
ρ_π	T.R. coefficient on inflation	1.5	0.25	2.022	0.178	1.975	0.179	1.885	0.184	1.869	0.189
ρ	T.R. interest rate smoothing	0.75	0.1	0.822	0.024	0.821	0.024	0.802	0.025	0.799	0.026
ρ_y	T.R. coefficient on output	0.125	0.05	0.085	0.025	0.087	0.025	0.089	0.023	0.086	0.022
ρ_{dy}	T.R. coefficient on d(output)	0.125	0.05	0.221	0.027	0.224	0.028	0.222	0.025	0.225	0.026
π	steady-state inflation rate	0.625	0.1	0.658	0.077	0.638	0.074	0.791	0.099	0.786	0.126
$100[(1/\beta)-1]$	steady-state nominal interest rate	0.25	0.1	0.210	0.091	0.210	0.091	0.149	0.059	0.131	0.053
l	steady-state hours worked	0	2	0.526	0.989	0.690	0.957	-0.107	0.813	-0.012	0.854
trend	trend growth rate	0.4	0.1	0.443	0.017	0.446	0.016	0.422	0.013	0.420	0.014
η_{ga}	response of gov.spending to prod. shock	0.5	0.25	0.640	0.097	0.633	0.097	0.573	0.089	0.559	0.090
α	capital share in production	0.3	0.05	0.266	0.045	0.269	0.045	0.193	0.018	0.194	0.017
lev	leverage ratio	2	0.5	-	-	-	-	1.607	0.263	1.701	0.280
v	surviving rate	0.97	0.02	-	-	-	-	0.986	0.009	0.985	0.015
ω	elasticity external risk premium	0.05	0.02	-	-	-	-	0.031	0.015	0.030	0.017
σ_a	σ productivity shock	0.1	2	0.431	0.027	0.429	0.027	0.460	0.028	0.457	0.028
σ_β	σ preference shock	0.1	2	-	-	0.251	0.024	-	-	0.240	0.026
σ_b	σ risk premium shock	0.1	2	0.242	0.024	-	-	0.227	0.030	-	-
σ_g	σ government spending shock	0.1	2	0.540	0.031	0.542	0.031	0.527	0.030	0.531	0.031
σ_i	σ investment shock	0.1	2	0.449	0.048	0.515	0.055	0.554	0.054	0.598	0.057
σ_r	σ interest rate shock	0.1	2	0.237	0.014	0.236	0.014	0.233	0.014	0.233	0.014
σ_p	σ inflation shock	0.1	2	0.124	0.017	0.123	0.017	0.123	0.017	0.124	0.017
σ_w	σ wage shock	0.1	2	0.266	0.026	0.267	0.027	0.247	0.025	0.246	0.025

Table 2-panel B: Estimation results (sample: 1966-2004)

Note: In Table 2 panel A and panel B, the column headed "Prior" reports the mean and the standard deviation of the prior distribution (see Section 3 of the text). The column headed "Posterior" reports the estimates of the mode and the standard deviation as discussed in Section 4. Estimates are reported for both specifications of the Smets and Wouters model (2003, 2007).

Variable	1966-2010	1966-2004
Output	0.97	0.88
Consumption	0.63	0.49
Investment	6.05	4.68
Labour	6.47	5.00
External risk premium	0.04	0.02

Table 3: Variance of selected variables (SW(2007) model with financial frictions)

