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Credit Market Shocks, Monetary Policy, and Economic Fluctuations

Abstract

This paper uses a dynamic stochastic general equilibrium model with credit market imperfections to estimate the role of credit market shocks and monetary policy in US business cycles. The estimated model captures much of the historical narrative regarding the conduct of monetary policy and developments in financial markets that led to episodes of financial excess and distress over the last two decades. The estimation suggests that credit market shocks are an important factor behind economic fluctuations accounting for 15% of the variance in real output since 1985. In addition, we find that once credit market imperfections are considered, monetary policy is also an important force behind real output fluctuations explaining 12.5% of its variance.

Keywords: financial accelerator, monetary policy, DSGE models, Bayesian estimation.

JEL Classification: E32-E44.

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1. INTRODUCTION

The US financial crisis that started in 2008 was quickly followed by contractions in output, investment and employment indicating that financial factors could have real economic consequences. In response to the financial stress, the Federal Reserve Board reduced aggressively its policy interest rate implying monetary authorities' belief that they can partially offset negative credit market shocks. However, at the onset of the crisis there were scarce measurements of the real-financial linkages and none of the studies put together financial data and a model-based mechanism to provide insights. This paper fills this gap by providing evidence for the US economy using a Bayesian maximum likelihood methods to estimate an extended version of the Bernanke, Gertler, Gilchrist (1999) (henceforth BGG) financial accelerator model using real and financial data.

Among the evidence that suggested the existence of important linkages between financial conditions and macroeconomic outcomes Gilchrist, Yankov, and Zakrajsek (2008) (henceforth GYZ) show that corporate bond spreads have significant predictive power for economic activity.[1] Later, Gilchrist and Zakrajšek (2011) and Gilchrist and Zakrajšek (2012) included financial bond premium information into an otherwise standard macroeconomic vector autoregression (VAR) to examine the macroeconomic consequences of financial disturbances finding that credit market shocks have important effects on output, consumption, investment and working hours. Unfortunately, these analyses lacked of a structural macroeconomic model to distinguish between changes in credit supply and demand and that can account for general equilibrium feedback effects between developments in the financial and real sectors of the economy.

[1] GYZ suggest that this predictive power likely reflects the information content of credit spreads for disruptions in financial markets or variations in the cost of default, two factors that would cause credit spreads to widen relative to expected default risk prior to an economic downturn.

Earlier work by Elekdag, Justiniano, and Tchakarov (2006), Tovar (2006), Christiano, Motto, and Rostagno (2007) (henceforth CMR), Christensen and Dib (2008), De Graeve (2008), and Queijo von Heideken (2008) sought to quantify these general equilibrium mechanisms by estimating dynamic stochastic general equilibrium (DSGE) models that incorporate credit market imperfections through the financial accelerator mechanism described in Carlstrom and Fuerst (1997) and BGG. Although details differ in terms of model estimation and shocks specification, all of these papers document an important role for financial factors in business cycles fluctuations. Queijo von Heideken (2008) for example, shows that the ability of a model with a rich array of real and nominal rigidities to fit both US and the euro area data improves significantly if one allows for the presence of a financial accelerator mechanism; and CMR demonstrates that shocks to the financial sector have played an important role in economic fluctuations over the past two decades, both in the United States and Europe. Queijo von Heideken (2008), however, estimate a structural model that is identified without reliance on financial data and that does not allow for shocks to the financial sector, whereas CMR, though allowing for a wide variety of shocks to the financial sector, do not estimate the parameters governing the strength of the financial accelerator mechanism.

This paper is the first to estimate simultaneously the key parameters of the financial accelerator mechanism along with the shocks to the financial sector using financial market data. An advantage of including financial factors in our model is that we can consider structural, as opposed to the criticized reduced-form, financial shocks and directly assess their importance as drivers of economic activity. The empirical exercise is conducted using US data from 1985 to 2008, the period of the so-called *great moderation*. We limit the sample to 2008 to avoid the zero-lower bound on interest rates that would complicate the identification of the monetary policy shocks using a Taylor-interest rate rule.

The model is a New Keynesian DSGE model with agency costs as in BGG. These credit market imperfections, caused by asymmetric information, would generate a link between the real and financial sectors of the economy. In the financial accelerator mechanism, originally proposed by Bernanke and Gertler (1989), that will be the mechanism adopted in this paper, borrower's financial position determine her cost of credit. Unexpected changes in borrower's financial position, caused by shocks that affect their expected returns, would change financial constraints and through the required financing it will impact investment activity. Therefore, this financial accelerator mechanism amplifies and propagates shocks to the economy.

Overall our estimations show that credit market shocks account for 15% of output fluctuations during the 1985Q1-2008Q2 period, exacerbating economic downturns and magnifying economic expansions. Meanwhile, monetary policy partially offset credit market shocks during the three periods of financial instability and economic downturn included in the sample and explains 12.5% of the variance in output. The impulse response functions of the estimated model show that financial shocks have important real effects as a 0.25% unexpected rise in the external finance premium causes a 0.73% decrease in output and a 2.8% decrease in investment. Meanwhile, a 0.44% unexpected reduction in the federal funds rate contributes to a 0.38% expansion in output and 1.42% increase in investment. The increase in output that comes with the expansionary monetary policy, by improving borrowers' financial positions, contributes to reduce the cost of external financing further contributing to the output expansion.

The outline of the paper is as follows. Section 2 presents empirical evidence of the effect of credit market shocks on economic activity using a VAR. Section 3 develops the DSGE model with agency costs that is used to describe a mechanism of how credit market conditions could affect economic activity. Section 4 discusses the estimation strategy and the empirical implementation. Section 5 contains the results. Section 6 concludes.

2. EVIDENCE OF THE EFFECT OF CREDIT MARKET SHOCKS ON ECONOMIC ACTIVITY

In this Section we present a standard macroeconomic VAR extended with data on credit risk premium to examine the effect of credit risk shocks on economic activity.

The VAR and the model presented in Section 3 are, both, estimated using the same data set. The variables included are quarterly data on growth rates of real output and investment, and levels of inflation, interest rates, and external finance premium.[2] As in Gilchrist and Zakrajšek (2011), following assumptions of contemporaneous effects, the VAR stacks the data in the following order: Growth rate of real investment, growth rate of real output, inflation, federal funds rate, and external finance premium. Figure 1, below, shows the effect of a credit risk premium shock. The innovations are expressed in percentage points and the mean and 90% confidence intervals are reported. In response to a 0.40% increase in the credit risk premium, output growth contracts 0.09%, while investment growth diminishes 0.50%. The direction of these responses is in line with empirical evidence reported in Gilchrist and Zakrajšek (2011) that documents the importance of credit market conditions for macroeconomic performance.

Even when this evidence shows us that credit market shocks have consequences for economic activity, without a structural

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[2] Data comes from FRED II, except from the external finance premium measures. Output growth rates are computed as natural logarithm (ln) differences of the seasonal adjusted real gross domestic product. The same procedure applies for investment which is the seasonal adjusted total real business fixed investment. Inflation rates are detrended ln differences of the consumer price index multiplied by four to annualize. Nominal interest rates are reported in levels and correspond to the detrended effective federal funds rate. The external finance premium comes from Gilchrist, Ortiz, and Zakrajšek (2008) and consists of the first principal component of risk-premium measure computed using detailed information from bond prices on outstanding senior unsecured debt issued by a large panel of non-financial firms.

model we cannot discuss the transmission mechanism of financial shocks to the economy. There are different ways in which one could introduce a role for credit market imperfections and with this to generate a link between the real and financial sectors. Focusing on borrowing constraints one could consider costly enforcement, collateral constraints or costly state verification (CSV).

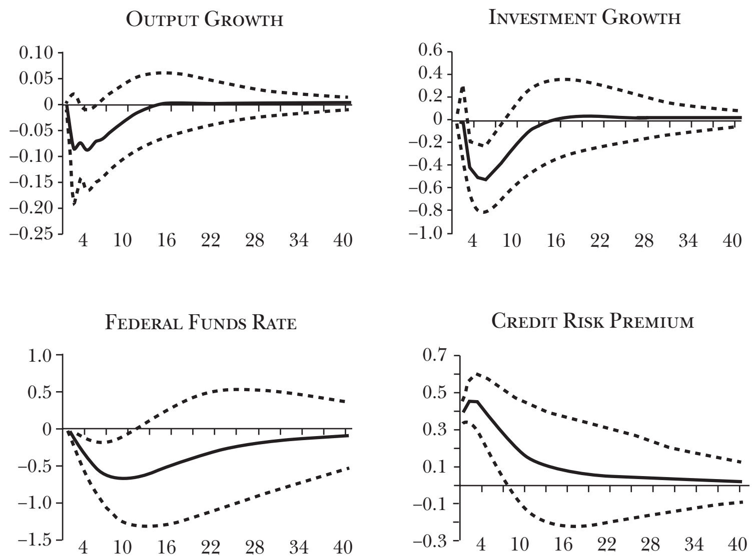
With costly enforcement, the credit market imperfection is associated to the inability to freely enforce contracts. In this paradigm, borrowers could decide to renege on debt and lenders anticipating this adverse behavior will limit the amount of credit. Despite its simplicity, this framework does not create default in equilibrium, nor changing external finance premium, neither a framework to analyze credit shocks.

Collateral could be used as a device to overcome costly enforcement, but if there are collateral constraints, the financial sector could still affect the real sector. A prominent work in this literature is Kiyotaki and Moore (1997) where there is loop between financial constraints and economic activity. In their model, assets play a dual role as factor of production and collateral. In this context, changes in the price of assets affect the value of collateral and with this credit access. With collateral constraints, the adjustment will mainly be in loanable quantities and not necessarily in the cost of credit, still a drawback for our identification strategy that needs changing cost of financing.

With CSV, the credit market imperfection is associated to asymmetric information. As first presented in Townsend (1979), and later adapted by Bernanke and Gertler (1989), one could consider a situation where borrowers have private information that lenders can only get by paying monitoring costs. This asymmetric information creates a role for the borrower's financial position and leads to the financial accelerator mechanism previously described. For our purposes, one advantage of this framework is that it allows for a changing external finance premium, which would be useful given that the identification of financial factors will be performed using financial data.

Figure 1

CREDIT MARKET SHOCKS, MONETARY POLICY, AND ECONOMIC FLUCTUATIONS



Note: The solid lines in each panel depict the mean impulse response function of each variable to one standard deviation external finance premium shock. The dashed lines give the 90% confidence intervals.

In the next section we develop a DSGE model with credit market imperfections under a CSV framework to describe the channels through which financial conditions affect economic outcomes. We will use the model to study the effects of financial shocks, as well as to analyze the role played by monetary policy in economic fluctuations.

3. MODEL

As stated in the introduction, the model is a monetary DSGE model with a financial accelerator mechanism as in BGG.[3] As

[3] The description of the core model follows Gilchrist and Saito

in BGG, we introduce money and price rigidities to study how credit market frictions may influence the transmission of monetary policy. Given that we are taking the model to the data we augment BGG original model with habits in consumption, investment growth adjustment costs, price indexation leading to a hybrid New Keynesian Phillips curve, and a monetary policy Taylor rule with an autoregressive component and that responds to contemporaneous inflation and output growth.

Christiano, Eichenbaum and Evans (2005), and Smets and Wouters (2007) show that these sources of inertia allow the model to better fit the data. However, we are aware that Chari, Kehoe and McGrattan (2009), when discussing the not readiness of New Keynesian models for policy analysis, criticizes the backward indexation and the autoregressive component of the Taylor-type monetary policy rule. Price indexation and the autoregressive component of interest rates are included to capture the persistence of inflation and the federal funds rates. In addition, the monetary policy rule that includes inflation and output tries to capture the dual mandate of the Federal Reserve System in effect since 1977. In the estimation we will use data to infer the macroeconomic degree of inflation and interest rate persistence. If these mechanisms generate counterfactuals movements of the variables, the estimation will try to cancel these features by producing small degrees of indexation and interest rate smoothing.

