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Real Effects of Financial Signals and Surprises

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Avihay Sorezcky

Abstract

The recent financial crisis in the US economy drew considerable interest in understanding the interaction between the financial and the real sectors. In this paper I develop a model with financial effects on business cycle fluctuations, based on Real Business Cycle and Financial Accelerator frameworks. In the model I distinguish between financial signals and surprises, i.e., between financial expectations and unexpected realizations. This allows me to decompose the real effects of those shocks. By estimating the model, using Bayesian methods on US data, I find that financial shocks have an important role in business cycle fluctuations. I also find that financial signals and financial surprises have similar effects on the real sector.

השפעות ריאליות של איתותים פיננסיים והפתעות פיננסיות

אביחי שורצקי

תקציר

המשבר הפיננסי האחרון בארצות הברית הביא להתעניינות רבה בקשר שבין המגזר הפיננסי למגזר הריאלי. המודל המנוסח בעבודה זו מציג השפעה של המגזר הפיננסי על תנודות מחזורי העסקים, זאת במסגרת המשלבת מחזורי עסקים ריאליים עם מאיץ פיננסי. המודל מפריד בין איתותים פיננסיים להפתעות פיננסיות, מה שמאפשר לבודד את ההשפעה הריאלית של זעזועים אלו. על ידי אמידת המודל, תוך יישום טכניקה בייסיאנית על נתוני ארצות הברית, נמצא שלזעזועים הפיננסיים תפקיד משמעותי בתנודות של מחזורי העסקים. כן נמצא, כי השפעתם של איתותים פיננסיים על המגזר הריאלי זהה להשפעתן של הפתעות פיננסיות.

1 Introduction

The US economy dove into a severe recession at the end of 2007. Much evidence indicates that this crisis was initiated by a financial turmoil. In particular, the roots of this crisis lie in the collapse of asset prices and the sharp decline in lending activity.[1] This episode in the US economy focuses attention on the linkage between the financial and the real sectors. Particularly, since the financial sector is forward looking, it is interesting to understand how financial information about the future can affect the real sector today, and how important are financial signals in explaining business cycle fluctuations. In this paper, I use a real business cycle (RBC) model with financial frictions to offer a theoretical mechanism through which financial expectations affect the real sector. For this purpose I decompose the financial effects on the real sector into financial signals and surprises.

The model used in this paper is based on the Jermann and Quadrini (2006) framework with a few, but important, differences. In the model, firms finance working capital and investment with debt and equity. Debt contracts are not fully enforceable, since firms have the possibility to default. Therefore, the ability to borrow is constrained, and the firms can only borrow up to a fraction of their value, which serves as collateral. Consequently, when the firms' value drops, so does their ability to borrow. As a result, the firms have to reduce their production and investment, which causes a further decline in their value. This process is related to the 'financial accelerator' mechanism developed by Bernanke and Gertler (1989) and Kiyotaki and Moore (1997).

Business cycle fluctuations are driven by two sources of shocks. The first is a productivity shock as in Kydland and Prescott (1982) and the standard RBC models. The second is a shock to the firms' probability to survive. When the firms' probability to survive declines, their value drops and their borrowing ability decreases. Since this shock affects the economy through a financial channel, I will refer to this as a 'Financial Shock'.

According to finance literature, the price of an asset should reflect the present value of its expected cash flow (Gordon, 1962). In order to capture this property in the model, I decompose the financial shock to 'signals' and 'surprises'. The first is a shock to the expected payments, and the other is a shock to the current payment. When a signal about future payments by the firms has been received, the firms' value reacts today. This is my main contribution to the related literature, and it allows me to decompose the financial influence on the real market to signal effects and surprise effects. It is also helps me to obtain the finding from the data, that GDP correlation with stock market prices is greatest when using stock market price lags.

By formulating the model, I offer a theoretical mechanism through which financial signals about the future affect the real sector today. To give a quantitative estimation of the contribution of financial signals and surprises to business cycle fluctuations, I estimated

[1]For further details about the 2007-2008 financial crisis see Brunnermeier (2008), and Gilchrist and Zakrajsek (2008).

the model using Bayesian methods on financial and real US data. I found that financial shocks are responsible for 22% of GDP fluctuations. Also, according to the estimation results, the last recession in the US was initiated by financial shocks.

The linkage between the real and the financial markets has been widely studied. Bernanke and Gertler (1989) built a model with asymmetric information for the borrowers and lenders, and costly borrowers' state verification. Because of the asymmetric information, the lenders ask for an external finance premium. In this model, a negative productivity shock reduces the borrowers' net worth, raises the external finance premium, and therefore reduces debt and economy activity. Kiyotaki and Moore (1997) suggested another channel in which financial frictions amplify business cycle volatility. They assumed that the firms' capital (land in the original paper) serves both for production and as collateral for loans. Consequently, a shock to this economy lowers the firms' collateral and their ability to borrow. This leads to a decline in production, and as a result, to a further shrinkage in the collateral value. Bernanke, Gertler and Gilchrist (1999) (BGG) included both financial accelerator channels in a general equilibrium model. Christiano, Motto and Rostagno (2003, 2007 ,2009) and Nolan and Thoenissen (2009) used the BGG framework to investigate the effects of financial shocks on the business cycle. Jermann and Quadrini (2006, 2008)[2] studied the role of financial frictions in reducing business cycle volatility, by building a model with a financial accelerator mechanism. As mentioned, this paper complements these studies by distinguishing between financial signals and surprises, and by letting financial signals influence the economy today.

The paper is structured as follows. Section 2 introduces the model analyzed in the paper. Section 3 describes the parametrization process. The theoretical and empirical results are presented at Section 4. Section 5 concludes.

2 The Model

The model is composed of intermediate-good firms, final-good firms and households. The intermediate-good firms invest in new capital, borrow, pay dividends to the shareholders and, using hired labor combined with capital, produce intermediate-goods. The final-good firms buy the intermediate-goods, produces the final-good and sell it in a competitive market. Finally, the households consume, own the firms and therefore receive dividends, supply labor and lend to the intermediate-good firms. In this section I present the agents' objectives, constraints and first-order conditions. I start with the intermediate-good firms which include the financial frictions in the model. Then, I continue with the other economic agents and describe the general equilibrium.

[2]Jermann and Quadrini published the same paper in two versions, one at 2006 and the other at 2008. Since there are important differences between those two versions, I refer to them separately.

2.1 The intermediate-good Firms

There is a continuum of firms normalized to the $[0,1]$ interval. Firm i produces the intermediate-good x_i using the technology:

$$x_{i,t} = f(z_t, k_{i,t-1}, l_{i,t-1}) = z_t k_{i,t-1}^{\theta} l_{i,t-1}^{1-\theta}, \qquad 0 < \theta < 1, \tag{1}$$

where k_t and l_t stand for capital and labor respectively, and z_t is a stochastic process, following an $AR(1)$ process:

$$z_t = z_{t-1}^{\xi} \exp\left[\psi_t\right], \qquad \psi_t \sim wn, \tag{2}$$

where ψ_t is an aggregate exogenous shock to productivity.