shocks / variables		Model with FA: SW (2007) 1966-2010							Model with FA: SW (2007) 1966-2004						
		productivity	risk premium	gov. spending	investment	interest rate	inflation	wage	productivity	risk premium	gov. spending	investment	interest rate	inflation	wage
t=0	output	23.67	29.90	24.63	8.72	11.38	1.65	0.05	18.62	24.80	34.37	14.66	5.77	1.72	0.06
	cons.	7.97	66.78	3.12	0.01	17.70	2.01	2.41	2.69	80.40	2.26	0.01	9.81	1.91	2.93
	invest.	1.99	8.64	0.21	77.63	9.88	0.97	0.68	3.11	2.27	0.63	88.70	4.61	0.67	0.00
	int. rate	5.98	35.35	1.37	1.43	48.24	6.35	1.27	9.48	22.66	1.71	2.18	54.82	6.85	2.29
	inflation	2.00	0.35	0.11	0.03	0.74	85.87	10.90	2.57	0.02	0.10	0.19	0.88	79.21	17.03
	wage	0.93	0.46	0.00	0.11	0.20	20.64	77.66	0.91	0.32	0.01	0.24	0.22	22.20	76.10
	labour	14.41	33.40	27.94	9.76	12.70	1.16	0.63	20.75	23.86	33.81	14.06	5.45	0.62	1.45
t=10	output	21.23	30.30	21.04	9.84	12.15	3.65	1.79	17.11	23.54	29.39	15.52	6.72	3.82	3.90
	cons.	9.31	59.18	3.48	0.96	16.51	4.41	6.15	4.41	64.32	3.44	0.98	9.94	5.44	11.48
	invest.	3.30	9.20	0.28	72.77	10.67	2.67	1.11	4.87	3.27	0.98	83.32	5.03	1.60	0.93
	int. rate	7.01	45.55	1.73	5.87	18.04	8.97	12.82	14.16	12.27	2.54	11.03	22.52	14.03	23.45
	inflation	4.33	0.90	0.51	0.05	2.88	54.05	37.28	3.72	0.50	0.31	0.40	3.00	44.29	47.78
	wage	2.34	1.11	0.00	0.42	0.78	20.72	74.63	2.14	0.40	0.02	0.76	0.66	22.78	73.23
	labour	2.26	28.89	10.61	11.77	20.17	13.64	12.66	4.44	7.57	15.28	15.99	12.40	12.49	31.83
t=40	output	21.13	29.91	20.17	10.09	12.12	4.37	2.21	17.43	22.63	28.26	15.47	6.74	4.61	4.86
	cons.	9.35	58.22	3.45	1.24	16.17	4.89	6.68	4.65	61.65	3.36	1.15	9.79	6.30	13.10
	invest.	3.73	9.71	0.33	70.22	10.77	3.71	1.53	5.53	3.14	1.08	81.55	5.01	2.12	1.57
	int. rate	7.55	40.44	2.81	6.97	15.22	7.73	19.28	12.42	13.11	3.34	11.54	19.25	11.96	28.38
	inflation	4.22	1.92	0.98	0.46	3.01	49.18	40.24	3.46	2.55	0.55	0.97	3.05	41.11	48.31
	wage	2.51	1.44	0.00	0.56	0.86	21.21	73.42	2.33	0.43	0.03	0.91	0.71	23.52	72.07
	labour	1.95	19.55	11.22	8.98	14.29	13.24	30.76	3.13	4.68	14.07	10.55	7.64	9.80	50.12

