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This paper is based on the third chapter of my doctoral dissertation at Boston University, under the advice of Simon Gilchrist. This paper was completed while I served as an Assistant Professor at Oberlin College.

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.

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 Reseve 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 filled 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) show that corporate bond spreads have significant predictive power for economic activity[1]. Later, Gilchrist and Zakrajsek (2011) included financial bond premium information into an otherwise standard VAR to examine the macroeconomic consequences of financial disturbances finding that credit market shocks have important effects on output, consumption, investment and 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.

Earlier work by Elekdag, Justiniano, and Tchakarov (2006), Tovar (2006), Christiano, Motto, and Rostagno (2007), 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 Christiano, Motto, and Rostagno (2007) demonstrate 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 Christiano, Motto, and Rostagno (2007), 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. At the moment of writing this paper, we were not aware of the existence of an empirical work that sought to estimate simultaneously the key parameters of the financial accelerator mechanism along with the shocks to the financial sector using financial market data.

Overall our estimations show that credit market shocks account for 15% of output fluctuations during the 1985 - 2008q2 period, exacerbating economic downturns and magnifying economic expansions. Meanwhile, monetary policy partially offset credit market shocks during

[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.

the 3 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% 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 the extended version of BGG model. Section 3 discusses the estimation strategy and the empirical implementation. Section 4 contains the results. Section 5 concludes.

2. MODEL

The model is a monetary dynamic stochastic general equilibrium model with a financial accelerator mechanism as in BGG[2] augmented with habits in consumption, investment growth adjustment costs, price indexation leading to a hybrid new Keynesian Phillips curve, and a monetary policy Taylor rule that responds to contemporaneous inflation and output growth. These sources of inertia allow the model to better fit the data. The investment growth adjustment costs imply that asset prices - the value of capital in place - increase during economic expansions. The log-linearized version of the model is presented in Appendix 1.

2.1 Structure of the Economy

We consider the problems of households, entrepreneurs, capital producers, and retailers in turn.

2.1.1 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

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

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, θ, and ξ are positive parameters. Consumption preferences exhibit habit formation captured by b.

[2] The description of the model closely follows Gilchrist and Saito (2006), which in turn builds on BGG (1999) and Gertler, Gilchrist, and Natalucci (2007).

The budget constraint is given by

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

where W_t is the nominal wage for the household labor, $\prod_t$ is 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

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

$$\lambda_t = \beta E_t \left[\lambda_{t+1} R_{t+1}^n \frac{P_t}{P_{t+1}} \right], \quad (2)$$

$$\lambda_t \frac{W_t}{P_t} = \theta H_t^{\gamma}. \quad (3)$$

where λ_t is the multiplier on the budget constraint.

2.1.2 Entrepreneurs

Entrepreneurs 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 depend on the entrepreneur's balance-sheet condition.

Entrepreneurs are risk neutral. 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.

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:

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

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 $E_t[\omega_t]=1$. The production for the wholesale goods is given by

$$Y_t = \omega_t (A_t L_t)^{\alpha} K_t^{1-\alpha}, \qquad (4)$$

where A_t is exogenous technology common to all the entrepreneurs. Let $P_{W,t}$ denote the nominal price of wholesale goods, Q_t the price of capital relative to the aggregate price P_t to be defined later, and δ 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:

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

In any period *t*, the entrepreneur chooses the demand for both household labor and entrepreneurial labor to maximize profits given capital K_t acquired in the previous period. The first-order conditions are

$$\alpha(1-\Omega)\frac{Y_t}{H_t} = \frac{W_t}{P_{W,t}}, \qquad (5)$$

and

$$\alpha\Omega\frac{Y_t}{H_t} = \frac{W_t^e}{P_{W,t}}. \qquad (6)$$

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 $Q_t K_{t+1}$ partly with net worth N_{t+1} and partly by issuing nominal debt B_{t+1}:

$$Q_t K_{t+1} = N_{t+1} + \frac{B_{t+1}}{P_t}$$

The entrepreneur's capital purchase decision depends on the expected rate of return on capital and the expected marginal cost of finance. 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:

$$R_{t+1}^{k} = \frac{\omega_{t+1}\left[\frac{P_{W,t+1}}{P_{t+1}}(1-\alpha)\frac{\overline{Y}_{t+1}}{K_{t+1}} + (1-\delta)Q_{t+1}\right]}{Q_t} \tag{7}$$

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, $E_t R_{t+1}^{k}$, is given by

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

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 costly state verification. Specifically, the idiosyncratic shock to entrepreneurs, ω_t, is private information for the entrepreneur. To observe this, the lender must pay an auditing cost that is a fixed proportion μ_δ of the realized gross return to capital held by the entrepreneur: $\mu_\delta R_{t+1}^{k} Q_t K_{t+1}$. 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 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; and if the entrepreneur defaults, the lender audits and seizes whatever it finds.