Firm i has the following revenue function:

$$\pi\left(k_{i,t-1}, l_{i,t-1}; S_t\right) = v_{i,t} x_{i,t}, \tag{3}$$

where $S_t = [z_t, Y_t]$ represents the firm's aggregate state variables, Y_t is the final-good product, and $v_{i,t}$ stands for the price of the intermediate-good i in terms of the final-good. Note that there is a one-period lag in the production process, i.e., the use of capital and labor at time t generates output and revenue at time $t+1$.[3] Therefore the firm needs working capital. The firm can finance the working capital by borrowing or by issuing new equity. Debt is always preferred over equity, since, as in Hennessy and Whited (2005) and in Jermann and Quadrini (2006), the firm has a tax advantage. Given $(1 + r_{t-1})$ is the lender return over the loan b_t, the firm pays $R_{t-1} = 1 + r_{t-1}(1-\tau)$, where τ is the rate of the subsidy. As in Kiyotaki and Moore (1997) and Jermann and Quadrini (2006), the firm's outstanding debt is limited by the following constraint:[4]

$$b_{t+1} \leq \phi E_t m_{t+1}\left[p_{t+1} V_{t+1} + (1 - p_{t+1}) L_{t+1}\right], \qquad 0 < \phi < 1, \tag{4}$$

where V_{t+1} is the firm's net worth, m_{t+1} is the market stochastic discount factor, p_{t+1} is the firm's probability of surviving and continuing its activity for another period, and L_{t+1} is the firm's liquidity value in a case of default. These expressions will be defined later. The parameter ϕ represents the fraction of the firm's value that can be used as collateral. This equation, which defines the relationship between the firm's debt and its net worth, is a key equation in the model, as in any other model that captures the financial accelerator mechanism.[5]

[3] The use of lags in the production process is supported by Kydland and Prescott (1982). They presented an RBC model with lags in the production process, and found it useful in improving the model's fit to the data.

[4] The borrowing constraint can be interpreted as the result of a renegotiation problem between the lender and the borrower. For details see Jermann and Quadrini (2006).

[5] In some papers, the relationship between debt and net worth is explicit from the debt constraint, as in Kiyotaki and Moore (1997) and Jermann and Quadrini (2006). In others, the net worth affects the spread between the interest on the firm's loan and the risk free interest rate. That, in turn, reduces the debt. For details see Bernanke and Gertler (1989), BGG and Christiano, Motto and Rostagno (2003, 2007, 2009).

As in Jermann and Quadrini (2006), in order to generate the financial accelerator mechanism, I add an equity issuing friction. This friction is important, since it prevents the firm from quickly substituting debt with equity. The equity issuing friction takes the form of the following quadratic adjustment cost:

$$\varphi(d_t) = d_t + \kappa(d_t - \widehat{d})^2, \tag{5}$$

where d_t is the dividend payment (negative equity issuing), $\widehat{d}$ is the long-run dividend payment, and κ is a parameter controlling the level of the friction.

As in Gordon (1962), the firm's value is equal to the present value of all current and expected receipts:

$$V_t = d_t + E_t m_{t+1}\overline{d}_{t+1} + E_t \sum_{j=2}^{\infty} \left(\prod_{\ell=1}^{j-1} p_{t+\ell} \right) m_{t+j}\overline{d}_{t+j}, \tag{6}$$

where $\overline{d}_t$ stands for the firm's average receipt for the shareholders, which takes into account the firm's probability of surviving. The variable $\overline{d}_t$ is defined as follows:

$$\overline{d}_t \equiv p_t d_t + (1 - p_t) L_t, \tag{7}$$

We can rewrite the firm's value in equation (6) recursively and get:

$$V(b_t, \pi_t, k_t; S_t) = d_t + E_t m_{t+1} \left[p_{t+1} V(b_{t+1}, \pi_{t+1}, k_{t+1}; S_{t+1}) + (1 - p_{t+1}) L_{t+1} \right]. \tag{8}$$

A firm that exits the economy is repurchased by a new firm. As a result there is a potential surplus. This potential surplus ,L_t^p, is defined as the gap between the firm's value using the old firm's or the new firm's state variables:

$$L_t^p \equiv V(b_t, \pi_t, k_t; S_t). \tag{9}$$

I assume that as a result of the firm's default there is a loss of resources,[6] and therefore the actual surplus from the repurchase process is less than the potential surplus. I also assume that the old firm enjoys the entire surplus.[7] The actual surplus, which is the firm's liquidity value, is define as follows:

$$L_t \equiv \sigma \left[V(b_t, \pi_t, k_t; S_t) \right], \tag{10}$$

where $(1 - \sigma)$ defines the loss of resources in a case of default.

Since there are many firms, which are normalized to the $[0, 1]$ interval, the law of large numbers implies that in each period, $(1 - p_{t+1})$ percent of the firms exit the economy and

[6] The loss of resources can be interpreted as monitoring cost and costly state verification, which was first analyzed in Townsend (1979) and then used in BGG and Christiano, Motto and Rostagno (2007, 2009).

[7] This assumption is for analytical convenience only, and would not affect the key results of the model.

are repurchased by new firms. This probability of exiting the economy refers to changes in stock market wealth that are not related to changes in preferences or technology. It can be interpreted, as in Christiano, Motto and Rostagno (2007), as a reduced form of an 'Asset Price Bubble' or as an 'Irrational Exuberance'.[8] The law of motion of the exit rate is defined as follows:

$$p_t = \gamma u_t, \qquad u_t = u_{t-1}^{\rho} \exp(\varepsilon_{t-1}) \exp(e_t), \tag{11}$$

where $\varepsilon_t, e_t \sim wn$, $\varepsilon_t \perp e_t$, and γ is the firm's steady state rate of surviving.

Equation (11) captures the main feature of the model. Note that ε_t is a signal about the firm's probability of defaulting in the next period. From equation (11) we can see that the firm's value responds to the expected rate of default in the next period. Consequently, a negative ε_t lowers the firm's probability of surviving in time $t+1$, and therefore reduces the firm's value today. This, in turn, will lead to real sector effects.[9] The shock e_t is a surprise regarding the actual rate of default at time t, i.e., an unexpected realization. Therefore, a positive e_t reflects a better realization than was expected. Since a shock to p_t influences the economy through a financial channel, I will refer to it as a 'financial shock'.

The firm maximizes its value:

$$V(b_t, \pi_t, k_t; S_t) = \max_{d_t, l_t, b_{t+1}, k_{t+1}} \{d_t + E_t m_{t+1} [p_{t+1} V(b_{t+1}, \pi_{t+1}, k_{t+1}; S_{t+1}) + (1 - p_{t+1}) L_{t+1}]\},$$

subject to the borrowing constraint:

$$b_{t+1} \leq \phi E_t m_{t+1} [p_{t+1} V_{t+1} + (1 - p_{t+1}) L_{t+1}],$$

and the budget constraint:

$$\pi(k_{t-1}, l_{t-1}; S_t) - w_t l_t + b_{t+1} - b_t R_{t-1} - \varphi(d_t) + (1 - \delta) k_t - k_{t+1} = 0, \tag{12}$$

where δ is the capital depreciation rate.