Table 4-panel A: Variance decomposition (SW(2007 model with the FA mechanism)

shocks / variables		Model without FA: SW (2007) 1966-2010							Model without FA: SW (2007) 1966-2004						
		productivity	risk premium	gov. spending	investment	interest rate	inflation	wage	productivity	risk premium	gov. spending	investment	interest rate	inflation	wage
t=0	output	17.99	25.89	29.38	17.13	7.94	1.61	0.06	17.20	22.84	33.84	19.03	5.43	1.63	0.03
	cons.	2.91	75.96	0.61	0.32	16.51	1.01	2.68	2.40	81.05	0.55	0.21	12.29	0.81	2.69
	invest.	1.81	7.64	0.31	83.32	4.87	1.95	0.09	2.62	4.23	0.66	87.94	3.00	1.54	0.00
	int. rate	6.23	25.52	1.96	3.35	54.35	7.07	1.51	7.63	20.99	2.03	3.38	57.26	6.25	2.46
	inflation	2.09	0.32	0.26	1.65	1.13	82.74	11.81	2.63	0.25	0.24	1.79	1.49	76.69	16.91
	wage	0.85	0.16	0.00	0.27	0.14	21.69	76.89	1.27	0.36	0.01	0.46	0.33	22.91	74.66
	labour	17.17	26.15	29.93	17.21	7.97	1.07	0.50	18.07	22.28	33.97	18.43	5.13	0.43	1.68
t=10	output	15.38	21.83	23.33	23.49	8.89	4.55	2.53	15.48	19.53	27.63	22.49	6.31	4.21	4.33
	cons.	4.93	59.95	0.98	4.66	16.42	4.53	8.51	4.94	62.22	1.22	2.02	12.56	4.35	12.68
	invest.	2.98	5.07	0.47	81.71	4.66	4.21	0.89	4.27	2.93	1.09	84.08	2.91	3.34	1.39
	int. rate	6.48	14.02	2.84	41.55	16.84	6.68	11.58	8.61	8.97	3.05	34.69	17.42	8.99	18.27
	inflation	4.04	0.89	0.96	5.47	3.97	47.74	36.94	3.47	0.49	0.63	4.76	4.40	40.19	46.07
	wage	2.13	0.32	0.01	2.70	0.77	22.06	72.02	3.23	0.41	0.04	2.40	0.94	23.79	69.19
	labour	2.19	9.36	9.37	41.50	13.05	13.69	10.85	3.03	5.95	12.31	31.71	9.16	11.46	26.38
t=40	output	15.07	20.78	22.19	24.90	8.98	5.26	2.82	15.58	18.81	26.69	23.02	6.42	4.85	4.64
	cons.	4.94	58.29	0.98	5.37	16.58	5.06	8.78	5.02	60.76	1.22	2.16	12.80	4.84	13.20
	invest.	2.99	4.64	0.46	81.28	4.65	4.81	1.17	4.39	2.75	1.09	83.59	2.92	3.74	1.53
	int. rate	6.30	11.28	3.73	40.62	13.74	5.64	18.68	7.50	7.30	3.30	32.07	14.34	7.48	28.00
	inflation	3.95	0.83	1.54	5.70	3.87	40.04	44.08	3.01	0.42	0.77	4.50	3.96	33.65	53.68
	wage	2.25	0.35	0.02	3.11	0.87	22.57	70.83	3.34	0.42	0.08	2.55	1.06	24.58	67.97
	labour	1.44	4.97	7.01	26.37	7.71	13.53	38.97	1.68	2.71	7.68	16.04	4.38	8.56	58.95