The introduction of habits creates a relation between the interest rate and the growth rate of consumption. By moving from levels to the growth rate of consumption, the model would generate a hump-shaped response of consumption when the economy is distorted by supply and demand shocks.[4] The investment growth adjustment costs imply that asset prices –the value of capital in place– increase during economic expansions in a way consistent to the behavior observed in the data.

(2006) that build on BGG (1999).

[4] Dennis (2009) discusses in detail the introduction of consumption habits in New Keynesian business cycles models.

The model will also include five exogenous distortions: Discount factor, credit risk premium, government expenditure, neutral technology, and monetary policy. Out of these shocks, when analyzing the prototype New Keynesian model in Smets and Wouters (2007), Chari, Kehoe and McGrattan (2009) criticize the credit risk premium and the government expenditure shocks as non-structural.[5] A structural government expenditure shock would require a careful description of the fiscal-side together with an open-economy specification to avoid accounting net exports as government expenditure, something that is out of the scope of the current paper as this margin is not our main concern. However, as shown below, we do tackle directly the issue of having a structural risk premium shock that has a clear interpretation within our model with credit market imperfections.

The log-linearized version of the model is presented in Appendix 1.

3.1 Households

Households consume, hold money, save in the form of a one-period riskless bond whose nominal rate of return is known at the time of the purchase, and supply labor to the entrepreneurs who manage the production of wholesale goods.

Preferences are given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \zeta_{C,t} \left\{ \ln(C_t - bC_{t-1}) - \nu \frac{H_t^{1+\gamma}}{1+\gamma} + \xi \ln \frac{M_t}{P_t} \right\},$$

where C_t is consumption, H_t is hours worked, $\frac{M_t}{P_t}$ is real balances acquired in period t carried into period $t+1$, $\zeta_{c,t}$ is an exogenous shock to time t preferences, and γ, ν, and ξ are positive parameters capturing the inverse Frisch elasticity of labor supply, the relative preference for labor, and the relative

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[5] Chari, Kehoe and McGrattan (2009) also criticize the shocks to wage markups and price markups in Smets and Wouters (2007) that are not included in the current paper.

preference for real money balances, respectively. Consumption preferences exhibit habit formation captured by b.

The budget constraint is given by

$$C_t = \frac{W_t}{P_t} H_t + \text{Profits}_t - T_t - \frac{M_t - M_{t-1}}{P_t} - \frac{B_{t+1} - R_t^n B_t}{P_t},$$

where W_t is the nominal wage for the household labor, Profits_t are the real dividends from ownership of retail firms, T_t is lump-sum taxes, B_{t+1} is a riskless bond held between period t and period $t+1$, and R_t^n is the nominal rate of return on the riskless bond held between period $t-1$ and period t.

The first-order conditions for the household's optimization problem include

1 $$\lambda_t = \frac{\zeta_{C,t}}{C_t - bC_{t-1}} - \beta b E_t \left[\frac{\zeta_{C,t+1}}{C_{t+1} - bC_t} \right],$$

2 $$\xi \frac{\zeta_{C,t}}{\frac{M_t}{P_t}} = -\lambda_t + \beta E_t \left[\lambda_{t+1} \frac{P_t}{P_{t+1}} \right],$$

3 $$\lambda_t E_t \left[\frac{P_{t+1}}{P_t} \right] = \beta E_t \left[\lambda_{t+1} R_{t+1}^n \right],$$

4 $$\lambda_t \frac{W_t}{P_t} = \zeta_{C,t} \nu H_t^{\gamma},$$

where λ_t is the multiplier on the budget constraint determined by Equation 1.

Equations 2 and 3 give the optimality conditions for real money balances and bond holdings, respectively. Equation 4 provides the optimality condition for labor supply. From these first order conditions we can appreciate that the exogenous shock to intertemporal preferences, $\zeta_{c,t}$, affects the marginal utility of consumption, the marginal utility of real money balances, and the marginal disutility of labor. Therefore, this intertemporal preference shock affects consumption and savings, different from the shock included in Smets and Wouters (2007) that also affects investment by generating a wedge between the interest rate controlled by the central bank and the return on assets held by the households. In our model, it will be credit market shocks the ones that will affect the investment decision.

3.2 Entrepreneurs

Entrepreneurs are introduced to generate the linkage between the real and financial sectors of the economy as their financing is affected by asymmetric information. There is a continuum of entrepreneurs that manage the production of wholesale goods. The production of wholesale goods uses capital constructed by capital producers and labor supplied by both households and entrepreneurs. Entrepreneurs purchase capital from capital goods producers, and finance the expenditures in capital with both entrepreneurial net worth (internal finance) and debt (external finance). We introduce financial market imperfections that make the cost of external funds depends on the entrepreneur's balance-sheet condition.

Entrepreneurs are risk neutral and discount the future at rate β. Given the high return to internal funds, they will postpone consumption indefinitely undoing capital misallocations. To capture the existing entry and exit of firms and to ensure that entrepreneurs do not accumulate enough funds to finance their expenditures on capital entirely with net worth, we assume that they have a finite lifetime. In particular, we assume that each entrepreneur survives until next period with probability η. New entrepreneurs enter to replace those who exit. To ensure that new entrepreneurs have some funds available when starting out, each entrepreneur is endowed with H_t^e units of labor that are supplied inelastically as a managerial input to the wholesale-good production at nominal entrepreneurial wage W_t^e. Here we are assuming the existence of an entrepreneurial labor market.

The entrepreneur starts any period t with capital, K_t, purchased from capital producers at the end of period $t-1$, and produces wholesale goods, Y_t, with labor and capital. Labor, L_t, is a composite of household labor H_t and entrepreneurial labor H_t^e, according to

$$L_t = H_t^{1-\Omega}(H_t^e)^{\Omega},$$

where Ω is the share of entrepreneurial labor in the total workforce.

The entrepreneur's project is subject to an idiosyncratic shock, ω_t, which affects both the production of wholesale goods and the effective quantity of capital held by the entrepreneur. We assume that ω_t is i.i.d. across entrepreneurs and time, satisfying $E_t\left[\omega_t\right]=1$ and with a normal distribution with standard deviation σ_ω. As this standard deviation increases, the agency costs problems become more severe. Below we will consider unexpected innovations to this standard deviation and we will call them credit risk premium shocks. The production of the wholesale goods is given by

5 $$Y_t = \omega_t(A_t L_t)^{\alpha} K_t^{1-\alpha},$$

where A_t is exogenous technology common to all the entrepreneurs and α is the share of labor in the production function. Let $P_{W,t}$ denote the nominal price of wholesale goods. Q_t is the price of capital relative to the aggregate price P_t to be defined later, and δ is the depreciation rate. The entrepreneur's real revenue in period t is the sum of the production revenues and the real value of the undepreciated capital given by

$$\omega_t\left(\frac{P_{W,t}}{P_t}(A_t H_t^{1-\Omega}(H_t^e)^{\Omega})^{\alpha} K_t^{1-\alpha} + Q_t(1-\delta)K_t\right).$$

In any period *t,* the entrepreneur chooses the demand for both household labor and entrepreneurial labor to maximize profits given capital acquired in the previous period. Below, when we derive the financial contract, we specify how capital is chosen, while the first-order conditions for labor inputs are

6 $$\alpha(1-\Omega)\frac{Y_t}{H_t}=\frac{W_t}{P_{W,t}},$$

and

7 $$\alpha\Omega\frac{Y_t}{H_t}=\frac{W_t^e}{P_{W,t}}.$$

At the end of period *t*, after the production of wholesale goods, the entrepreneur purchases capital K_{t+1} from capital producers at price Q_t. The capital is used as an input to the production of wholesale goods in period $t+1$. The entrepreneur finances the purchase of capital Q_tK_{t+1} partly with net worth N_{t+1} and partly by issuing nominal debt B_{t+1}, both determined at the end of period *t*, where debt in real terms is given by

$$\frac{B_{t+1}}{P_t}=Q_tK_{t+1}-N_{t+1}.$$

The entrepreneur's capital purchase decision depends on the expected rate of return on capital and the expected marginal cost of finance. By definition, the real rate of return on capital between period *t* and period $t+1$, R_{t+1}^k, depends on the marginal profit from the production of wholesale goods and the capital gain according to

8 $$R_{t+1}^k=\frac{\omega_{t+1}\left[\frac{P_{W,t+1}}{P_{t+1}}(1-\alpha)\frac{\overline{Y}_{t+1}}{K_{t+1}}+(1-\delta)Q_{t+1}\right]}{Q_t},$$

where $\overline{Y}_{t+1}$ is the average wholesale good production per entrepreneur $\left(Y_{t+1}=\omega_{t+1}\overline{Y}_{t+1}\right)$. Under our assumption of $E_t\omega_{t+1}=1$, the expected real rate of return on capital, $E_tR_{t+1}^k$, is given by

9 $$E_tR_{t+1}^k=E_t\left[\frac{\frac{P_{W,t+1}}{P_{t+1}}(1-\alpha)\frac{\overline{Y}_{t+1}}{K_{t+1}}+(1-\delta)Q_{t+1}}{Q_t}\right].$$

Equations 8 and 9 suggest that unexpected changes in asset prices are the main source of unexpected changes in the real rate of return on capital by looking at the difference between the realized rate of return on capital in period *t*, R_t^k, and the rate of return on capital anticipated in the previous period, $E_{t-1}R_t^k$, where the latter is the marginal cost of external funds between period $t-1$ and t.

As shown below, in the presence of financial market imperfections, the marginal cost of external funds depends on the entrepreneur's balance-sheet condition. As in BGG, we assume asymmetric information between borrowers (entrepreneurs) and lenders and a CSV. Specifically, the idiosyncratic shock to entrepreneurs, ω_{t+1}, is private information of the entrepreneur. To observe this, the lender must pay an auditing cost that is a fixed proportion μ of the realized gross return to capital held by the entrepreneur: $\mu R_{t+1}^k Q_t K_{t+1}$. The entrepreneur and the lender negotiate a financial contract that induces the entrepreneur to not misrepresent her earnings and minimizes the expected auditing costs incurred by the lender. We restrict attention to financial contracts that are negotiated one period at a time and offer lenders a payoff that is independent of aggregate risk. Under these assumptions, the optimal contract is a standard debt contract with costly bankruptcy: If the entrepreneur does not default, the lender receives a fixed payment independent of the realization of the idiosyncratic shock ω_{t+1}; and if the entrepreneur defaults, the lender audits and seizes whatever it finds.

Let $\overline{w}_{t+1}$ be the productivity cut-off value below which the entrepreneur defaults and the lender audits. Under the standard debt contract, a share $f(\overline{\omega}) \equiv \int_{\overline{\omega}}^{\infty} \omega\varphi(\omega)d\omega - \left[1-\varphi(\overline{\omega})\right]\overline{\omega}$ of the project's expected gross return, $E_t\left\{R_{(t+1)}^k Q_t K_{(t+1)}\right\}$, will go to the entrepreneur, and a share $g(\overline{\omega}) \equiv \left[1-\Phi(\overline{\omega})\right]\overline{\omega} + (1-\mu)\int_0^{\overline{\omega}} \omega\varphi(\omega)d\omega$ will go to the lender. To solve for the financial contract we can set the problem on the side of the entrepreneur, then the end-of-time-*t* contracting problem is given by

10 $$\max_{\kappa_t,\bar{\omega}_{t+1}} E_t\left\{R^k_{t+1}\kappa_t f\left(\bar{\omega}_{t+1}\right)\right\}$$

subject to

11 $$E_t\left\{R^k_{t+1}g\left(\bar{\omega}_{t+1}\right)\frac{\kappa_t}{\kappa_t-1}\ \lambda_{t+1}\right\}\geq R^n_{t+1}E_t\left\{\lambda_{t+1}\frac{P_t}{P_{t+1}}\right\},$$

where for convenience we express this problem in terms of leverage denoted by $\kappa_t\equiv\left(\frac{Q_tK_{t+1}}{N_{t+1}}\right)$ with N_{t+1} denoting next-period net worth. The left-hand side of expression 11 is the lender's expected return and the right-hand side is the expected required real return to participate in the contract. The optimality conditions for the productivity cut-off value, $\bar{\omega}_{t+1}$, the leverage ratio, κ_t, and the participation constraint are