Solving the firm's problem we get the following first-order conditions (the detailed derivation is provided in Appendix B):

$$d_t : 1 - \lambda_t \varphi_d(d_t) = 0, \tag{13}$$

$$l_t : (1 + \mu_t \phi) E_t m_{t+1} [p_{t+1} + (1 - p_{t+1}) \sigma] \lambda_{t+1} \pi_l(k_t, l_t; S_{t+1}) - \lambda_t w_t = 0, \tag{14}$$

$$b_{t+1} : -(1 + \mu_t \phi) E_t m_{t+1} [p_{t+1} + (1 - p_{t+1}) \sigma] \lambda_{t+1} R_t + \lambda_t - \mu_t = 0, \tag{15}$$

[8] The firm's probability of exiting the economy was first used in BGG. The first use of this probability as a shock was by Christiano, Motto and Rostagno (2003), and it was also used by Christiano, Motto and Rostagno (2007, 2009) and Jermann and Quadrini (2006).

[9] Signal shocks have been studied in the literature mainly for technology shocks, see for example Beaudry and Portier (2000), Davis (2008), and Blanchard, L'huillier and Lorenzoni (2009). Signals for financial shocks appear in Christiano, Motto and Rostagno (2009).

$$k_{t+1}:(1+\mu_t\phi)E_t m_{t+1}\left[p_{t+1}+(1-p_{t+1})\sigma\right]\left\{\begin{array}{c}(1+\mu_{t+1}\phi)m_{t+2}\left[p_{t+2}+(1-p_{t+2})\sigma\right]\times\\ \lambda_{t+2}\pi_k(k_{t+1},l_{t+1};S_{t+2})+\lambda_{t+1}(1-\delta)\end{array}\right\}-\lambda_t=0, \tag{16}$$

where μ and λ are the Lagrange multipliers for the borrowing constraint and the budget constraint respectively.

These first-order conditions capture the financial accelerator mechanism in this model. A positive productivity shock leads to higher revenue, which reduces λ_t. From equation (13) we get that a decline in λ_t leads to an increase in the dividend payments in time t. Higher dividend payments increase the firm's value, which reduces μ_t. Lower μ_t, which allows the firm to increase its debt, leads to an increase in the firm's demand for labor and capital. Increase in the demand for inputs leads to higher productivity and revenue in the future. That, in turn, will lead to higher dividend payments, which raise the firm's value today, and so on. This process can also be motivated by a financial shock. Higher survival probability at time $t+1$ will increase the firm's value today, which generates the process described above. Note that the financial accelerator mechanism operates through changes in the Lagrange multipliers. This is the motivation for including the firm's tax advantage and equity adjustment cost in the model. The firm's tax advantage causes the borrowing constraint to bind around the steady state, while the equity adjustment cost allows changes in λ_t. Therefore, in order to capture the financial accelerator mechanism in the model, we must have $\tau, \kappa > 0$.[10]

2.2 The final-good Firms

The final-good firms use intermediate-goods to produce the final-good Y according to a Constant Elasticity of Substitution production function:

$$Y_t=\left(\int_{i=0}^{1}x_{i,t}^{\eta}di\right)^{\frac{1}{\eta}}, \tag{17}$$

where $x_{i,t}$ are intermediate-goods purchased at the price of $v_{i,t}$, and η is a parameter that represents the elasticity of substitution between the intermediate-goods. The final-good firms maximize their profits as follows:

$$\max_{x_{i,t}}\left\{\left(\int_{i=0}^{1}x_{i,t}^{\eta}di\right)^{\frac{1}{\eta}}-\left(\int_{i=0}^{1}v_{i,t}x_{i,t}di\right)\right\}. \tag{18}$$

This problem's first-order-condition is:

$$v_{i,t}=Y_t^{1-\eta}x, \tag{19}$$

[10] $\kappa=0$ leads to $\lambda_t=1, \forall t$. In this case λ_t is permanent over time and there are no financial accelerator effects in the model.

This expression describes the demand for the intermediate-good x_i at time t. Substituting equations (19) and (1) into equation (3) we get the following explicit expression for the intermediate-good firm revenue function:

$$\pi\left(k_{i,t-1}, l_{i,t-1}; S_t\right) = Y_t^{1-\eta}\left(z_t k_{i,t-1}^{\theta} l_{i,t-1}^{1-\theta}\right)^{\eta}. \tag{20}$$

2.3 The Households

There is a continuum of homogeneous households that are interested in maximizing their lifetime utility:

$$\max_{c_t, l_t, b_{t+1}, s_{t+1}} \sum_{t=0}^{\infty} \beta^t U\left(c_t, l_t\right), \tag{21}$$

where β is the households' subjective discount factor, and c_t is consumption. The periodical utility function is:

$$U\left(c_t, l_t\right) = (1-\alpha)\ln(c_t) + \alpha \ln(1-l_t). \tag{22}$$

The households maximize their utility subject to the following budget constraint:

$$w_t l_t + b_t(1+r_{t-1}) + s_t\left(\bar{d}_t + p_t q_t\right) = b_{t+1} + s_{t+1}q_t + c_t + T_t, \tag{23}$$

where:

s_t : households' share in the intermediate-good firms.

$q_t = V_t - d_t$: market price of surviving intermediate-good firms after paying the dividend at time t.

$T_t = b_t r_{t-1}\tau$: lump sum tax to finance the intermediate-good firm's subsidy.

The households hold two assets, a risk free bond b_t, which pays the interest rate r_{t-1}, and equity shares. Firms which survive to time t pay the shareholders the average periodical payment (the liquidity value L_t, with probability $(1-p_t)$, and dividend d_t, with probability p_t), and if they survive to time $t+1$ their market price is q_t.

Solving the households problem we get the following first-order conditions for the labor supply, risk free interest rate and the price of shares:

$$l_t : U_l\left(c_t, l_t\right) + U_c\left(c_t, l_t\right) w_t = 0, \tag{24}$$

$$b_{t+1} : \beta E_t U_c\left(c_{t+1}, l_{t+1}\right)\left(1+r_t\right) - U_c\left(c_t, l_t\right) = 0, \tag{25}$$

$$s_{t+1} : \beta E_t U_c\left(c_{t+1}, l_{t+1}\right)\left(\bar{d}_{t+1} + p_{t+1}q_{t+1}\right) - U_c\left(c_t, l_t\right) q_t = 0, \tag{26}$$

Rearranging equation (26) we get:

$$q_t = \beta E_t \frac{U_c\left(c_{t+1}, l_{t+1}\right)}{U_c\left(c_t, l_t\right)}(\bar{d}_{t+1} + p_{t+1}q_{t+1}).$$

Using forward substitution and assuming $\lim_{j\to\infty}\beta^j E_t\left(\prod_{\ell=1}^{j} p_{t+\ell}\right)\frac{U_c(c_{t+j},l_{t+j})}{U_c(c_{t+j-1},l_{t+j-1})}q_{t+j}=0$, we get:

$$q_t=\beta E_t\frac{U_c\left(c_{t+1},l_{t+1}\right)}{U_c\left(c_t,l_t\right)}\overline{d}_{t+1}+E_t\sum_{j=2}^{\infty}\beta^j\frac{U_c\left(c_{t+j},l_{t+j}\right)}{U_c\left(c_t,l_t\right)}\left(\prod_{\ell=1}^{j-1}p_{t+\ell}\right)\overline{d}_{t+j}. \tag{27}$$

Note that equation (27) is related to equation (6) which expresses the firms' market value. The link is $q_t=V_t-d_t$. The result is that the firms' optimization is consistent with the households' optimization. Therefore, the market stochastic discount factor m_t, can be written as:

$$m_{t+j}=\beta^j\frac{U_c\left(c_{t+j},l_{t+j}\right)}{U_c\left(c_t,l_t\right)}.$$

In particular, from equation (25) we get:

$$Em_{t+1}=\frac{1}{1+r_t}.$$

2.4 General Equilibrium and Model Solution

In this section I introduce the general equilibrium conditions derived from the model, and describe the model solution technique.