Table 4-panel B: Variance decomposition (SW(2007) model without the FA mechanism)

Note: In Table 4 panel A and panel B, the contribution of each structural shock (rows) to variance of observed variables (columns) is reported on impact (t=1) and at various horizons (2.5 years and 10 years)

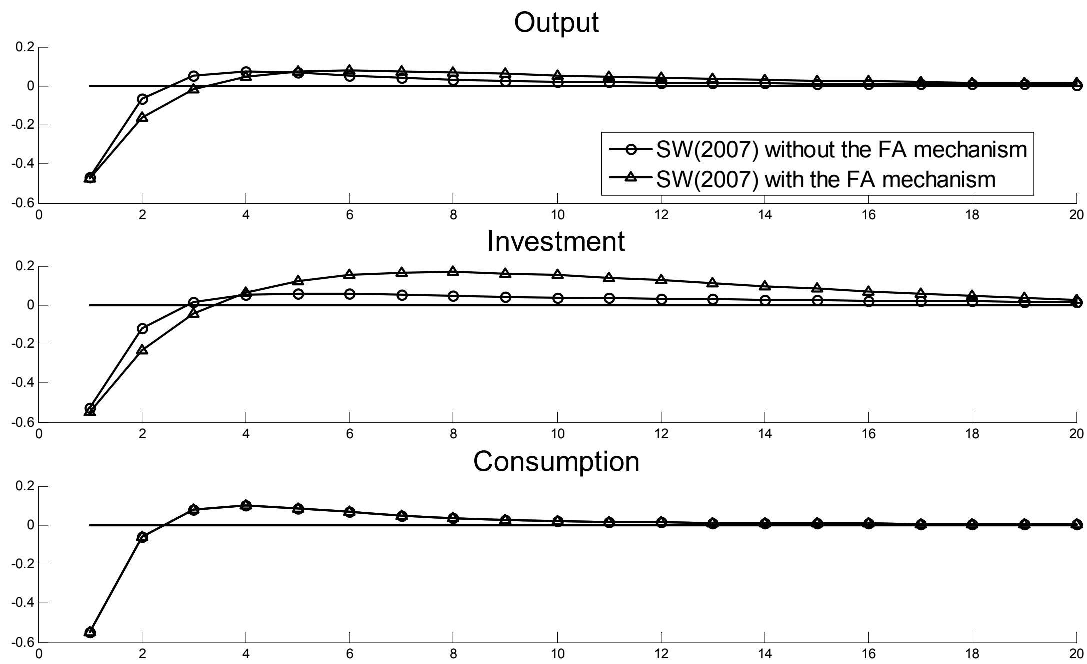

Figure 1: IRFs to the risk premium shock

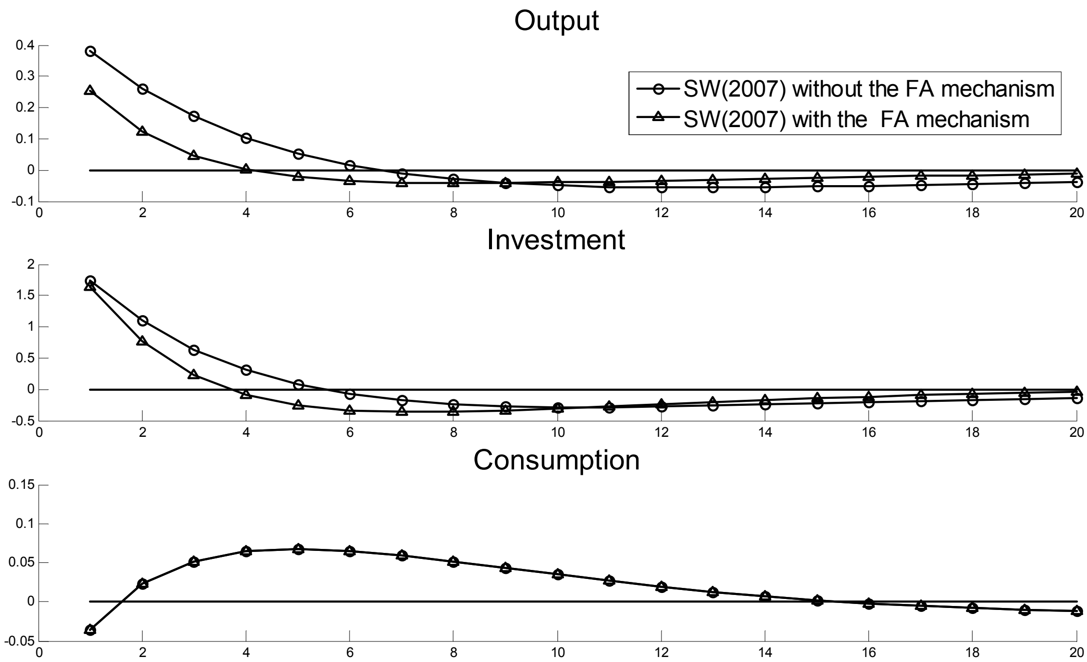

Figure 2: IRFs to the investment shock

Note: Variables showed in Figure 1 and Figure 2 are percentage deviations from the steady-state. The line marked with circles is from the original SW(2007) model. The line marked with triangles is from the SW(2007) model augmented by financial frictions. The IRFs are based on estimated parameters.