12 $$E_t\left\{R^k_{t+1}\kappa_t f'\left(\bar{\omega}_{t+1}\right)\right\}=\Xi_t E_t\left\{R^k_{t+1}g'\left(\bar{\omega}_{t+1}\right)\frac{\kappa_t}{\kappa_t-1}\lambda_{t+1}\right\},$$

13 $$E_t\left\{R^k_{t+1}f\left(\bar{\omega}_{t+1}\right)\right\}=-\Xi_t\frac{1}{\left(\kappa_t-1\right)^2}E_t\left\{R^k_{t+1}g\left(\bar{\omega}_{t+1}\right)\lambda_{t+1}\right\},$$

14 $$E_t\left\{R^k_{t+1}g\left(\bar{\omega}_{t+1}\right)\frac{\kappa_t}{\kappa_t-1}\ \lambda_{t+1}\right\}=R^n_{t+1}E_t\left\{\lambda_{t+1}\frac{P_t}{P_{t+1}}\right\},$$

where Ξ_t is the multiplier on the lender's participation constraint. Equation 12 equates the marginal cost of an increase in the productivity cut-off value, which lowers the marginal return to the entrepreneur, in the left-hand side, to the marginal benefit of a looser participation constraint of the lender. Equation 13 equates the marginal benefit of increasing leverage in terms of the expected total net return, in the left-hand-side, to the marginal cost of a tighter participation constraint. Equation 14 gives the participation constraint with equality that will hold given the risk neutrality of entrepreneurs. Using Equation 12 and Equation 14 we can express Equation 13 as

13'
$$\frac{E_t\left\{R_{t+1}^k f\left(\bar{\omega}_{t+1}\right)\right\}}{R_{t+1}^n E_t\left\{\lambda_{t+1}\dfrac{P_t}{P_{t+1}}\right\}}=-\left[\frac{E_t\left\{R_{t+1}^k f'\left(\bar{\omega}_{t+1}\right)\right\}}{E_t\left\{R_{t+1}^k g'\left(\bar{\omega}_{t+1}\right)\lambda_{t+1}\right\}}\right]\frac{1}{\kappa_t}.$$

In equilibrium, the cost of external funds between period t and period $t+1$ is equated to the expected real rate of return on capital (9). Let s_t denote the borrowing external finance premium, given by the ratio of the entrepreneur's cost of external funds to the opportunity cost of internal funds, where the latter is equated to the cost of funds in the absence of financial market imperfections $E_t\left\{R_{t+1}^n\dfrac{P_t}{P_{t+1}}\right\}$. Then s_t is defined as

15
$$s_t=\frac{E_t\left\{R_{t+1}^k\right\}}{E_t\left\{R_{t+1}^n\dfrac{P_t}{P_{t+1}}\right\}}.$$

The agency problem presented above and partly summarized by Equation 13" implies that the cost of external funds depends on the financial position of the borrowers. In particular, the external finance premium increases when a smaller fraction of capital expenditures is financed by the entrepreneur's net worth:

16
$$s_t=s\left(\frac{Q_tK_{t+1}}{N_{t+1}}\right)=s\left(\kappa_t\right),$$

where $s(\cdot)$ is an increasing function for $\kappa>1$. To derive the specific form of the function $s(\cdot)$, log-linearize equations 13' and 14 around the steady-state to get

13"
$$E_t\left\{r_{t+1}^k\right\}-\left(r_{t+1}^n-E_t\left\{\pi_{t+1}\right\}\right)=\left(\Psi-\theta_f\right)E_t\bar{\omega}_{t+1}-\kappa_t$$

and

14'
$$E_t\left\{r_{t+1}^k\right\}-\left(r_{t+1}^n-E_t\left\{\pi_{t+1}\right\}\right)=\left(\frac{1}{\kappa-1}\right)\kappa_t-\theta_g E_t\bar{\omega}_{t+1},$$

where lower case letters, r_t^k, r_t^n, and, π_t denote log-deviations from their steady-state of the corresponding capital letter variables. In addition, using $\bar{\omega}$ to denote the steady-state productivity cut-off value, we have defined $F(\bar{\omega}_{t+1}) \equiv \frac{-f'(\bar{\omega}_{t+1})}{g'(\bar{\omega}_{t+1})}$,

$$\Psi \equiv \frac{\bar{\omega}F'(\bar{\omega})}{F(\bar{\omega})} > 0,\ \theta_g \equiv \frac{\bar{\omega}g'(\bar{\omega})}{g(\bar{\omega})}, \text{with } 0 < \theta_g < 1, \text{and } \theta_f \equiv \frac{\bar{\omega}f'(\bar{\omega})}{f(\bar{\omega})} < 0.$$

Solving 13" and 14' we have

17
$$E_t\bar{\omega}_{t+1} = \frac{\kappa}{\kappa-1}\frac{1}{\left(\Psi-\theta_f+\theta_g\right)}\kappa_t$$

and

18
$$E_t\left\{r_{t+1}^k\right\} - \left(r_{t+1}^n - E_t\left\{\pi_{t+1}\right\}\right) = \left[\frac{\left(\Psi-\theta_f+\theta_g\right)-\kappa\theta_g}{(\kappa-1)\left(\Psi-\theta_f+\theta_g\right)}\right]\kappa_t = \chi\kappa_t\ .$$

Equation 18 shows that the elasticity of the external finance premium with respect to leverage, captured by the term $\chi \equiv \left[\frac{\left(\Psi-\theta_f+\theta_g\right)-\kappa\theta_g}{(\kappa-1)\left(\Psi-\theta_f+\theta_g\right)}\right]$, depends on the primitive parameters of the CSV problem, including the bankruptcy cost parameter μ and the distribution of the idiosyncratic shock ω_t. However, this same expression shows that we can adopt the following simplified functional form for the determination of the external finance premium:

19
$$s_t = \frac{E_t\left\{R_{t+1}^k\right\}}{E_t\left\{R_{t+1}^n\frac{P_t}{P_{t+1}}\right\}} = \zeta_{s,t}\left(\frac{Q_tK_{t+1}}{N_{t+1}}\right)^{\chi},$$

where $\chi > 0$ is the elasticity of the external finance premium with respect to leverage, $\frac{Q_tK_{t+1}}{N_{t+1}}$, which is consistent with the micro-structured financial contract. In this expression we have added an exogenous shock to time t external finance premium, $\zeta_{s,t}$, which is fundamentally equivalent to a shock to the standard deviation of the distribution of the entrepreneurial productivity, σ_ω, that aggravates the credit market imperfections' problems. Therefore, within the context of the agency costs problem proposed in this model, and similar to CMR, this credit risk premium shock is structural and has a clear economic interpretation as opposed to the reduced-form shock included in Smets and Wouters (2007).

The aggregate net worth of entrepreneurs at the end of period t is the sum of the equity held by entrepreneurs who survive from period $t-1$ and the aggregate entrepreneurial wage, which consists of the wage earned by the entrepreneurs surviving from period $t-1$ and the wage earned by newly emerged entrepreneurs in period t according to

20
$$\begin{aligned} N_{t+1} &= \eta\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k \frac{B_t}{P_{t-1}} \right) + \frac{W_t^e}{P_t} \\ &= \eta\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k (Q_{t-1} K_t - N_t) \right) + \frac{W_t^e}{P_t}, \end{aligned}$$

where the second line used the relation $Q_{t-1} K_t = N_t + \frac{B_t}{P_{t-1}}$.

Equations 8, 9, 19 and 20 provide the financial accelerator mechanism. As already discussed, from Equations 8 and 9, unexpected changes in asset prices are the main source of changes in the ex post return to capital. In turn, Equation 20 suggests that these unexpected movements in the real rate of return on capital are the main source of changes in the entrepreneurial net worth, under the calibration that the entrepreneurial wage is small. Finally, Equation 18 implies that a change in leverage is the main source of changes in the external finance premium. Thus, movements in asset prices play a key role in the financial accelerator mechanism.

Entrepreneurs going out of business in period t consume the residual equity according to

21 $$C_t^e = (1-\eta)\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k \frac{B_t}{P_{t-1}} \right),$$

where C_t^e is the aggregate consumption of the entrepreneurs who exit in period t.

Overall, the financial accelerator mechanism implies that an unexpected increase in asset prices increases the net worth of entrepreneurs and improves their balance-sheet conditions. This in turn reduces the external finance premium and increases the demand for capital by these entrepreneurs. In equilibrium, the price of capital increases further and capital producers increase the production of new capital. This additional increase in asset prices strengthens the mechanism just described. Thus, the countercyclical movement in the external finance premium implied by the financial market imperfections magnifies the effects of shocks to the economy.

3.3 Capital Producers

Capital producers are introduced to decentralize the capital accumulation process.[6] Capital producers use both final investment goods I_t and existing capital K_t to construct new capital K_{t+1}. They lease existing capital from the entrepreneurs. As in Christiano, Eichenbaum, and Evans (2005), capital production is subject to adjustment costs, which are assumed to be a function of investment growth $\frac{I_t}{I_{t-1}}$. The aggregate capital accumulation equation is given by

22 $$K_{t+1} = (1-\delta)K_t + I_t - \psi\left(\frac{I_t}{I_{t-1}}\right) I_t,$$

[6] In this version of the model, capital accumulation could equally be carried out directly by households without differences in the results. However, when introducing investment-specific technology shocks, together with preferences shocks, it could be advantageous to have a different agent in charge of the capital accumulation process to have a shock affecting the consumption Euler equation and a different shock affecting the investment Euler equation.

where $\psi(\cdot)$ is a function with the property that in steady state $\psi = \psi' = 0$, and $\psi'' > 0$. Below, in the estimation, we will use data to infer the value of ψ'', which has two contrasting effects as higher adjustment costs dampen the response of investment to aggregate shocks, but imply larger movements in the price of installed capital and with this bigger financial accelerator effects when agency costs are considered.[7]

Taking the relative price of capital Q_t as given, capital producers choose inputs I_t and K_t to maximize profits from the formation of new capital according to

$$E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \left\{ Q_t \left[(1-\delta)K_t + I_t - \psi\left(\frac{I_t}{I_{t-1}}\right) I_t \right] - Q_t (1-\delta) K_t - P_t I_t \right\},$$

where λ_t is the multiplier on the household's budget constraint.

3.4 Retailers

Retailers are mainly introduced to generate price rigidities. There is a continuum of monopolistically competitive retailers of unit measure. Retailers buy wholesale goods from entrepreneurs in a competitive manner and then differentiate the product slightly at zero resource cost.

Let $Y_t\ (z)$ be the retail goods sold by retailer z, and let $P_t\ (z)$ be its nominal price. Final goods, Y_t, are the composite of individual retail goods

$$Y_t = \left[\int_0^1 Y_t\ (z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

[7] As suggested by an anonymous referee, one can think of the introduction of the adjustment costs to investment growth as assuming that capital is a factor with semi-fixed supply, at least in the short run, and therefore all changes in demand will be fully reflected in prices.

where $\varepsilon > 0$ determines the elasticity of demand between varieties *z*. The corresponding price index, P_t, is given by

$$P_t = \left[\int_0^1 P_t(z)^{1-\varepsilon} dz \right]^{\frac{1}{1-\varepsilon}} .$$

Households, capital producers, and the government demand the final goods.

Each retailer faces an isoelastic demand curve given by

23 $$Y_t(z) = \left(\frac{P(z)}{P_t} \right)^{-\varepsilon} Y_t .$$

As in Calvo (1983), each retailer resets price with probability $(1-\theta)$, independently of the time elapsed since the last price adjustment. Thus, in each period, a fraction $(1-\theta)$ of retailers reset their prices, while the remaining fraction θ indexes its prices to past inflation $\Pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$ with a degree of persistence ρ_π. The real marginal cost to the retailers of producing a unit of retail goods is the price of wholesale goods relative to the price of final goods $\left(\frac{P_{W,t}}{P_t} \right)$. Each retailer takes the demand curve (23) and the price of wholesale goods as given and sets the retail price $P_t(z)$. All retailers given a chance to reset their prices in period *t* choose the same price P_t^* given by

24 $$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{i=0}^{\infty} \theta^i \Lambda_{t,i} P_{W,t+i} Y_{t+i} \left(\frac{1}{P_{i+1}} \right)^{1-\varepsilon}}{E_t \sum_{i=0}^{\infty} \theta^i \Lambda_{t,i} Y_{t+i} \left(\frac{1}{P_{i+1}} \right)^{1-\varepsilon}} ,$$

where $\Lambda_{t,i} = \frac{\beta^i \lambda_t}{\lambda_{t+i}}$ is the stochastic discount factor that the retailers take as given.