2.4.1 General Equilibrium Equations

After presenting the agents' maximization problems and deriving their first-order conditions, I can present the general equilibrium equations. In general equilibrium, all the agents' constraints and first-order conditions must be satisfied.

Labor Market: The equations that need to be fulfilled in equilibrium in the labor market are the households' first-order condition for labor supply, equation (24), and the firms' first-order condition for labor demand, equation (14).

Goods Market: Since the intermediate-good firms are all identical, in a symmetric equilibrium they all produce the same quantity. Therefore we get $Y_t=x_t\left(\int_{i=0}^{1}di\right)^{\frac{1}{\eta}}=x_t$. Further conditions are the households' and intermediate-good firms' budget constraints, equations (23)[11] and (12).

[11] Since the households are the only shareholders of the firms and all households are the same, symmetric equilibrium must satisfy $s_t=s_{t+1}=1$.

Financial Market: Financial market equilibrium must satisfy the firms' borrowing constraint, equation(4), and the firms' and households' first-order conditions for debt, equations (15) and (25). Additionally, equilibrium conditions in the financial market are the firms' value equation (8), and the firms' first-order conditions for dividend and next period capital, equations (13) and (16).[12]

One more equation that determines the general equilibrium is the law of motion of the survival probability of the intermediate-good firms to survive, equation (11).

2.4.2 Model Solution

There are 11 general equilibrium equations with 11 variables. The model solution is defined as finding the agents' dynamic policy functions as a response to the state variables $[k_{t-1}, k_t, b_t, r_{t-1}, l_{t-1},]$ and the exogenous shocks $\left[\psi_{t,} \varepsilon_t, e_t\right]$. The solution was computed after log linearizing the model around the steady state.[13,14]

3 Parameterization

In this section I describe the model's parametrization. As in Christiano, Motto and Rostagno (2009), I divided the model parameters into two sets. The first set contains the parameters that control the steady state level. The values for most of these parameters was set using calibration. The parameter controlling the losses caused by firms' default, σ, was estimated, since I do not have accurate enough values for this parameter. The second set of parameters contain the parameters which govern the dynamics of the model. This set of parameters was estimated using US data and Bayesian techniques, as discussed in An and Schorfheide (2007) and Smets and Wouters (2003).[15]

3.1 Calibration

The model was calibrated in quarterly terms. The parameters related to the intermediate-good firms were chosen as follows. The capital depreciation rate parameter was set to $\delta = 0.025$, a reasonable value when using quarterly frequency. The subsidy rate for the firms' debt was set to $\tau = 0.3$, as in Jermann and Quadrini (2006). Capital's share in the

[12]As was shown, the households' first order condition for the share at the intermediate good firms is identical to the firms' value equation. Therefore this equation is canceled out, along with the variable q.

[13]The model solution was computed using the Dynare toolbox for Matlab.

[14]When log linearizing the model there is a possibility that $\mu_t \leq 0$ (that is when the borrowing constraint is not binding), and $p_t > 1$. I have checked the simulated data and found that μ_t always remains positive, and p_t is smaller than 1 for 99.5% of the time.

[15]For further implementations of the Bayesian estimation technique in DSGE models see Christiano, Motto and Rostagno (2003, 2007, 2009), Jermann and Quadrini (2008) and Gilchrist and Zakrajsek (2008).

production function was chosen to be $\theta = 0.4$, which is widely used in related literature. The collateral parameter from the borrowing constraint was set to $\phi = 0.45$, in order to reproduce the average leverage rate as observed in the data.[16] Finally, firms' steady state survival probability, which is determined by the parameter γ, took the value of $\gamma = 0.975$. This implies an annual exit rate of 10%, which is similar to Jermann and Quadrini (2006) and supported by OECD publications (2001).

There are two parameters related to the households. The subjective discount factor was set to $\beta = 0.987$, a conventional value in the literature. The utility parameter was set to $\alpha = 0.6$, in order to achieve a labor steady state value of 0.34.

The elasticity of substitution from the final-good firms' production function determines the intermediate-good firms' monopolistic mark up. I set this elasticity to $\eta = 0.85$, which implies a 15% markup, a commonly used value in related macro studies. A summary of the calibration values is presented in Table 1.

Table 1: Calibration Values

Parameter	**Description**	**Value**
	intermediate-good Firm	
δ	Capital depreciation rate	0.025
τ	Subsidy rate	0.3
θ	Production function parameter	0.4
ϕ	Debt enforcement parameter	0.45
γ	Steady state probability to survive	0.975
	final-good Firm	
η	Production function elasticity of substitution	0.85
	Households	
β	Discount factor	0.987
α	Utility parameter	0.6

[16]In model terms, the leverage rate is the debt to net worth ratio, $\frac{V_t}{b_t}$. The source of those series is the Flow of Funds Accounts compiled by the Federal Reserve Board. Debt is 'Credit Market Instruments' of Nonfarm, Nonfinancial Corporate Business and Nonfarm, Noncorporate Business. Firms' value is the reported 'Net Worth' in the Nonfinancial Corporate Business and Noncorporate Business.

3.2 Estimation

There are seven more parameters that need to be estimated. These parameters are the volatility of the exogenous shocks $[std_\psi, std_e, std_\varepsilon]$, the persistence of the stochastic processes $[\xi, \rho]$, the losses resulting from default $[\sigma]$, and the equity adjustment cost parameter $[\kappa]$. As mentioned, these parameters were estimated using Bayesian methods on US data.[17] I chose GDP and debt data for the estimation process.[18] These series were chosen since they capture the main properties of the model, the linkage between the financial and the real markets. I used deviations from the HP filter of the log of these series,[19] and used seasonally adjusted, real and per capita terms. The sample used for the estimation was 1985q1- 2008q2.[20]

Artificially smoothed series for the unobservable variables were generated using the model equations, as described in section 2.4, and the Kalman filter. These series, together with the actual series, are presented in Appendix C. The sources of the data series are reported in Appendix A. Appendix C shows that for most variables, smoothed series are rather close to the actual data. For investment, the smoothed series is more volatile than the actual series. The reason for this, apparently, is that I did not add investment adjustment costs to the model, as was done in related models in order to fit the data better.[21]

The priors were set as follows. For the standard-deviation of the exogenous shocks' and the exogenous stochastic processes' persistence I followed Christiano, Motto and Rostagno (2009). I set Inverse Gamma distribution for the shocks' standard-deviation, and Beta distribution for the stochastic processes' persistence. Since the parameter for the losses resulting from the default must be included in the interval $[0, 1]$, I used Beta distribution as a prior. From Jermann and Quadrini (2008), the equity adjustment cost parameter is rather small in the estimated period. Therefore I used Inverse Gamma distribution as a prior. Full details about the estimation priors and results are presented in Table 2.

[17] The estimation was executed using the Dynare toolbox for Matlab.