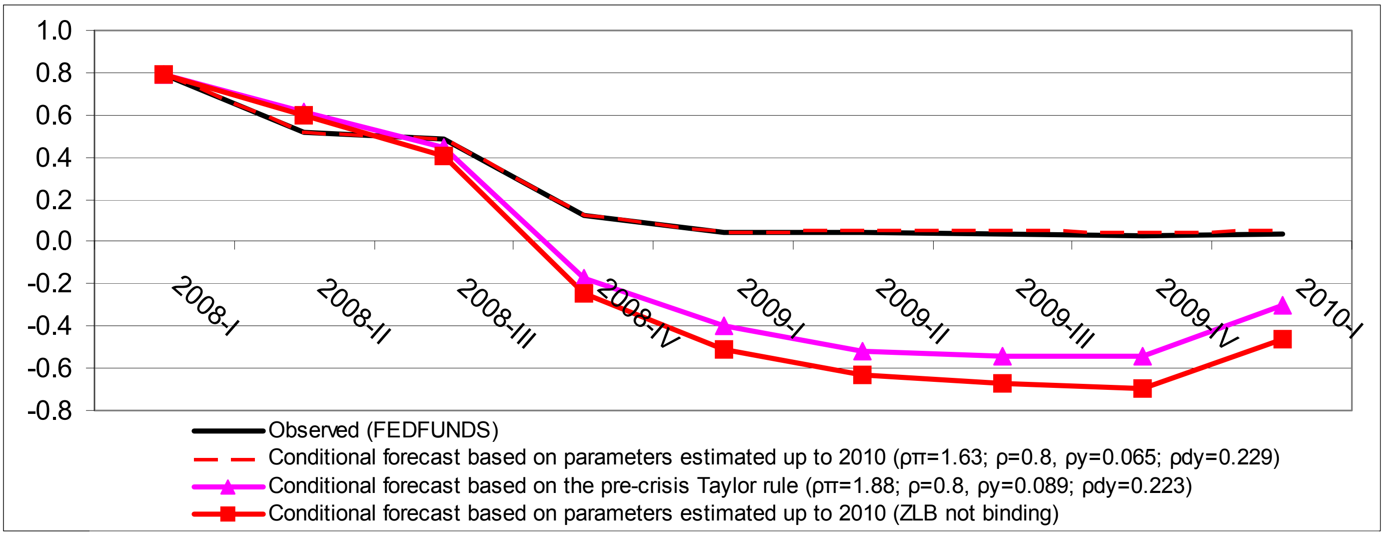

Figure 3: Conditional forecast for the nominal interest rate

Note: The black solid line depict the observed interest rate. The SW(2007) model with financial frictions estimated up to 2010Q1 (dashed line) is able to replicate the observed interest rate. The line marked with triangles depicts the conditional forecast of the interest rate in the SW (2007) model with financial frictions estimated up to 2004Q4. The line marked with squared depicts the conditional forecast of the interest rate in the SW (2007) model with financial frictions estimated up to 2010Q1 not constrained by the ZLB on interest rate.

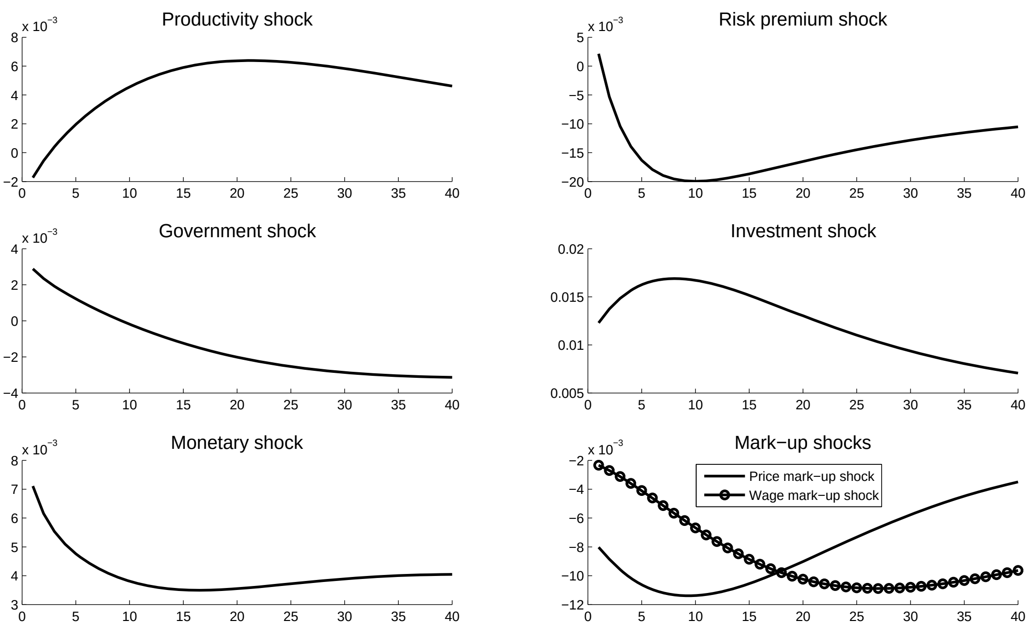

Figure 4: Responses of the external finance risk premium to each shock

Note: IRFs of the external finance risk premium are showed as deviations from the steady-state expressed as percentage points. The IRFs are based on estimated parameters from the SW(2007) model with financial frictions.