The aggregate price evolves according to

25 $$P_t = \left[\theta \left(\Pi_{t-1}^{\rho_\pi} P_{t-1} \right)^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}.$$

Combining Equations 24 and 25 yields the canonical form of the new optimization-based Phillips curve that arises from an environment of time-dependent staggered price setting.

3.5 Aggregate Resource Constraint

The aggregate resource constraint for final goods is

26 $$Y_t = C_t + C_t^e + I_t + G_t + \mu \int_0^{\bar{\omega}} \omega dF(\omega) R_t^k Q_{t-1} K_t ,$$

where G_t is the government expenditures that we assume to be exogenous, while $\mu \int_0^{\bar{\omega}} \omega dF(\omega) R_t^k Q_{t-1} K_t$ corresponds to the aggregate monitoring costs.[8]

3.6 Government

Exogenous government expenditures G_t are financed by lump-sum taxes T_t and money creation according to

27 $$G_t = \frac{M_t - M_{t-1}}{P_t} + T_t .$$

The money stock is adjusted to support the interest rate rule specified below. Lump-sum taxes adjust to satisfy the government budget constraint.[9]

3.7 Monetary Policy

The monetary authority conducts monetary policy using the following interest rate rule

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[8] In the numerical exercise we assume that actual resource costs to bankruptcy are small.

[9] As discussed before, given that the set-up of this economy is a closed-economy model, the government expenditure will capture the residual of aggregate demand including net exports.

$$\left(\frac{R_t^n}{R^n}\right)=\left[\frac{R_{t-1}^n}{R^n}\right]^{\rho_{r^n}}\left[\Pi_t^{\gamma_\pi}\left(\frac{Y_t-Y_{t-1}}{Y_{t-1}}\right)^{\gamma_y}\right]^{1-\rho_{r^n}}\zeta_{r^n,t},$$

where R^n is the steady-state nominal interest rate on the one-period bond, ρ_{r^n} captures the degree of interest-rate smoothing, $\Pi_t=\frac{P_t}{P_{t-1}}$ is inflation, γ_π is the weight on inflation, γ_y is the weight on output growth, and $\zeta_{r^n,t}$ is a monetary policy shock.

3.8 Shocks

It is assumed that the exogenous disturbances to the discount factor, financial distress, government spending, and technology obey autoregressive processes according to:

$$\ln(\zeta_{C,t})=\rho_{\zeta_C}\ln(\zeta_{C,t-1})+\varepsilon_t^{\zeta_C}$$

$$\ln(\zeta_{S,t})=\rho_{\zeta_S}\ln(\zeta_{S,t-1})+\varepsilon_t^{\zeta_S}$$

$$\ln(G_t)=\rho_g\ln(G_{t-1})+\varepsilon_t^g$$

$$\ln(A_t)=\rho_a\ln(A_{t-1})+\varepsilon_t^a$$

while the monetary policy shock is i.i.d.:

$$\zeta_{r^n,t}=\varepsilon_t^{r^n}.$$

All shocks $\left\{\varepsilon_t^{\zeta_C},\varepsilon_t^{\zeta_S},\varepsilon_t^g,\varepsilon_t^a,\varepsilon_t^{r^n}\right\}$ are assumed to be distributed normally with a zero mean and standard deviations $\left\{\sigma_{\zeta_c},\sigma_{\zeta_s},\sigma_g,\sigma_a,\sigma_{r^n}\right\}$, respectively.

4. ESTIMATION STRATEGY AND EMPIRICAL IMPLEMENTATION

The model presented is estimated using Bayesian methods.[10]

[10] A detailed description of the methods is found in An and Schorfheide (2007). Textbook treatments are available in Canova (2007)

This Section describes the methods and parameters used for estimation.

4.1 Bayesian Estimation of the DSGE Model

The object of interest is the vector of parameters

$$\varphi=\left\{b,\theta,\psi,\chi,\gamma_{\pi},\rho_{r^{n}},\rho_{\pi},\rho_{\zeta_{c}},\rho_{\zeta_{s}},\rho_{g},\rho_{a},\sigma_{r^{\pi}}\sigma_{\zeta_{c}},\sigma_{\zeta_{s}},\sigma_{g},\sigma_{a}\right\}$$

Given a prior p(φ), the posterior density of the model parameters, φ , is given by

$$p\left(\varphi \mid Y^{T}\right)=\frac{L\left(\varphi \mid Y^{T}\right)p(\varphi)}{\int L\left(\varphi \mid Y^{T}\right)p(\varphi)d\varphi} \ ,$$

where $L\left(\varphi \mid Y^{T}\right)$ is the likelihood conditional on observed data $Y^{T}=\left\{Y_{1},\ldots,Y_{T}\right\}$. In our case $Y_{t}=\left[\Delta y_{t}+a_{t},\Delta i_{t}+a_{t},4\pi_{t},4R_{t}^{n},4s_{t}\right]'$ for $t=1,\ldots,T$, where $\Delta y_{t}+a_{t}$ is the growth rate of real output, $\Delta i_{t}+a_{t}$ is the growth rate of real investment, $4\pi_{t}$ is annualized CPI inflation, $4R_{t}^{n}$ is annualized effective federal funds rate, and $4s_{t}$ is annualized external finance premium from Gilchrist, Ortiz, and Zakrajšek (2008).

The likelihood function is computed under the assumption of normally distributed disturbances by combining the state-space representation implied by the solution of the linear rational expectations model and the Kalman filter. Posterior draws are obtained using Markov Chain Monte Carlo methods. After obtaining an approximation to the mode of the posterior, a random walk Metropolis algorithm with 1,000,000 iterations is used to generate posterior draws. Point estimates and measures of uncertainty for φ are obtained from the generated values.

4.2 Parameters

In the quantitative analysis we fixed a subset of the parameters that determine the non-stochastic steady-state and that the

and Dejong and Dave (2007).

estimation cannot fully identify and concentrate in the estimation of parameters describing the monetary policy, habit formation, investment, price rigidities, the financial accelerator mechanism, and the exogenous processes. The calibrated parameters are presented in the next subsection, while the priors for the estimated parameters are presented in subsection 4.2.2.

4.2.1 Calibration

The calibrated parameter values are standard; the values on the financial contract come from BGG, while the technological and government values match US data. The mean technology growth rate, g_{ss}, is 0.00427, which imply that the steady-state technology growth, $A = e^{g_{ss}}$, is 1.00428, while the discount factor, β, is set at 0.99. These values imply an annual steady-state nominal interest rate, $4\left(R^n - 1\right) = 4\left(\frac{\beta}{A} - 1\right)$, of 5.77%. The steady-state capital return, R^K, is set at 1.0195 that implies a 2% annual external finance premium. In the production function, the share of labor, α, is 0.65, while the share of entrepreneurial labor, Ω^e, is 0.01. The elasticity of the marginal disutility of labor, $1+\gamma$, is 1.33. The capital depreciation rate, δ, is 0.025, while the steady state capital-net worth ratio, κ, is set at 2. The entrepreneur' survival rate, η, is set to 0.9728, the standard deviation of the entrepreneurial productivity distribution, σ_{ss}, is fix at 0.28, and the monitoring costs, μ, are set to 0.12, to be consistent with a quarterly default rate of 0.0075. The steady-state government expenditure-output ratio, $\frac{G}{Y}$, is 0.2, while the steady-state entrepreneurial consumption-output ratio, $\frac{C^e}{Y}$, is fixed at 0.01. The parameter controlling money demand, ξ, does not affect the dynamics of the model as the monetary authority will supply any amount of money required to implement the nominal interest rate determined by the policy rule. Table 1, below, summarizes these calibrated values.

4.2.2 Priors

There are five common prior distributions used in the literature of Bayesian DSGE estimation. Uniform distributions are used when the researcher wants to limit the range of the parameters, but does not want to take a stance on the mass of particular values. Normal distributions are used to center prior means without introducing skewness in the distribution. Beta distributions are used for most parameters whose range is in the [0, 1] interval as the autoregressive parameters. Gamma distributions are used for parameters restricted to be positive. Inverse gamma distributions are used for the standard deviation of shocks to allow a positive density at zero. In our case, as described below, priors were selected on the basis of previous estimations and available information. The information of the chosen priors is summarized in the third to fifth columns of Table 2. Appendix 2 shows the distributions for each parameter.

The habit parameter, b, is assumed to follow a beta distribution with prior mean of 0.7 and standard deviation of 0.1. The second derivative of adjustment cost function with respect to investment growth, ψ'', is assumed to follow a gamma distribution with prior mean of five and standard deviation of 0.5. The elasticity of the external financial premium with respect to changes in net worth, χ, is assumed to follow a beta distribution with prior mean of 0.06 and standard deviation of 0.03.

The parameters related to prices and monetary policies follow. The Calvo probability of not adjusting prices, θ, is assumed to follow a gamma distribution with prior mean of 0.7 and standard deviation of 0.1. The degree of price indexation, ρ_{π}, is assumed to follow a beta distribution with mean 0.3 and standard deviation 0.1. The autoregressive component of nominal interest rate, ρ_{r^n}, is assumed to follow a beta distribution with mean of 0.5 and standard deviation of 0.2, while the Taylor rule coefficients on inflation, γ_{π}, and output growth, γ_y, are assumed to follow a gamma distribution with mean of 1.5 and 0.5, respectively and a common standard deviation of 0.25.

Table 1

CALIBRATED PARAMETERS

Coefficient	*Description*	*Value*
g_{ss}	Mean technology growth rate	0.00427
β	Discount rate	0.99
R_{ss}^{k}	Steady-state capital return	1.0195
α	Share of labor in production	0.65
Ω^{e}	Share of entrepreneurial labor	0.01
$1+\gamma$	Elasticity of marginal disutility of labor	1.33
κ	Steady-state capital-net worth ratio	2
η	Entreprenurial survival rate	0.9728
σ_{ss}	Standard deviation of entrepreneurial productivity distribution	0.028
μ	Monitoring costs	0.12
G/Y	Steady-state government expenditure-output ratio	0.2
C^{e}/Y	Steady-state entrepreneurial consumption-output ratio	0.01

All the autoregressive parameters associated to the shock processes are assumed to have a beta distribution. Preferences, ρ_{ς_c}, and credit market, ρ_{ζ_s}, innovations are assumed to have prior mean of 0.5 and standard deviation of 0.25, while government, ρ_g, and technology, ρ_a, have a prior mean of 0.9 and standard deviation of 0.1. The standard deviations of the shock processes, $\sigma_{\zeta_c}, \sigma_{\zeta_s}, \sigma_g, \sigma_a$, are assumed to have an inverse gamma distribution with prior mean of 1 and standard deviation of 4, the only exception is the mean of the standard deviation of the nominal interest rate innovation, σ_{r^n} which is set to 0.4.

5. RESULTS

In this section we present the estimation results, the Bayesian impulse-response functions, the historical shock decomposition, and the variance decomposition.

5.1 Estimation

Table 2, below, summarizes the estimation results. The estimated coefficients and their descriptions are presented in columns 1 and 2, the prior densities' distributions, means, and standard deviations are reported in the next three columns. The posterior mode and 90% confidence intervals are reported in columns 6 to 8 for the no financial accelerator case, and in the last three columns for the financial accelerator case. The marginal likelihoods are not comparable because the model without the financial accelerator does not use financial data.[11] Overall, the parameter estimates in the models with and without the financial accelerator mechanism are similar. The main differences are in the degree of price indexation, which is bigger in the model without the financial accelerator, and in the standard deviation of the preference shock which is smaller in the model without the financial accelerator.