[18] Recall that in the model there is one-period lag in production. The use of inputs in time t generates output in time $t + 1$. Therefore, in model terms, GDP stands for the output in time $t + 1$.

[19] The HP filter was computed using a smoothing parameter of 1600.

[20] The sample's first observation was chosen to be 1985q1 since, according to Jermann and Quadrini (2008), in this period the US financial market encountered a structural break. The sample's last period was set to 2008q2, as I omitted the last three observations due to using the HP filter (the last observation available is for 2009q1)

[21] I did not add investment adjustment costs since I did not want to add a component that could shift the attention from the main focus of this paper, the linkage between the real and the financial markets.

Table 2: Estimation Priors and Results

Parameter	Prior	Posterior Mode	Std
std_ψ	Inv. Gamma $[0.01, 5]$	0.0038	0.0003
std_e	Inv. Gamma $[0.01, 5]$	0.0034	0.0008
std_ε	Inv. Gamma $[0.01, 5]$	0.0033	0.0008
ξ	Beta $[0.5, 0.2]$	0.8655	0.0419
ρ	Beta $[0.5, 0.2]$	0.8377	0.0443
σ	Beta $[0.5, 0.2]$	0.5755	0.1299
κ	Inv. Gamma $[0.01, 5]$	0.0043	0.0016

4 Results

In this section I discuss the main results of the model. I start by introducing theoretical results, and focus on the financial signal and surprise effects derived from the model. Then I discuss some empirical results derived from the estimation. All the results that are reported below were received using the estimation mode values for the estimated parameters.

4.1 Impulse Response

I now discuss the impulse responses of the economy's variables to the financial shocks. Impulse response to productivity shock is similar to other related RBC models, and is presented in Appendix D.

Figure 1 displays the impulse response to a one-standard-deviation adverse shock to a financial signal ,(ε_t), and surprise (e_t).

First I want to emphasize two general points. As can be seen, a signal shock generates about the same fluctuations in the economy as a surprise shock does. The reason for this finding is that the estimated standard-deviation of these shocks is rather close to each other. The second general finding is that the model generates a hump shaped impulse response, which is consistent with most empirical findings. This result is compatible with BGG finding that a model with financial frictions generates a hump shaped impulse response for the economy's main variables.

I now turn to the economic intuition behind the impulse response functions. Since the shape of the responses to signal and surprise shocks are very similar to each other, I discuss the general response to a negative financial shock.

When a negative financial shock occurs, firms' values decrease. This affects households' and firms' decisions. From the households' point of view, there is a negative wealth effect.

Since the households are the firms' shareholders, a decrease in the firms' value reduces their wealth. As a result of the negative wealth effect, the households consume less and increase their labor supply. On the firms' side, when their value drops, the Lagrange multiplier of the borrowing constraint, μ_t, rises, and the firms need to decrease their debt. The decline in the firms' debt leads to an increase in the Lagrange multiplier of the budget constraint, λ_t, which in turn, leads to a lower dividend payment.[22] The firms' value, equation (8), implies that a decline in the dividend payments leads to a further decrease in the firms' value. This, in turn, will lead to a further decline in the firms' debt , and so on. The decrease in the firms' debt also leads to a drop in investment and labor demand (as a response to a signal shock, the investment rises moderately on impact because of the decline in the interest rate, and from period $t+1$ starts to decline). The process described above is related to the 'financial accelerator' mechanism.

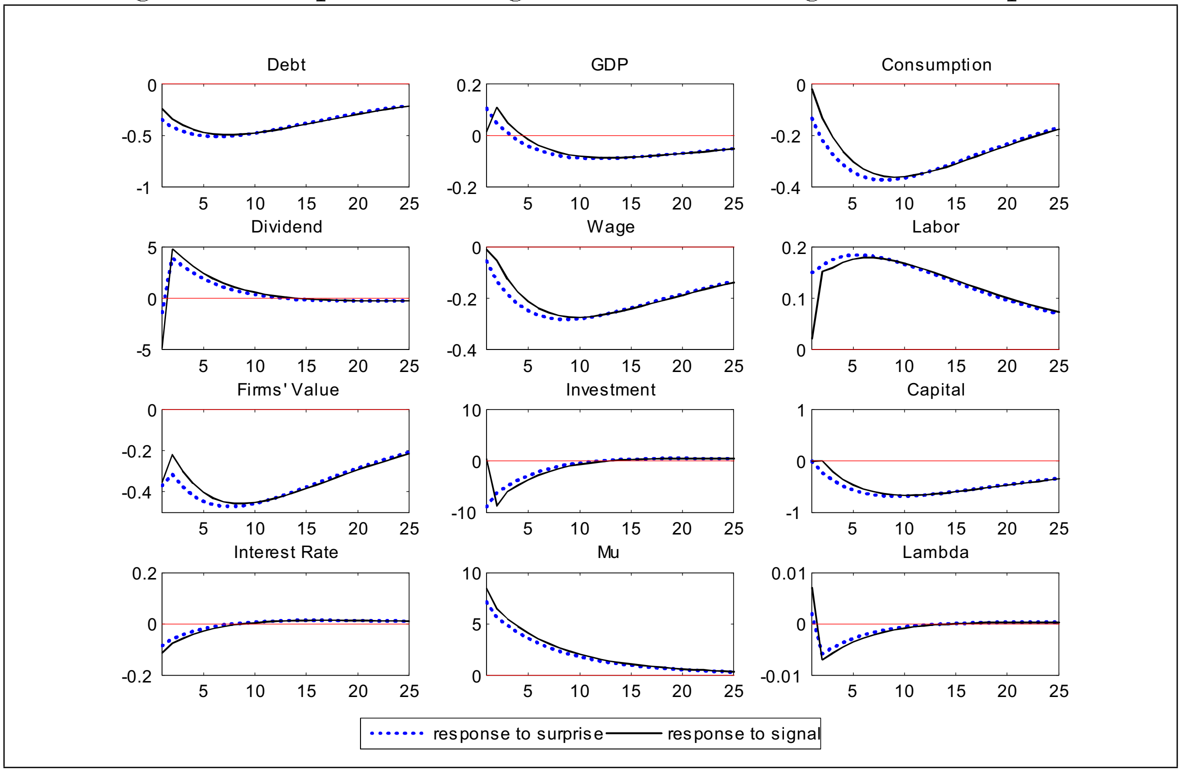
In time t, labor increases (this is the net result of rise in the supply and the drop in the demand) while capital stays at its steady state level (since it is predetermined). As a result, the GDP level rises. As a response to a surprise shock, from time $t+1$ the effect of the drop in the capital is stronger than that of the rise in labor. Therefore we get a decline in production. As a response to a signal shock, at time $t+1$ there is a further increase in production, since when the realization occurs, it generates a further increase in the labor supply. From time $t+2$ the drop in capital becomes more influential, and there is a drop in production.[23] The late decline in the GDP level in response to a negative financial shock reproduces the property mentioned in the introduction, that stock market prices (firms' value in model terms) can be used as a leading indicator of GDP.[24]

[22] Recall that from the firms' first order condition for dividends, equation (13), an increase in λ_t leads to a decrease in d_t.