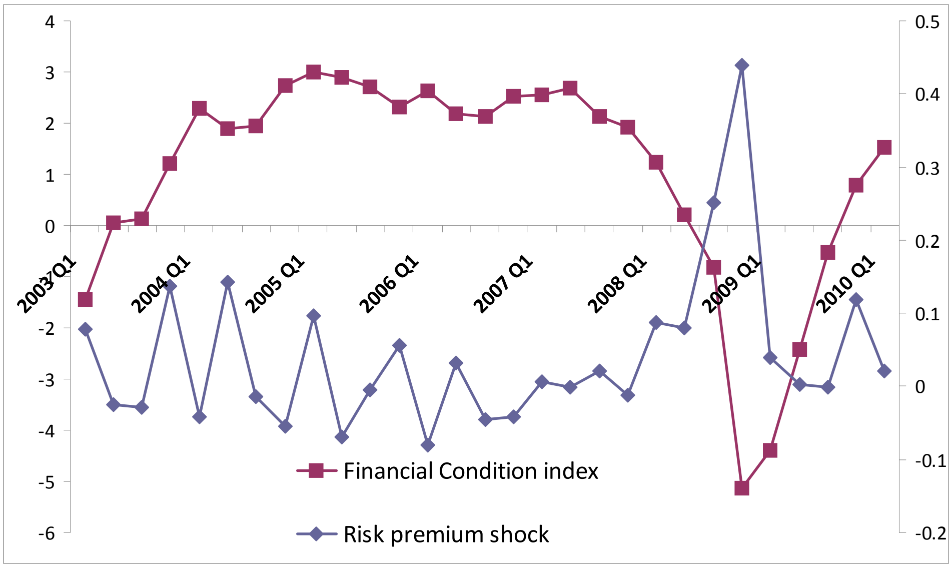

Figure 5: Financial Condition Index (source: OECD, Economic Outlook N.90) and risk premium shock

Note: The figure reports on the left scale the risk premium shock (based on estimated parameters from the SW(2007) model with financial frictions) and on the right scale the OECD Financial Condition Index for the US economy (for further details, see the Appendix)

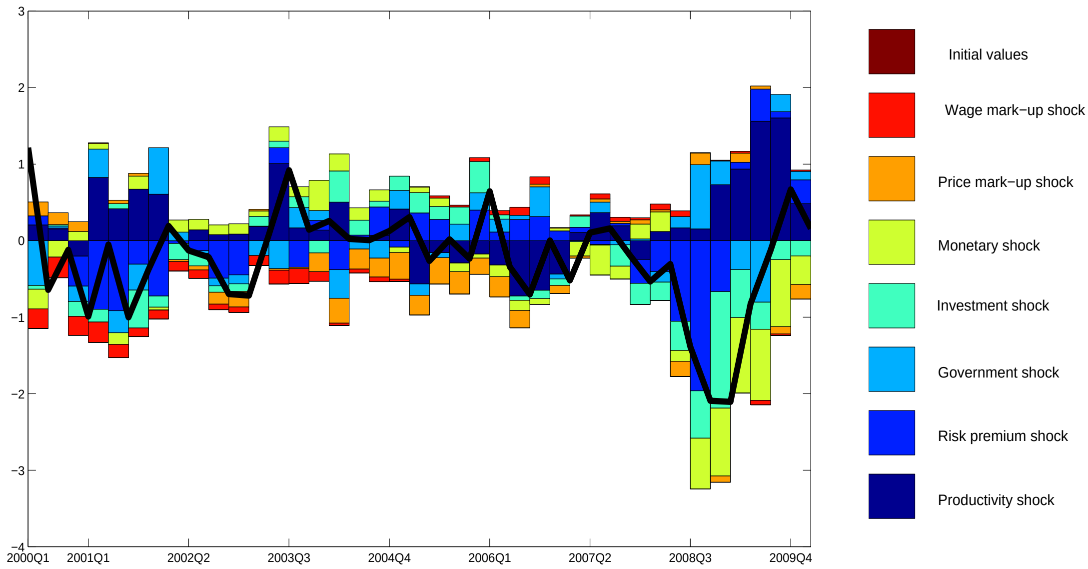

Figure 6: Historical decomposition of output growth

Note: The figure shows how various shock contribute to the (percentage) deviations from steady-state of the real GDP growth (solid black line)