The habit parameter estimate, b, is 0.918, slightly higher than in the model without the financial frictions at 0.898, suggesting that in the presence of credit market imperfections consumers try harder to smooth consumption. The second derivative of the adjustment cost function with respect to investment growth, ψ'', is 5.559, which is a smaller number than the one reported by CMR in a model that also has capital utilization rate, but higher than in the model without financial frictions at 4.551. Recall that higher adjustment costs dampen the response of investment but, through the changes in the price of installed capital, magnifies the financial accelerator. In the model with financial frictions, the elasticity of the external financial premium with respect to changes in net worth, χ, is estimated at 0.009, lower than previous estimates between 0.03 and 0.1.

[11] We have estimated the no financial accelerator model using financial data and including measurement errors to the external finance premium. In this case the Log data densities are comparable, and the model with a financial accelerator has a superior fit to the data as the model without this financial mechanism cannot reproduce the observed behavior of the external finance premium.

The parameters related to prices and monetary policies follow. The estimate of the Calvo probability of not adjusting prices, θ, is 0.929, also higher than in the model without financial frictions at 0.896. The estimate of the degree of price indexation, ρ_{π}, is 0.224, much lower than the 0.516 in the model without financial frictions. In the model with financial frictions the autoregressive component of nominal interest rate, ρ_{r^n}, is 0.939, while the Taylor rule coefficient on inflation, γ_{π}, is 1.264 and output growth, γ_{y}, is 0.236. In the model without financial frictions the estimates are 0.903, 1.237, and 0.252, respectively, what suggests that the different dynamics observed between the two models is not due to differences in monetary policy estimates.

In the model with financial frictions the autoregressive processes imply autoregressive coefficients of 0.788 for preferences ρ_{ζ_c}, 0.957 for government expenditure ρ_g, 0.980 for technology ρ_a, and 0.725 for credit market ρ_{ζ_s}. The shock processes have standard deviations of 0.121 for nominal interest rates σ_{r^n}, 4.834 for preferences σ_{ζ_c}, 2.704 for government expenditure σ_g, 0.320 for technology σ_a, and 2.353 for credit market σ_{ζ_s} innovations. In the model without financial frictions credit markets are not included, so the autoregressive coefficients for preferences, government expenditure, and technology are 0.767, 0.971, and 0.991, respectively. The standard deviations for nominal interest rates, preferences, government expenditure, and technology are 0.123, 3.592, 2.838, and 0.209, respectively.

5.2 Impulse-Response Functions

Figure 2 shows the impulse response functions of output, investment, and the external finance premium to one standard deviation in the monetary policy shock. Figure 3 shows the evolution of output, investment, and the federal funds rate to one standard deviation external finance premium shock. All the innovations are expressed in percentage points and the mean and 90% confidence intervals are reported. The

Table 2

PRIORS AND POSTERIOR ESTIMATES

					No financial accelerator model[a]			Financial accelerator model[b]		
Log data density					−593.9			−654.1		
		Prior			*Posteriors*[c]			*Posteriors*		
Coefficient	*Description*	*Prior density*[d]	*Prior mean*	*Prior standard deviation*	*Posterior mean*	*5%*	*95%*	*Posterior mean*	*5%*	*95%*
b	Consumption habit	B	0.70	0.10	0.90	0.87	0.93	0.92	0.91	0.92
θ	Calvo probability of not adjusting prices	G	0.70	0.10	0.90	0.88	0.91	0.93	0.92	0.94
ψ''	Investment adjustment costs	G	5.00	0.50	4.55	3.84	5.31	5.56	4.57	6.47
χ	Elasticity of external finance premium w.r.t. leverage	B	0.06	0.03	–	–	–	0.009	0.008	0.011
ρ_π	Degree of price indexation	B	0.30	0.10	0.52	0.34	0.67	0.22	0.11	0.34
γ_π	Taylor rule inflation	G	1.50	0.25	1.24	1.11	1.37	1.26	1.00	1.49
γ_y	Taylor rule output growth	G	0.50	0.25	0.25	0.07	0.43	0.24	0.08	0.38
ρ_{r^n}	Taylor rule smoothing	B	0.90	0.10	0.90	0.88	0.93	0.94	0.93	0.95
ρ_g	Government spending	B	0.90	0.10	0.97	0.94	1.00	0.96	0.92	1.00

ρ_a	Neutral technology growth	B	0.90	0.10	0.99	0.98	1.00	0.98	0.98	0.98
ρ_{ζ^c}	Intertemporal preference	B	0.50	0.25	0.77	0.70	0.85	0.79	0.76	0.81
ρ_{ζ^s}	External finance premium	B	0.50	0.25	–	–	–	0.73	0.71	0.76
Standard deviation of shocks		*Prior density*	*Prior mean*	*Prior standard deviation*	*Posterior mean*	*5%*	*95%*	*Posterior mean*	*5%*	*95%*
σ_{r^n}	Monetary policy	I	0.40	4.00	0.12	0.11	0.14	0.12	0.11	0.14
σ_g	Government spending	I	1.00	4.00	2.84	2.45	3.22	2.70	2.31	3.22
σ_a	Neutral technology growth	I	1.00	4.00	0.21	0.16	0.26	0.32	0.21	0.43
σ_{ζ^c}	Intertemporal preference	I	1.00	4.00	3.59	2.16	5.00	4.83	4.60	5.00
σ_{ζ^s}	External finance premium	I	1.00	4.00	–	–	–	2.35	1.83	2.83

Note: calibrated coefficients: mean technology growth $g_{ss} = 0.00427$, discount factor $\beta = 0.99$, labor share in production $\alpha = 0.65$, share of entrepreneurial labor $\Omega^e = 0.01$, marginal disutility of labor $\gamma = 0.33$, depreciation rate $\delta = 0.025$, steady-state government expenditure-to-output ratio $G/Y = 0.2$, and steady-state entrepreneurial consumption-to-output ratio $C^e/Y = 0.01$. For the financial accelerator model the following parameters are also calibrated: entrepreneurial survival rate $\eta = 0.98$, a steady-state risk premium $rp = 0.02/4$ and a steady-state leverage ratio $\kappa = 2$. [a] In the no financial accelerator model no financial data was used, there is no external finance premium shocks and the elasticity of risk premium, χ, is set to 0. [b] In the financial accelerator model the external finance premium data was used to identify the external finance premium shocks and the elasticity of risk premium, χ. [c] Posterior percentiles are from two chains of 1,000,000 draws generated using a random walk Metropolis algorithm. We discard the initial 500,000 and retain one every five subsequent draws. [d] B-beta, G-gamma, and I-inverted-gamma distribution.

black lines show the case of the financial accelerator, while the model without financial frictions is represented with the gray lines.

Before discussing the results it is important to remind that, under the financial accelerator environment, an expansion in output causes an increase in the value of assets in place and a rise in the entrepreneurial net worth. As entrepreneurs' net worth expands relative to their borrowing, the external finance premium falls, causing a further increase in both asset values and investment demand. These general equilibrium feedback effects, in turn, further amplify the financial accelerator mechanism. For the financial accelerator model, this mechanism is in effect for both financial and non-financial shocks.

Figure 2 shows that an unexpected expansionary monetary policy innovation generates hump-shaped expansions in output and investment, accompanied by inflationary pressures (not shown), and due to the mechanism described above, a decrease in the external finance premium. This last effect is the key transmission mechanism that explains why monetary policy could have additional stabilizing effects in the presence of credit market imperfections as exemplified by the additional response of output and investment.

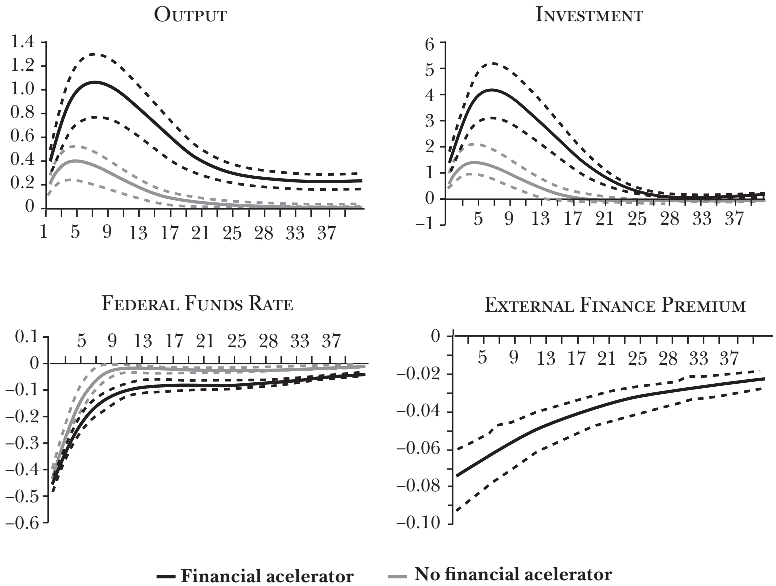
Figure 3 shows that an increase in the external finance premium by tightening credit market constraints contributes significantly to output and investment contractions, without alleviating inflationary pressures (not shown) through the supply-side costs of decreased capital accumulation, and creating constraints on monetary policy. These movements are in line with the empirical evidence of the VAR presented in Section 2.

The real effect of this mechanism is quantitatively large –a 0.25% rise in the external finance premium causes a 0.73% decrease in output and a 2.8% decrease in investment. These numbers are in the ball-park of the empirical evidence presented in Gilchrist and Zakrajšek (2012) that analyzes the economy's response to excess bond premium shocks.

For sake of completeness, we describe the responses of the

Figure 2

MODEL RESPONSES TO A MONETARY POLICY SHOCK



Note: The solid lines in each panel depict the mean impulse response function of each variable to one standard deviation monetary policy shock. The dashed lines give the 90% confidence intervals. The black lines in each panel depict the financial accelerator case. The gray lines depict the responses generated by the model without the financial accelerator.

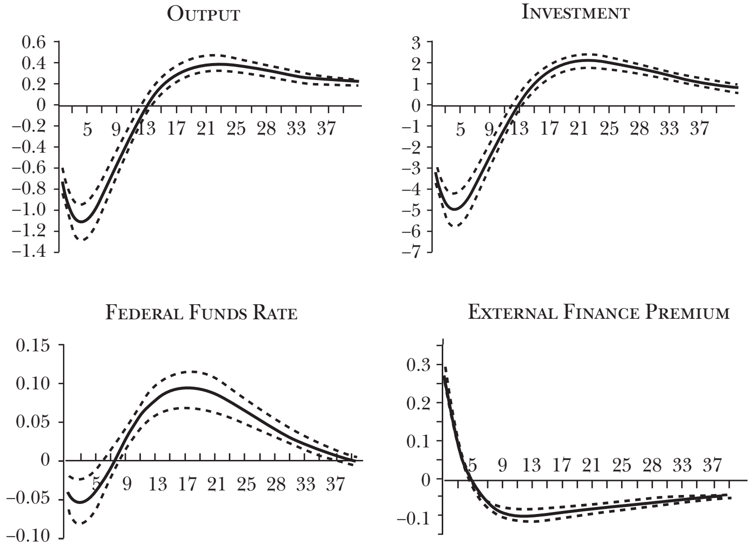
observable variables to the other three shocks: Government expenditure, technology and discount factor.[12]

A positive government expenditure shock causes an expansion in output and investment together with inflationary pressures that are faced with higher interest rates. In the financial accelerator model, the increase in the price of installed capital brought about by this demand driven expansion improves the entrepreneurs' financial position and eases the credit market conditions by lowering the external finance premium.

[12] The impulse-response figures are available upon request.

Figure 3

MODEL RESPONSES TO A CREDIT (EXTERNAL FINANCE) RISK PREMIUM SHOCK



Note: The solid lines in each panel depict the mean impulse response function of each variable to one standard deviation external finance premium shock. The dashed lines give the 90% confidence intervals. The black lines in each panel depict the financial accelerator case. Here there are no gray lines as the model without the financial accelerator does not have financial shocks.

A positive technology shock increases output and investment and lowers inflation at the time that interest rates drop. Again, in the financial accelerator model, credit conditions amplify the effect of the shock.