[23] Since the rise in the labor supply has a greater effect than the decline in demand, we get an increase in labor along with a decrease in production. As a result, in the model simulation we get a negative correlation between labor and output. This result is counter-factual. Labor market frictions, choosing other sets of parameters for the calibration or adding structural exogenous shocks to the model, may lead to the desired results. Since the labor market is not my main interest in this paper, I left it unchanged.

[24] Appendix E presents the response of GDP together with the response of the firms' value to a financial signal and surprise. The Appendix shows that as a response to a financial shock, there is an immediate decline in firms' value, while GDP begins to drop only after few periods.

Figure 1: Response to Negative Financial Signal and Surprise



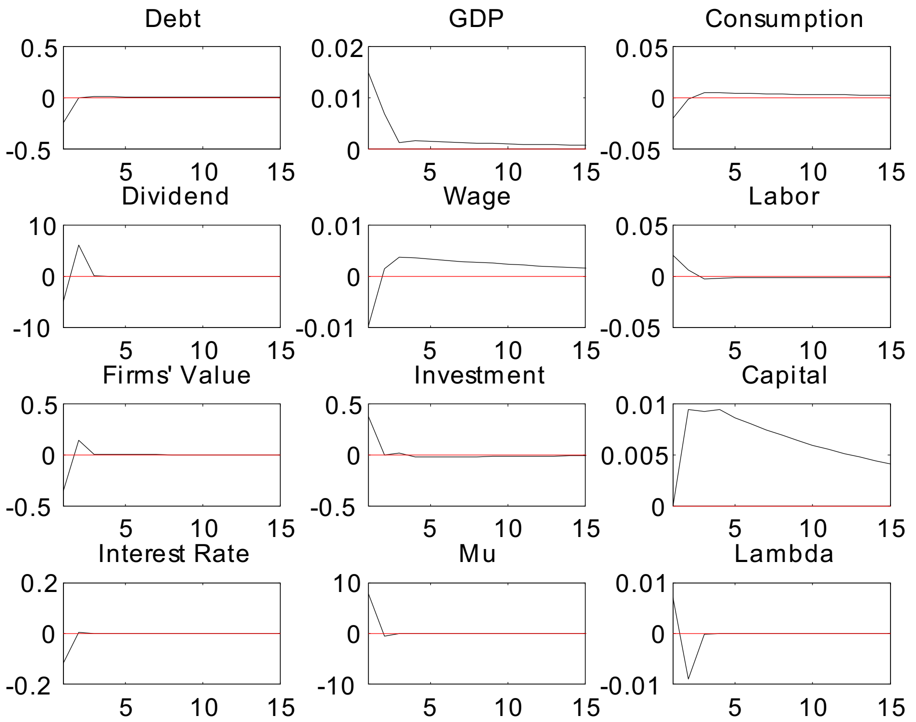
4.1.1 Impulse Response to Financial 'Noise'

In this section I will examine the response to the following scenario: A one-standard-deviation negative signal shock followed by an identical positive surprise shock in the next period. In that case, the actual rate of default stays at its steady state value. Since the signal shock was not realized, it can be interpreted as 'noise'. Figure 2 displays the impulse response to the noise shock.

As we can see, although the default rate does not change in practice, the noise shock generates fluctuations in the economy's variables. The economy's variables' response to the noise scenario is rather small relative to the signal or surprise shock, but it emphasizes one of the main results of the model i.e., financial signals about the next period have real effects on the economy today.

The negative signal shock received at time t starts the process described in the section above. The economic agents prepare themselves for a negative shock (as mentioned above, this will lead to a rise in labor and a moderate rise in investment). In time $t+1$ the agents observe the default rate realization, and understand that the negative expectations were not realized. As a result, the financial variables return to the steady state rather quickly, but the real variables stay above their steady state level for a while.

Figure 2: Response to Financial 'Noise'



4.2 Empirical Results

In this section I will discuss two main empirical results concerning the past effects of financial shocks, using the estimation results. These results are the variance decomposition of the shocks' contributions to GDP and debt fluctuations, and the historical estimated shocks in the last recessions.

4.2.1 Historical Variance Decomposition

In the model there are two sources of shocks, financial and productivity. It is interesting to know what each source contributes to business cycle fluctuations. The variance decomposition for the GDP and debt are shown at Table 3.

The table shows that the financial signals' and surprises' contributions are similar.

Another finding is that the financial shocks have an important role in business cycle fluctuations. They are responsible for 22% and 93% of the GDP and debt volatility respectively. This result is consistent with the findings of Christiano, Motto and Rostagno (2009), but stands in contrast to those of Jermann and Quadrini (2008). In Christiano, Motto and Rostagno (2009) there are two kinds of financial shock, one of them is identical to the financial shock in the model described in this paper (the expression used for this shock in Christiano, Motto and Rostagno (2009) is 'wealth' shock). The financial shock in Jermann and Quadrini (2008) is a shock to the collateral parameter in the borrowing constraint. Since the financial shock in the model presented in this paper is identical to the one in the Christiano, Motto and Rostagno (2009) model, I find similar results. A reasonable conclusion to be drawn from the different results obtained from the model presented here and that of Christiano, Motto and Rostagno (2009) on the one hand, and those of Jermann and Quadrini (2008) model on the other, is that shocks to the firms' probability of surviving are much more important to economic fluctuations than shocks to the collateral parameter.

Table 3: Variance Decomposition (percent)

	Financial Surprise	**Financial Signal**	**Productivity**
GDP	11	11	78
Debt	47	46	7

4.2.2 Estimated Economic Shocks

At the end of 2007 the US economy encountered a recession which some economists describe as the most severe crisis since the Great Depression. Most economists also agree that this recession was initiated in the financial sector. Since in the model there are financial sector and real sector shocks, I can examine whether the model results are consistent with the economists' assumption about the trigger for the last recession. By estimating the model I can compute the estimated historical economic shocks, and see if according to the model estimation the last crisis was motivated by financial shocks.[25]

Figure 3 presents the sum of the estimated economy shocks for the last recessions[26] (the full series of historical estimated shocks can be found in Appendix F). The sum of the shocks is presented in order to see which shock was the most influential during past downturns. Note that the 1990 and 2001 recessions include three quarters, while the 2008 recession includes only two quarters (since the last observation for the estimation is 2008q2).

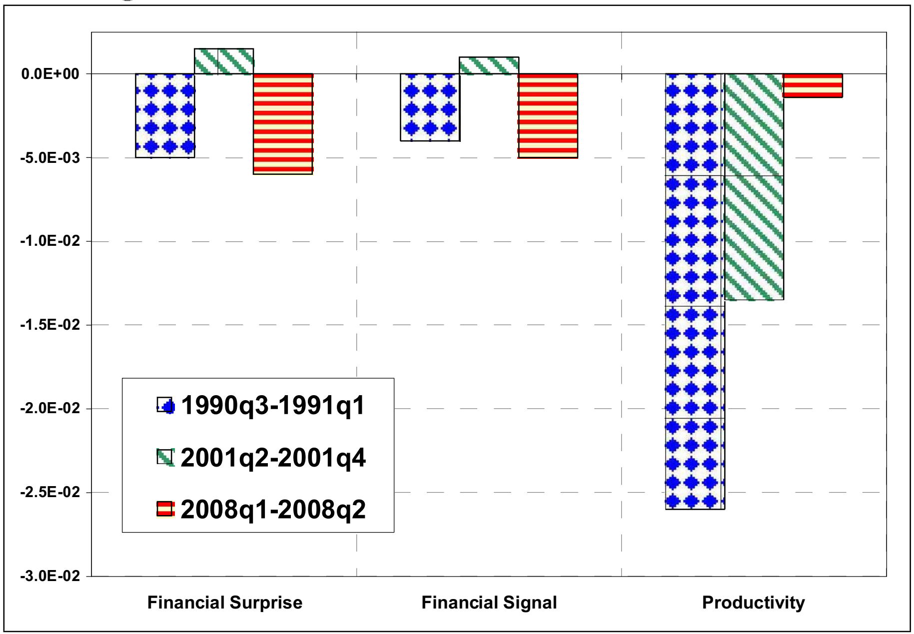
It can be seen from the table, that according to the model estimation, the last recession was motivated by financial shocks. The aggregate financial shocks estimated for the last recession are greater than those that were estimated for the 1990 and 2001 recessions. The aggregate productivity shocks, that were the most influential in past recessions, are