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 (8). We define the external finance premium s_t as the ratio of the entrepreneur's cost of external funds to the cost of internal funds, where the latter is equated to the cost of funds in the absence of financial market imperfections $E_t\left[R_{t+1}^{n}\frac{P_t}{P_{t+1}}\right]$

$$s_t = \zeta_{s,t}\frac{E_t\left[R_{t+1}^{k}\right]}{E_t\left[R_{t+1}^{n}\frac{P_t}{P_{t+1}}\right]}, \tag{9}$$

where $\zeta_{s,t}$ is an exogenous shock to time t external finance premium. In the absence of financial market imperfections, there is no external finance premium ($s_t = \zeta_{s,t}$).

The agency problem 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:

$$s_t = s\left(\frac{Q_t K_{t+1}}{N_{t+1}}\right), \tag{10}$$

where s(·) is an increasing function for $N_{t+1} < Q_t K_{t+1}$. The specific form of the function s(·) depends on the primitive parameters of the costly state verification problem, including the bankruptcy cost parameter μ_δ and the distribution of the idiosyncratic shock ω_t. We adopt a simplified functional form for the determination of the external finance premium (10):

$$s_t = \left(\frac{Q_t K_{t+1}}{N_{t+1}}\right)^{\chi},$$

where $\chi > 0$ is the elasticity of the external finance premium with respect to leverage $\frac{Q_t K_{t+1} - N_{t+1}}{N_{t+1}}$.

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*:

$$\begin{aligned} N_{t+1} &= \eta\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k \frac{B_t}{P_{t-1}}\right) + \frac{W_t^e}{P_t} \\ &= \eta\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k (Q_{t-1} K_t - N_t)\right) + \frac{W_t^e}{P_t}, \end{aligned} \tag{12}$$

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

Unexpected changes in asset prices are the main source of changes in the entrepreneurial net worth, and hence the external finance premium. Equations (7) and (8) suggest that unexpected changes in asset prices are the main source of unexpected changes in the real rate of return on capital –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*. Equation (12) in turn suggests that the main source of changes in the entrepreneurial net worth is unexpected movements in the real rate of return on capital, under the calibration that the entrepreneurial wage is small. Finally, equation (10) implies that changes in the entrepreneurial net worth are 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:

$$C_t^e = (1-\eta)\left(R_t^k Q_{t-1} K_t - E_{t-1} R_t^k \frac{B_t}{P_{t-1}}\right), \tag{13}$$

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.

2.1.3 Capital Producers

Capital producers use both final 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, Motto, and Rostagno (2007), 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

$$K_{t+1} = (1-\delta)K_t + I_t - \psi\left(\frac{I_t}{I_{t-1}}\right)I_t\,, \tag{14}$$

where $(\cdot)$ is a function with the property that in steady state $\psi = \psi' = 0$, and $\psi'' > 0$.

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 budget constraint.

2.1.4 Retailers

There is a continuum of monopolistically competitive retailers of measure unity. 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

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

and the corresponding price index, P_t, is given by

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

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

Each retailer faces an isoelastic demand curve given by

$$Y_t(z) = \left(\frac{P(z)}{P_t} \right)^{-\varepsilon} Y_t. \tag{16}$$

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 keeps their prices unchanged. 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 (16) 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

$$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{i=0}^{\infty} \theta^i \Lambda_{t,i} P_{W,t+i} Y_{t+i} \left(\frac{1}{P_{i+1}} \right)^{1-\varepsilon}}{E_t \sum_{i=0}^{\infty} \theta^i \Lambda_{t,i} Y_{t+i} \left(\frac{1}{P_{i+1}} \right)^{1-\varepsilon}} \tag{17}$$

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

The aggregate price evolves according to

$$P_t = \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \tag{18}$$

Combining equations (17) and (18) yields the canonical form of the new optimization-based Phillips curve that arises from an environment of time-dependent staggered price setting given by

$$\frac{P_t}{P_{t-1}} = \left(\frac{\varepsilon}{\varepsilon - 1} \frac{P_{W,t}}{P_t} \right)^{\frac{(1-\theta)(1-\beta\theta)}{\theta}} E_t \left\{ \frac{P_{t+1}}{P_t} \right\}^{\beta} \tag{19}$$

2.1.5 Aggregate Resource Constraint

The aggregate resource constraint for final goods is

$$Y_t = C_t + C_t^e + I_t + G_t, \tag{20}$$

where G_t is the government expenditures that we assume to be exogenous[3].

2.1.6 Government

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

$$G_t = \frac{M_t - M_{t-1}}{P_t} + T_t. \tag{21}$$

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

2.1.7 Monetary Policy

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

$$R_t^n = R^n \pi_t^{\gamma_\pi} \left(\frac{Y_t}{\exp(\mu) Y_{t-1}} \right)^{\gamma_y} \zeta_{r^n,t},$$

where R^n is the steady-state nominal interest rate on the one-period bond, $\pi_t = \frac{P_t}{P_{t-1}}$ is inflation, and μ is the mean growth rate of technology.

2.1.8 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.:

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

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

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 $\left\{\sigma_{\zeta_c}, \sigma_{\zeta_s}, \sigma_g, \sigma_a, \sigma_{r^\pi}\right\}$, respectively.