A positive discount factor shock increases consumption and in both models it has a positive initial response in output. However, the response of our model economy to discount factor shock has contrasting effects depending on the inclusion of a financial accelerator mechanism. Without the financial accelerator mechanism, the initial increase in output brought by the increase in consumption is quickly overturned by the drop in investment. When financial factors are considered, the improvement in credit market conditions is enough to keep investment strong. In both cases there are inflationary pressures and the federal funds rate is increased.

5.3 Shock Decomposition

To understand the implications of the model for the conduct of monetary policy and to evaluate the importance of financial market frictions in determining business cycle outcomes, we calculate the portion of the movement in the observed data that can be attributed to each shock. Figure 4 presents the contribution of each shock, monetary policy, government expenditure, technology, taste (discount factor), and external finance credit (credit risk) premium, to explain the observed behavior of demeaned output growth in the financial accelerator case. In Appendix 3, we present the graphs for the other four observable variables in the financial accelerator case.

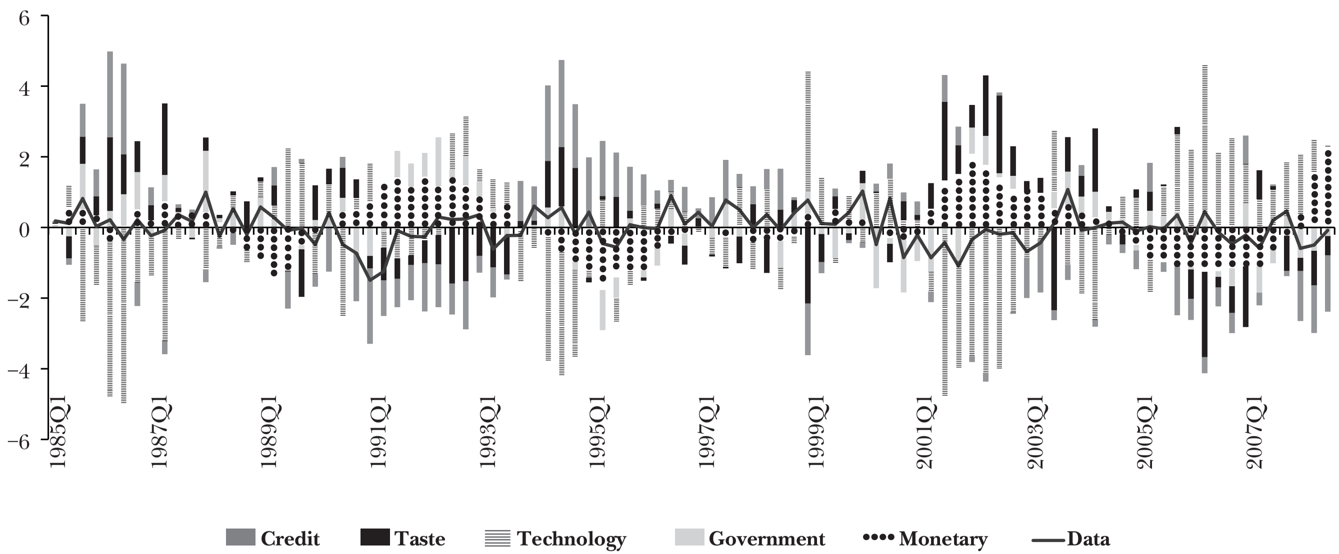
This figure shows the preponderance of technology innovations as engine of economic fluctuations and the relatively small role attributed to government shocks.[13] This historical shock decomposition also shows that there are clear episodes when monetary policy and financial disturbances were important in the determination of the economic fluctuations.

To gain more intuition, now we concentrate on the portion of the movement in the observable variables that can be credited to monetary policy and credit market innovations. Figure 5 shows the historical decomposition of monetary policy shocks in the cases with and without the financial accelerator, while Figure 6 focuses on the financial shocks.

[13] McGrattan and Prescott (2010) point out the important role that intangible capital played during the output expansion in the 1990s. Extending the current model with intangible investment and non-neutral technology change with respect to producing intangible investment goods would be a natural extension to verify the robustness of the presented shock decomposition, especially given the negative contributions of technology during part of the 1990s.

Figure 4

Historical Shock Decomposition of Output Growth in the Financial Accelerator Model



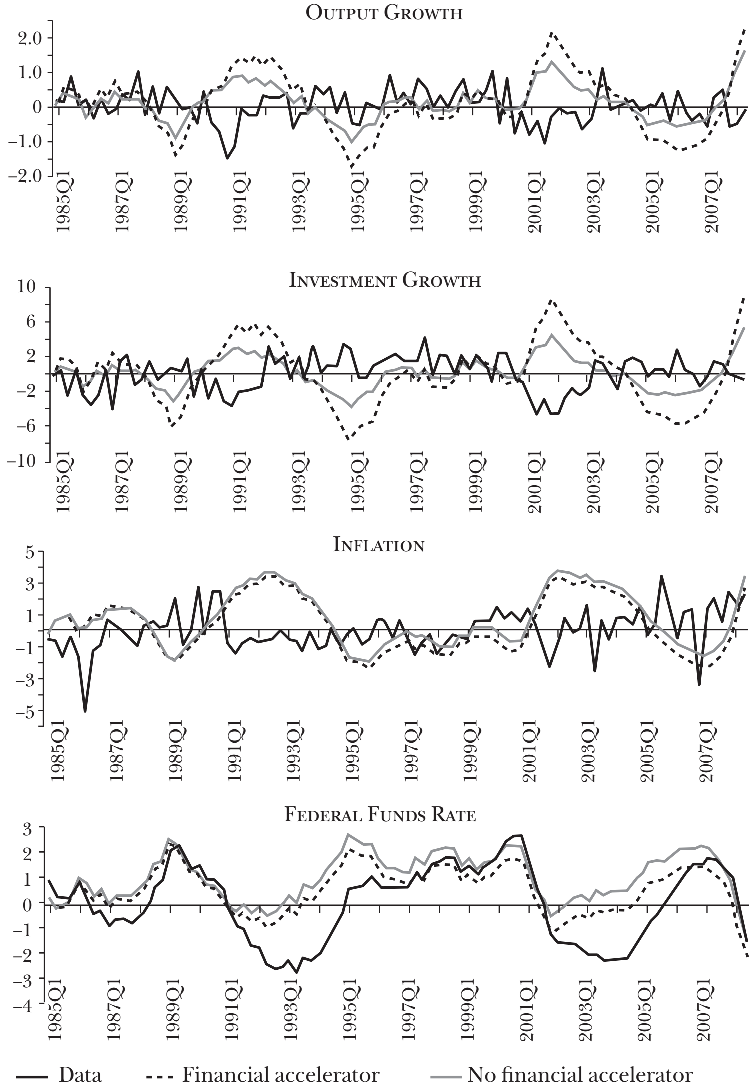
Note: This figure presents the historical shock decomposition of demeaned output growth computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter, present the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

Figure 5 shows that the effect of monetary policy shocks on the economy accords well with the historical record regarding the conduct of monetary policy since the mid-1980s. Monetary policy was tight in the late 1980s prior to the onset of the 1990-1991 recession but was eased substantially during the economic downturn of the early 1990s. According to our estimates, tight monetary policy also contributed to the slowdown in business investment and output during the 1994-1995 period. The stance of monetary policy was roughly neutral up to the collapse of the stock market in early 2000, and according to our estimates, policy was eased significantly during the 2001 recession. Monetary policy was again relatively tight during the housing boom of the 2005-2007 period. The rapid sequence of cuts in the federal funds rate during 2007 also appears as a significant easing of monetary conditions that has supported the expansion in investment and output during that period. An appealing feature of this model is that the monetary transmission mechanism works in part through its impact on balance sheet conditions –that is, the external finance premium is strongly countercyclical in response to monetary policy shocks.

Figure 6 shows that the estimated effects of financial disturbances and their impact on the real economy also accord well with historical perceptions of the likely effects of tight credit conditions on economic activity. According to our estimates, the economy showed signs of financial distress at the onset of the 1990-1991 recession, and adverse financial conditions remained a drag on the real economy throughout the jobless recovery of the early 1990s. Indeed, between 1989 and 1993, shocks to the financial sector caused the external finance premium to rise by 150 basis points, an increase that led to an extended period of subpar economic performance. Credit market conditions improved markedly during the second half of the 1990s, a period during which the external finance premium fell about 250 basis points. The premium moved higher after the bursting of the dot-com bubble, and financial conditions deteriorated further at the onset of the collapse in the housing sector in 2005. The

Figure 5-a

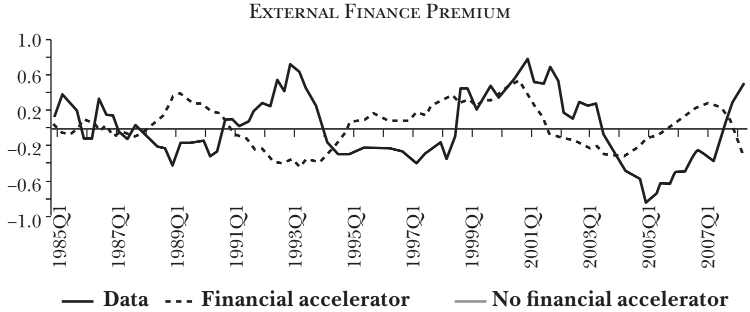
HISTORICAL DECOMPOSITION OF MONETARY POLICY SHOCKS



Note: The solid black line in each panel depicts the behavior of actual variables expressed in percentage point deviations from steady state. The dotted line in each panel depicts the estimated effect of monetary policy shocks under the financial accelerator model. The solid gray line in each panel depicts the estimated effect of monetary policy shocks in the model without the financial accelerator.

Figure 5-b

HISTORICAL DECOMPOSITION OF MONETARY POLICY SHOCKS



model also captures the current financial crisis as a shock to the financial sector, manifested as a 75 basis point jump in the external finance premium that has led to a sharp slowdown in the growth of investment and output during the last four quarters.

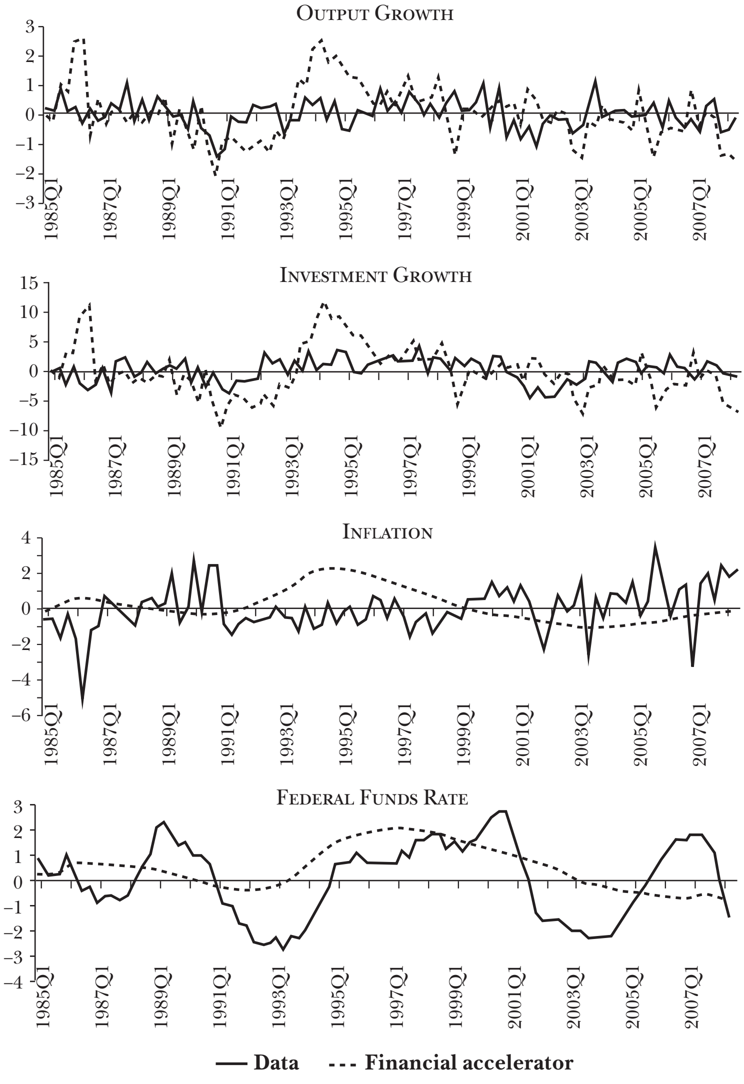
In summary, this relatively simple model of the financial accelerator –when estimated using both real and financial market data– does remarkably well at capturing much of the historical narrative regarding the conduct of monetary policy and developments in financial markets that led to the episodes of financial excess and distress over the last two decades. As shown during the three episodes when credit market innovations were dragging output growth, monetary policy partially offset these effects.