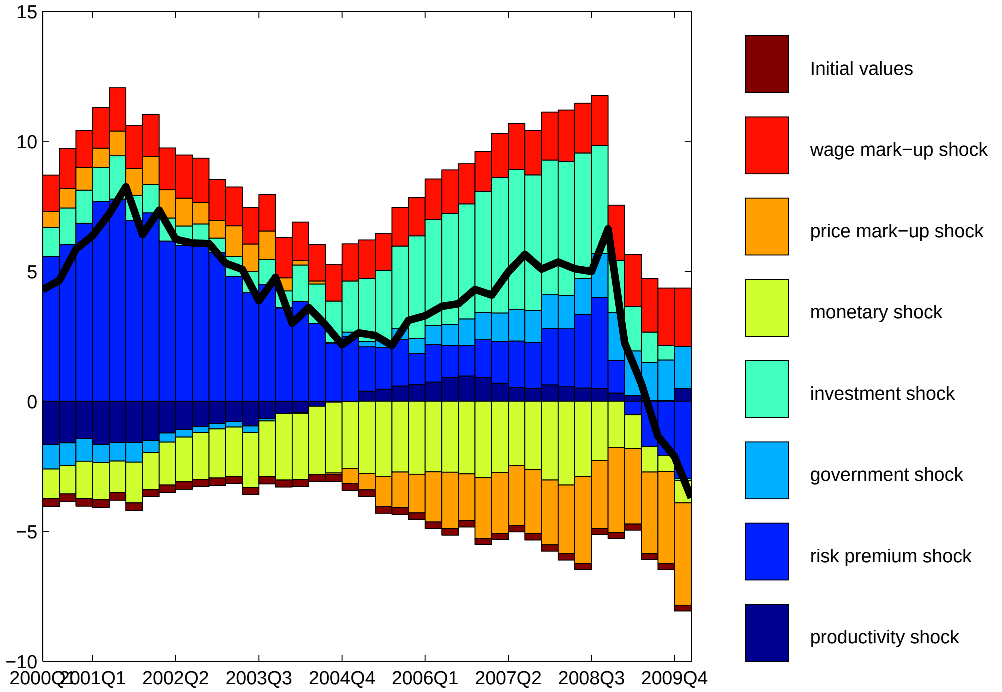

Figure 7: Historical decomposition of leverage ratio

Note: The figure shows how various shock contribute to the deviations from steady-state of the leverage ratio (solid black line)

Appendix: data description

Source of the original data

- GDP : Real Gross Domestic Product - Billions of Chained 2005 Dollars, Seasonally Adjusted Annual Rate

  Source: U.S. Department of Commerce, Bureau of Economic Analysis

- GDPDEF : Gross Domestic Product - Implicit Price Deflator - 2005=100, Seasonally Adjusted

  Source: U.S. Department of Commerce, Bureau of Economic Analysis

- CONS : Personal Consumption Expenditures - Billions of Dollars, Seasonally Adjusted Annual Rate

  Source: U.S. Department of Commerce, Bureau of Economic Analysis

- FPI : Fixed Private Investment - Billions of Dollars, Seasonally Adjusted Annual Rate

  Source: U.S. Department of Commerce, Bureau of Economic Analysis

- CE16OV : Civilian Employment: Sixteen Years & Over, Thousands, Seasonally Adjusted

  Source: U.S. Department of Labor: Bureau of Labor Statistics

- CE16OV index : CE16OV (1992:3)=1

- Federal Funds Rate : Averages of Daily Figures - Percent

  Source: Board of Governors of the Federal Reserve System

- LNS11000000 : Civilian Labor Force Status : Civilian no-institutional population - Age : 16 years and over -Seasonally Adjusted - Number in thousands

  Source: U.S. Bureau of Labor Statistics

- LNSindex : LNS10000000(1992:3)=1

- PRS85006023 - Nonfarm Business, All Persons, Average Weekly Hours Duration : index, 1992 =100, Seasonally Adjusted

  Source : U.S. Department of Labor

- PRS85006103 - Nonfarm Business, All Persons, Hourly Compensation Duration : index, 1992 =100, Seasonally Adjusted

  Source : U.S. Department of Labor

Definition of data variables used in the estimation

- consumption = LN((CONS / GDPDEF) / LNSindex) * 100

- investment = LN((FPI / GDPDEF) / LNSindex) * 100

- output = LN(GDP / LNSindex) * 100

- hours = LN((PRS85006023 * CE16OV / 100) / LNSindex) * 100
- inflation = LN(GDPDEF / GDPDEF(-1)) * 100
- real wage = LN(PRS85006103 / GDPDEF) * 100
- interest rate = Federal Funds Rate / 4

The OECD Financial Condition Index

The OECD financial conditions index (hereafter, FCI) for the United States includes real short-term interest rates, real long-term interest rates, the real effective exchange rate, bond spreads, household wealth and credit standards. The weight of each variable in the FCI is based on the estimated relative effect of a one-unit change in that variable on US GDP after four to six quarters. Estimation was undertaken using two methods: a reduced-form equation for the output gap and an unrestricted vector auto-regression (VAR) to explain GDP growth. For more details on the construction of the OECD FCI, see Guichard, Haugh and Turner (2009).
A tightening in financial condition is indicated by a fall in the FCI.
Source: OECD, Economic Outlook N.90.