[25]For further details about estimation of historical shocks see Smets and Wouters (2003) and Christiano, Motto and Rostagno (2009).

[26]A quarter is included as a recession period if at least two month of that quarter are defined as a recession period by the National Bureau of Economic Research.

negligible in the 2008 recession. As mentioned above, these findings are consistent with the initial assumption.

Figure 3: Estimated Shocks in Past Recessions



5 Conclusion

At the end of 2007, the US economy encountered a severe recession. Many believe that this was initiated by a financial crisis. In this paper I introduce a theoretical real business cycle model with financial frictions, that includes the financial accelerator mechanism. The financial frictions allow me to examine the real effects of financial shocks, understand the theoretical mechanism of these effects, and evaluate the contribution of financial markets to business cycle fluctuations. In particular, the model allows me to study the effects of financial market expectations and signals on the real market, and to decompose these effects from the real effects of financial surprises.

After introducing the model, I perform an estimation using Bayesian methods. This helped me to derive some empirical results. I found that the financial signals' and surprises' contributions to business cycle fluctuations are about the same. I also found that financial shocks play an important role in GDP volatility. Finally, the estimation results imply that the last recession was motivated by financial shocks, which is consistent with the prior assumption mentioned above.

In this paper, my focus was on the linkage between the real and financial sectors. Therefore, while getting desirable properties at this range, I got counter-factual results in others. In particular, I got a negative correlation between GDP and labor, and high volatility in investment. Therefore, it would be useful to include the financial mechanism suggested in this paper in a wider framework, i.e., a model with labor market frictions and investment adjustment costs. It could also be useful to include this mechanism in a small open economy model. This would make it possible to learn about the pass-through from external financial shocks to the local economy.

Appendix

A Data Sources

The data sources that were used for the calibration and estimation processes are as follows: For debt, firms' value, households' working hours and wages I used the same data as in Christiano, Motto and Rostagno (2009). Debt is measured as 'Credit Market Instruments' of Nonfarm, Nonfinancial Corporate Business and Nonfarm, Noncorporate Business, taken from the Flow of Funds data. Firms' value is measured as the Dow Jones Industrial average, scaled by the GDP deflator. For households' working hours I used 'Nonfarm Business Sector Index', Hours of All Persons, provided by the Bureau of Labor Statistics. For wages I used Compensation Per Hour in the Nonfarm Business Sector, from the Bureau of Labor Statistics. For GDP, consumption and investment I used the data available in the Bureau of Economic Analysis. Consumption is measured as Personal Consumption Expenditures, and for investment I used Gross Private Domestic Investment.

All series were transformed to seasonally adjusted and per capita terms, and I used the deviations of the log of these series from the HP filter (using a smoothing parameter of 1600).

B intermediate-good Firms' First-Order Conditions

The intermediate-good firms' problem is to maximize their value ,equation (8), subject to the borrowing constraint, equation (4), and the budget constraint, equation (12). Taking first-order conditions we get:

$$d_t : 1 - \lambda_t \varphi(d_t) = 0$$

$$l_t : (1 + \mu_t \phi) E m_{t+1} \left[p_{t+1} + (1 - p_{t+1})\sigma \right] V_\pi(b_{t+1}, \pi_{t+1}, k_{t+1}; S_{t+1}) \pi_l(k_t, l_t; S_{t+1}) - \lambda_t w_t = 0$$

$$b_{t+1} : (1 + \mu_t \phi) E m_{t+1} \left[p_{t+1} + (1 - p_{t+1})\sigma \right] V_b(b_{t+1}, \pi_{t+1}, k_{t+1}; S_{t+1}) + \lambda_t - \mu_t = 0$$

$$k_{t+1} : (1 + \mu_t \phi) E m_{t+1} \left[p_{t+1} + (1 - p_{t+1})\sigma \right] V_k(b_{t+1}, \pi_{t+1}, k_{t+1}; S_{t+1}) - \lambda_t = 0$$

The envelope conditions are:

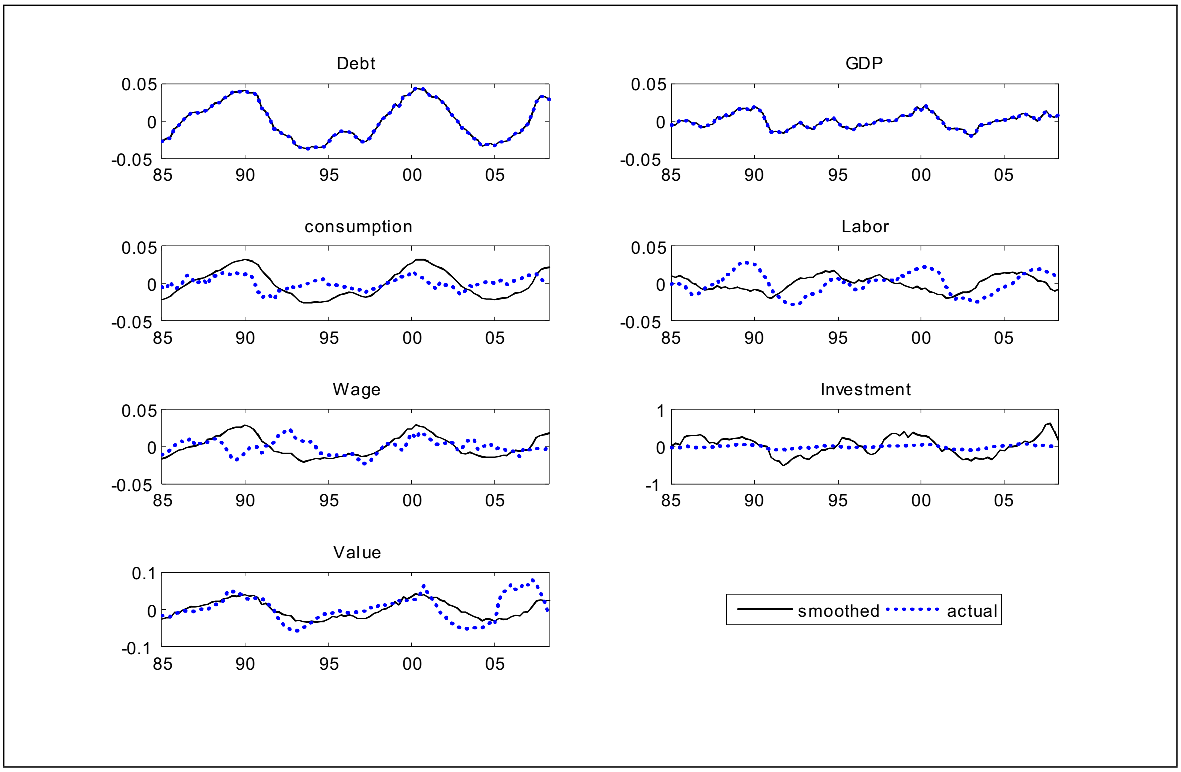
$$V_\pi(b_t, \pi_t, k_t; S_t) = \lambda_t$$