5.4 Variance Decomposition

Table 3 summarizes the asymptotic variance decomposition for the models with and without financial factors. In both cases technology innovations are the main force explaining the fluctuation in output, investment, inflation, and nominal interest rates. In the case of the external finance premium the variance is mostly explained by shocks to preferences with 50% and financial shocks (external finance premium) with 34.8%, while technology only accounts for 11.1% of its variance.

Figure 6-a

HISTORICAL DECOMPOSITION OF FINANCIAL SHOCKS



Note: The solid black line in each panel depicts the behavior of actual variables expressed in percentage point deviations from steady state. The dotted line in each panel depicts the estimated effect of monetary policy shocks under the financial accelerator model. Here there is no solid gray line as in the model without the financial accelerator there are no financial shocks.

Figure 6-b

HISTORICAL DECOMPOSITION OF FINANCIAL SHOCKS

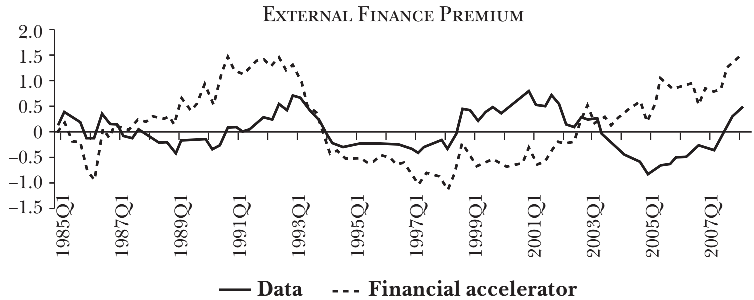


Table 3

ASYMPTOTIC VARIANCE DECOMPOSITION OF THE MODEL WITHOUT FINANCIAL FACTORS AND OF THE MODEL WITH FINANCIAL FACTORS

Shock/Variable	*Output*	*Investment*	*Inflation*	*Interest rate*	*External finance premium*
Monetary	18.5/12.5	26.1/17.1	10.6/7.1	10.4/9.6	–/3.8
Government	27.3/6.5	1.2/0.5	0.4/0.6	1.5/2.3	–/0.6
Technology	44.7/51.3	44.6/53.0	64.0/52.0	66.9/42.2	–/11.1
Discount factor	9.5/14.7	28.0/6.9	25.0/38.1	21.2/37.6	–/49.7
External finance premium	–/15.1	–/22.5	–/2.1	–/8.4	–/34.8

Note: The table reports the percentage of the variance of each variable (reported in columns) that is explained by each of the shocks (reported in rows). Each cell shows two numbers separated by a slash. The first number corresponds to the share in the model without financial factors and the second number is the share in the model with these factors included.

In the version with financial factors, monetary innovations explain 12.5% of the output variance, while credit market innovations explain 15.1%.[14] Meanwhile, in the case of investment,

[14] Using the same measure of the external finance premium, but a factor-augmented vector autoregression specification instead of

monetary policy explains 17.1%, while credit market innovations account for 22.5%. In the model without financial factors, government expenditure shocks (a residual in the aggregate resource constraint) capture most of the portion that is really explained by financial factors, while in the case of investment the discount factor does it.

6. CONCLUSIONS

Using macroeconomic and financial data in an estimated DSGE model with financial frictions, this paper shows that financial market frictions have been important in US business cycles amplifying real and nominal disturbances in the economy. The estimated model shows that financial shocks have important real effects as a 0.25% rise in the external finance premium causes a 0.73% decrease in output and a 2.8% decrease in investment. A 0.44% unexpected reduction in the federal funds rate contributes to a 0.38% expansion in output and 1.42% increase in investment. In the presence of credit market imperfections the increase in output that comes with the expansionary monetary policy, by improving borrowers' financial positions, contributes to reduce the cost of external financing further contributing to the output expansion. We provide evidence that disturbances originated in the financial sector have significant real consequences for output and investment activity accounting for 12.5% and 17.1% of their respective variances since 1985. We also observed that monetary policy was effective partially offsetting adverse shocks that originated in the financial market during the three most recent recessions.

the DSGE model presented here, Gilchrist, Yankov, and Zakrajsek (2008) find that shocks emanating from the corporate bond market account for about 20% of the variance of industrial production at the two- to four-year horizon.

Appendices

Appendix 1. Log Linearized Model

The log-linearized version of the model is presented below. As in BGG (1999) the model is presented in terms of four blocks of equations: *1)* aggregate demand; *2)* aggregate supply; *3)* evolution of state variables; and *4)* monetary policy rule and shock processes. All lower case variable denote log-deviations from steady-state, while variables without a time subscript represent steady-state variables.

Aggregate Demand

Resource constraint:

A.1
$$y_t = \frac{C}{Y}c_t + \frac{C^e}{Y}c_t^e + \frac{1}{Y}i_t + \frac{G}{Y}g_t + \varphi_t$$

Marginal utility in the case of internal habit:

A.2
$$\lambda_t = \frac{1}{b^2\beta - bA(1+\beta) + A^2}[-\left(b^2\beta + A^2\right)c_t + bAc_{t-1} + \\ + bA\beta E_t\left\{c_{t+1}\right\} - bAa_t + bA\beta E_t\left\{a_{t+1}\right\}]$$

Consumption-savings:

A.3
$$\lambda_t = E_t\{\lambda_{t+1}\} - r_{t+1}^n - E_t\{\pi_{t+1}\} - E_t\{a_{t+1}\} - \zeta_{c,t}$$

Entrepreneurial consumption:

A.4
$$r_t^e = n_{t+1}$$

Definition of the external finance premium:

A.5
$$s_t = E_t\left\{r_{t+1}^k\right\} - \left(r_{t+1}^n - E_t\left\{\pi_{t+1}\right\}\right) + \zeta_{s,t}$$

Determination of the external finance premium:

A.6 $$s_t = \chi\left(q_t - k_{t+1} + n_{t+1}\right)$$

Expected real rate of return on capital:

A.7 $$E_t\left\{R_{t+1}^K\right\} = \frac{(1-\alpha)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A}{(1-\alpha)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A + (1-\delta)}\left(E_t\left\{y_{t+1}\right\} - k_{t+1} + E_t\left\{a_{t+1}\right\} + \right.$$
$$\left. + E_t\left\{mc_{t+1}\right\}\right) + \frac{(1-\delta)}{(1-\alpha)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A + (1-\delta)}E_t\left\{q_{t+1}\right\} - q_t$$

Relation between price of capital q_t and investment adjustment cost as a function of growth rate of I_t:

A.8 $$q_t = (1+\beta)\psi A^2 i_t - \psi A^2 i_{t-1} - \beta\psi A^2 E_t\left\{i_{t+1}\right\} +$$
$$+\psi A^2 a_t - \beta\psi A^2 E_t\left\{a_{t+1}\right\}$$

Aggregate Supply

Aggregate supply of final goods:

A.9 $$y_t = \alpha\Omega h_t + (1-\alpha)k_t - (1-\alpha)a_t$$

Labor market equilibrium:

A.10 $$y_t - h_t + mc_t + \lambda_t = \gamma h_t$$

Phillips curve:

A.11 $$\pi_t = \frac{1}{1+\beta\rho_\pi}\frac{(1-\theta)(1-\beta\theta)}{\theta}mc_t + \frac{\beta}{1+\beta\rho_\pi}E_t\left\{\pi_{t+1}\right\} + \frac{\rho_\pi}{1+\beta\rho_\pi}\pi_{t-1}$$

Evolution of State Variables

Capital accumulation:

A.12 $$k_{t+1} = \left(1 - \frac{1-\delta}{A}\right)i_t + \frac{1-\delta}{A}(k_t - a_t)$$

Evolution of net worth:

$$n_{t+1} = n_t + \frac{K}{N} r_t^k - \left(\frac{K}{N} - 1\right) E_{t-1} r_t^k + \alpha(1-\Omega)\frac{Y}{N}\frac{\varepsilon - 1}{\varepsilon}\left(y_t + mc_t\right) - a_t \quad \text{(A.13)}$$

or using the definition of the external finance premium $E_{t-1}\left\{r_t^k\right\} = s_{t-1} + \left(r_t^n + E_{t-1}\pi_t\right)$.

$$n_{t+1} = n_t + \frac{K}{N} r_t^k - \left(\frac{K}{N} - 1\right)\left[s_{t-1} + \left(r_t^n + E_{t-1}\pi_t\right)\right] + \\ + \alpha(1-\Omega)\frac{Y}{N}\frac{\varepsilon - 1}{\varepsilon}\left(y_t + mc_t\right) - a_t \quad \text{(A.14)}$$

Monetary Policy Rule and Shock Processes

The monetary policy rule follows:

$$r_t^n = \rho_{r^n} r_{t-1}^n + \left(1 - \rho_{r^n}\right)\left[\gamma_\pi \pi_t + \gamma_y\left(y_t - y_{t-1} + a_t\right)\right] + \varepsilon_t^{r^n} \quad \text{(A.15)}$$

It is assumed that the exogenous disturbances to government spending, technology, discount factor, and financial distress obey autoregressive processes:

$$g_t = \rho_g g_{t-1} + \varepsilon_t^g \quad \text{(A.16)}$$

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a \quad \text{(A.17)}$$

$$\zeta_{c,t} = \rho_{\zeta_c} \zeta_{c,t-1} + \varepsilon_t^{\zeta_c} \quad \text{(A.18)}$$

$$\zeta_{s,t} = \rho_{\zeta_s} \zeta_{s,t-1} + \varepsilon_t^{\zeta_s} \quad \text{(A.19)}$$

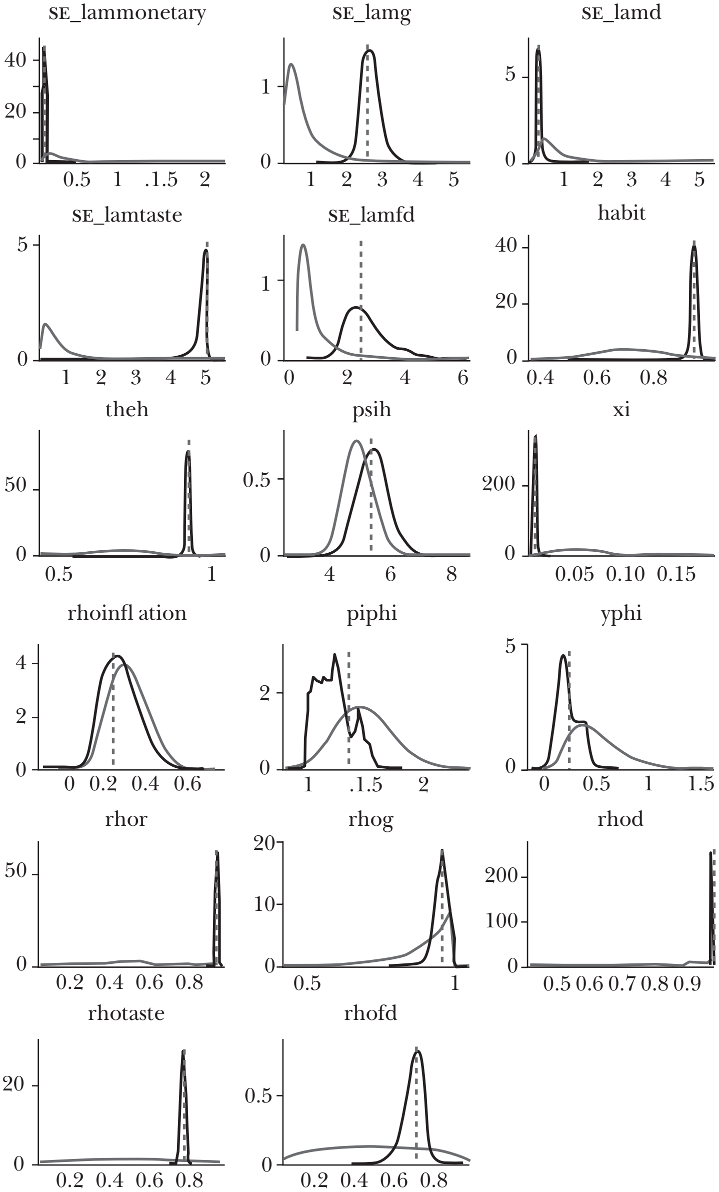
while the monetary policy shock is i.i.d.:

$$\zeta_{r^n,t} = \varepsilon_t^{r^n} \quad \text{(A.20)}$$

Appendix 2. Prior and Posterior Distributions

Figure A.1

ESTIMATED PARAMETERS' PRIOR AND POSTERIOR DISTRIBUTIONS



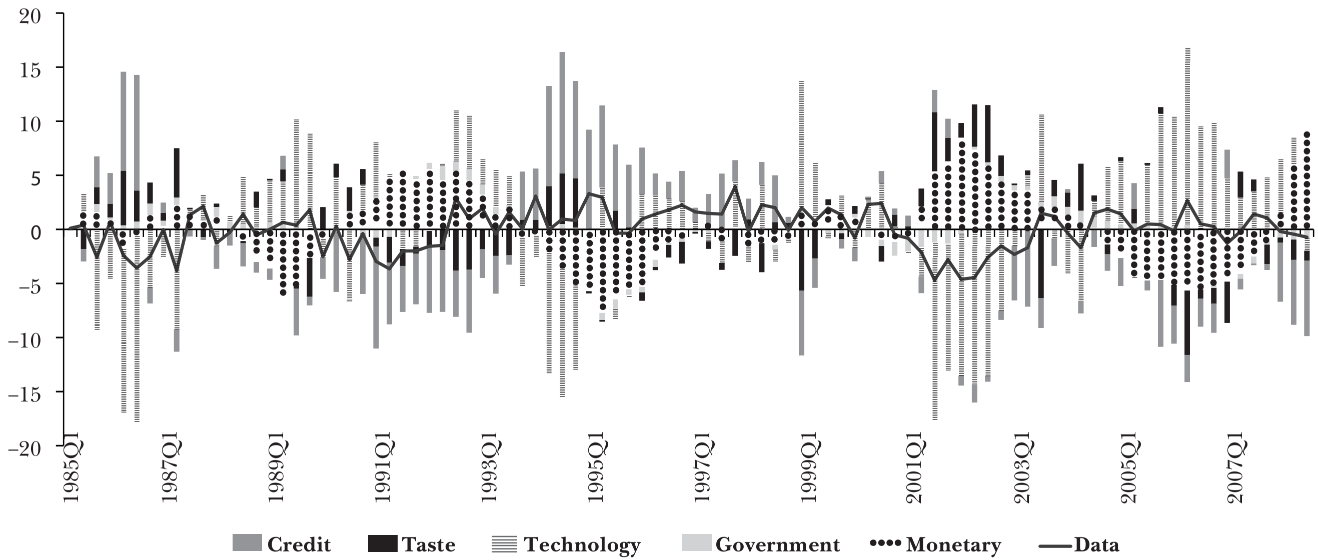
Note: The figure presentes the prior (grey) and posterior (black) distributions for the parameters estimates, along with the posterior mode (vertical line).

Appendix 3. Shock Decomposition

Figures A.2 to A.5 report the contribution of each shock to the observed data for the financial accelerator case. For example, Figure A.2 shows the contribution of monetary policy, government expenditure, technology, taste (discount factor), and credit (external finance premium) shocks to explain demeaned investment growth. Figures A.3 to A.5 report the results for stationary CPI inflation, stationary effective federal funds rate, and stationary external finance premium, respectively, where as specified in the text all variables are demeaned using the sample mean.

Figure A.2

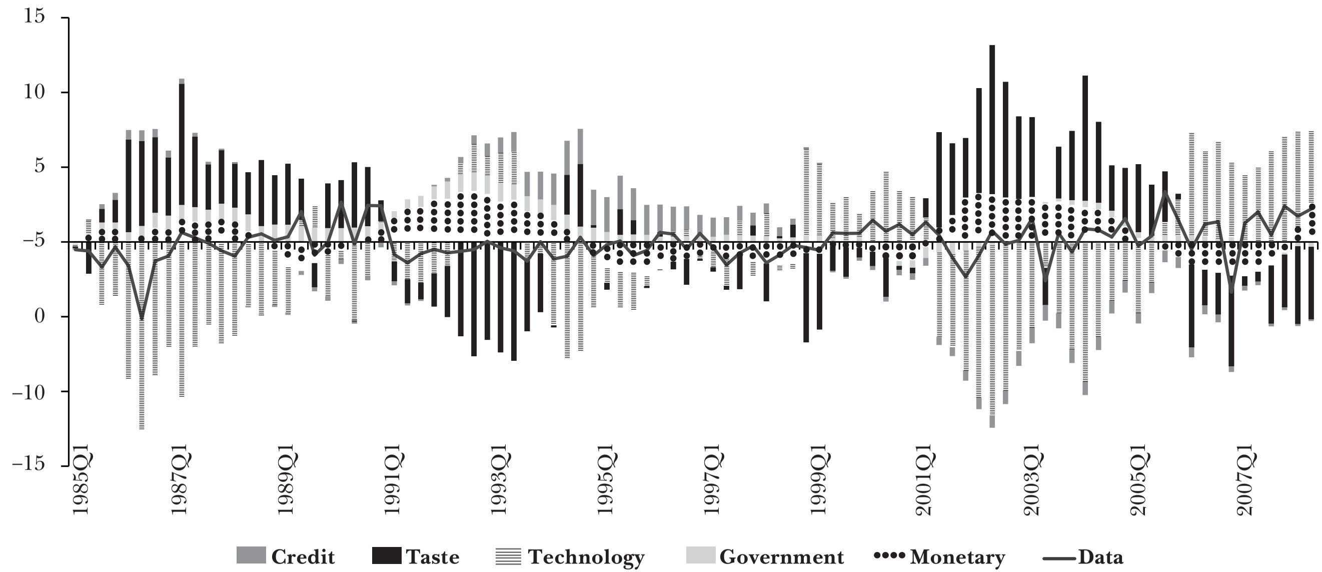
INVESTMENT GROWTH



Note: This figure presents the historical shock decomposition of investment growth computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter presents the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

Figure A.3

STATIONARY CPI INFLATION



Note: This figure presents the historical shock decomposition of stationary CPI inflation computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter presents the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

Figure A.4

STATIONARY FEDERAL FUNDS

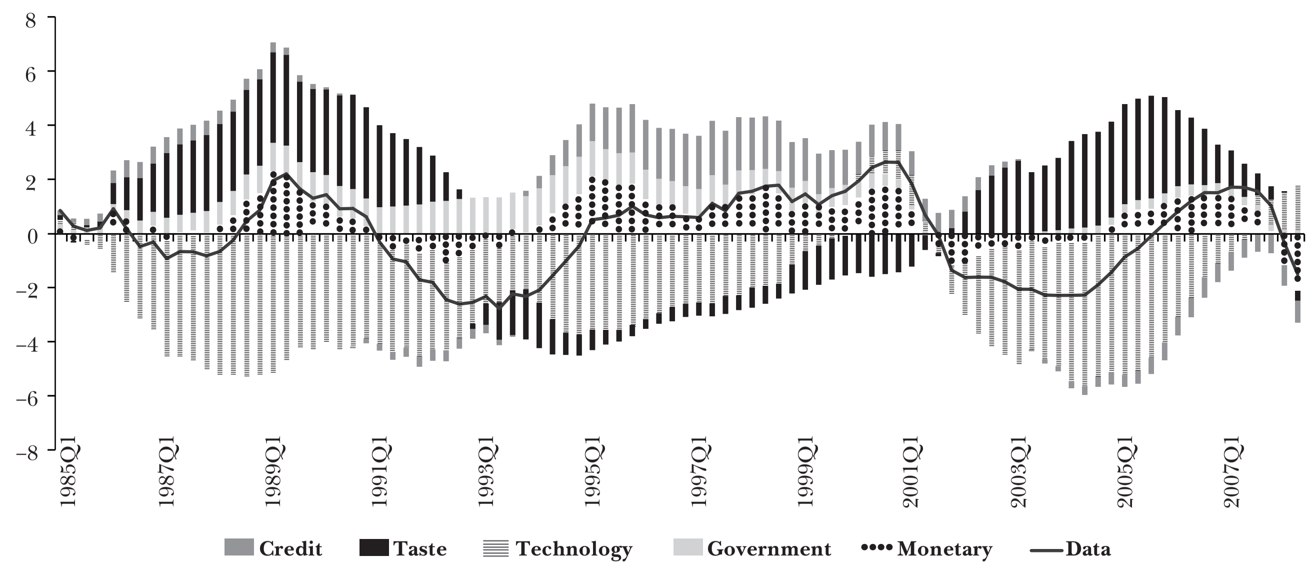
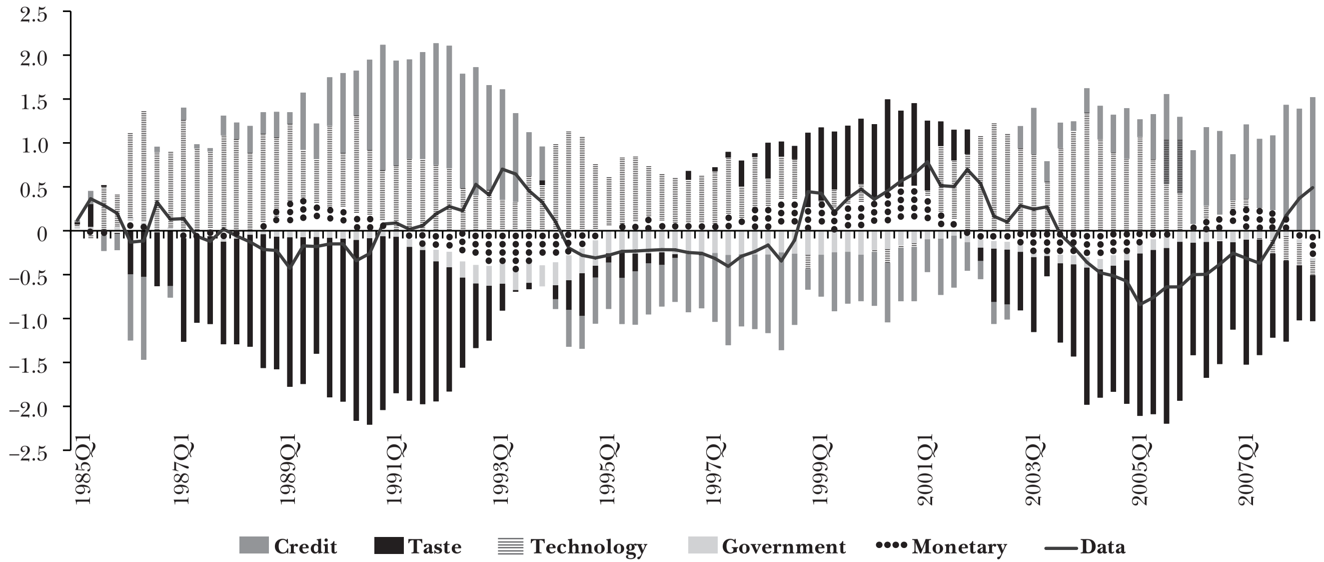


Figure A.5

Stationary Risk Spread



Note: This figure presents the historical shock decomposition of stationary credit risk spread computed using the estimated model. The solid line depicts the behavior of this variable expressed in percentage point deviations from steady state. Each of the bars associated with each quarter presents the contribution of each shock to the observed behavior. The sum of the five shocks adds to the data.

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