$$V_b(b_t, \pi_t, k_t; S_t) = -\lambda_t R_{t-1}$$

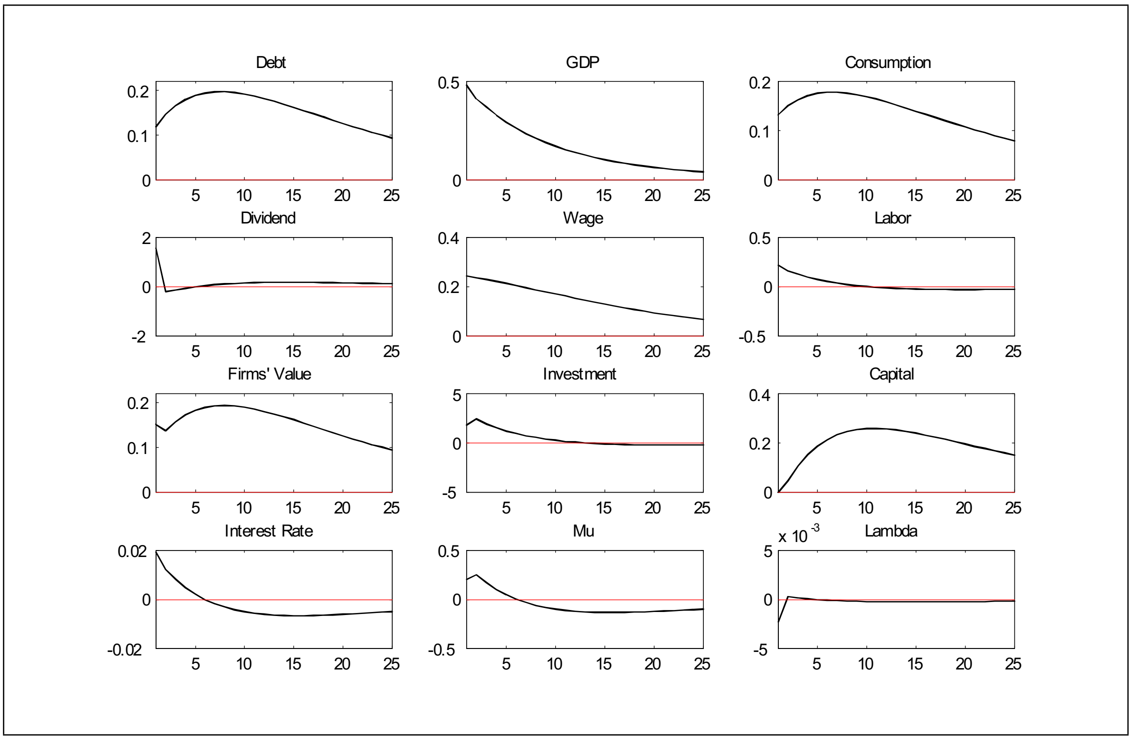
$$V_k(b_t, \pi_t, k_t; S_t) = (1+\mu_t\phi)Em_{t+1}\left[p_{t+1} + (1-p_{t+1})\sigma\right] V_\pi(b_{t+1}, \pi_{t+1}, k_{t+1}; S_{t+1})\pi_k(k_t, l_t; S_{t+1}) + \lambda_t(1-\delta)$$

Substituting the envelope conditions into the first-order conditions we get equations (13)-(16)

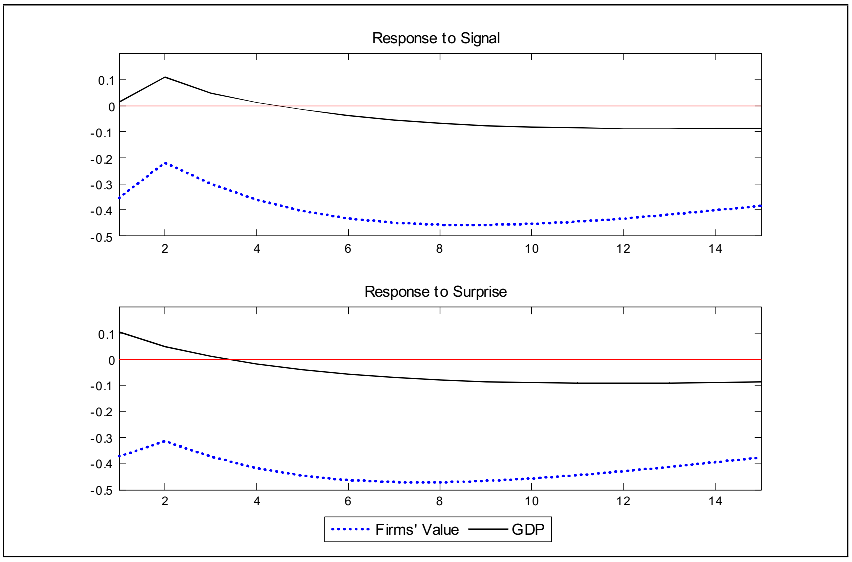
C Actual and Smoothed Series



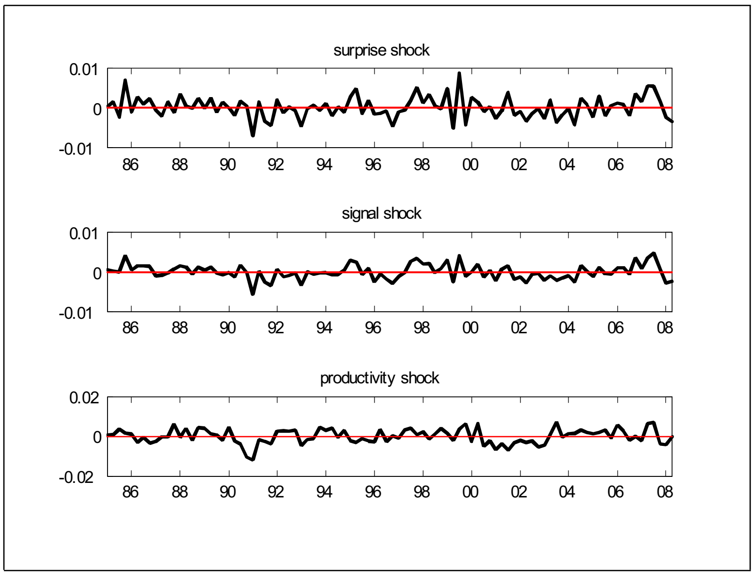
D Impulse Response to Productivity Shock



E Response of GDP and firms' value to financial signal and surprise



F Historical Estimated Shocks



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