3. ESTIMATION STRATEGY AND EMPIRICAL IMPLEMENTATION

The model presented above is estimated using Bayesian methods[4]. This section describes the methods, data, and parameters used for estimation.

3.1 Bayesian estimation of the DSGE model

The object of interest is the vector of parameters

$$\phi = \left\{b, \theta, \psi, \chi, \gamma_\pi, \rho_{r^n}, \rho_\pi, \rho_{\zeta_c}, \rho_{\zeta_s}, \rho_g, \rho_a, \sigma_{r^\pi} \sigma_{\zeta_c}, \sigma_{\zeta_s}, \sigma_g, \sigma_a\right\}.$$

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

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

where $L\left(\phi \mid Y^T\right)$ is the likelihood conditional on observed data $Y^T = \left\{Y_1, \ldots, Y_T\right\}$. In our case, as detailed below, $Y_t = \left[\Delta y_t + z_t, \Delta i_t + z_t, 4\pi_t, 4R_t^n, 4s_t\right]'$ for $t = 1, \ldots, T$.

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.

3.2 Data

The model is estimated using quarterly data on growth rates of real output and investment, and levels of inflation, interest rates, and external finance premium. 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 a risk-premium

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

measure computed using detailed information from bond prices on outstanding senior unsecured debt issued by a large panel of non-financial firms. All data is demeaned prior to estimation.

3.3 Parameters

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

3.3.1 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, $4(R^n - 1) = 4\left(\frac{\beta}{A} - 1\right)$, of 5.77%. The steady-state capital return, R^K, 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 $1\frac{1}{3}$. The capital depreciation rate, δ, is 0.025, while the steady state capital - net worth ratio, $\frac{K}{N}$, is set at 2. The entrepreneur' survival rate, η, is 0.9728. 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.

3.3.2 Priors

Priors were selected on the basis of previous estimations and available information. 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 5 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 policy 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.

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.

4. Results

In this section I present the estimation results, the Bayesian impulse response functions, and the shock decomposition.

4.1 Estimation

Table 1, below, summarizes the estimation results. Prior means, standard deviations (in parenthesis), and distributions are reported in columns 2 and 3. The posterior mode and 90% confidence intervals (in parenthesis) are reported in columns 4, the financial accelerator case, and 5, the no financial accelerator case. The marginal likelihoods are not comparable because the model without the financial accelerator does not use financial data. 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 shock preference which is smaller in the model without the financial accelerator.

The habit parameter estimate, b, is 0.928, 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 Christiano et al. (2007) in a model that also has capital utilization rate, but higher than in the model without financial frictions at 4.551. 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.

Table 1: Priors and Posterior Estimates

			Financial Accelerator	No Finanacial Accelerator	
Log data density is			-654.09	-593.92	
parameters	prior (std. dev.)	distribution	posterior (90% confidence interval)	posterior (90% confidence interval)	definition
b	0.7 (0.1)	Beta	0.928 (0.911 , 0.923)	0.898 (0.866 , 0.934)	**habit parameter**
θ	0.7 (0.1)	Gamma	0.929 (0.923 , 0.937)	0.896 (0.880 , 0.912)	**Calvo probability of not adjusting prices**
ψ	5 (0.5)	Gamma	5.559 (4.5695 , 6.466)	4.551 (3.840 , 5.310)	**Second derivative of adjustment costs function with respect to investment growth**
χ	0.06 (0.03)	Beta	0.009 (0.008 , 0.011)	_____	**elasticity of external finance premium with respect to leverage**
ρ_π	0.3 (0.1)	Beta	0.224 (0.113 , 0.335)	0.516 (0.338 , 0.665)	**Degree of price indexation**
γ_π	1.5 (0.25)	Gamma	1.264 (1.000 , 1.491)	1.237 (1.105 , 1.369)	**Monetary policy coefficient on inflation**
γ_y	0.5 (0.25)	Gamma	0.236 (0.083 , 0.379)	0.252 (0.068 , 0.426)	**Taylor rule coefficient on output growth**
ρ_{rn}	0.9 (0.1)	Beta	0.939 (0.927 , 0.954)	0.903 (0.877 , 0.929)	**degree of nominal interest rate smoothing**
ρ_g	0.9 (0.1)	Beta	0.957 (0.924, 1.000)	0.971 (0.940 , 1.000)	**AR(1) government expenditure shock**
ρ_a	0.9 (0.1)	Beta	0.980 (0.978 , 0.982)	0.991 (0.984 , 1.000)	**AR(1) technology shock**
ρ_{ς^c}	0.5 (0.25)	Beta	0.788 (0.755 , 0.814)	0.767 (0.699 , 0.845)	**AR(1) preferences shock**
ρ_{ς^s}	0.5 (0.25)	Beta	0.725 (0.706 , 0.756)	_____	**AR(1) external finance premium shock**
standard deviation of shocks					
σ_{rn}	0.4 (4)	Invg	0.121 (0.107 , 0.136)	0.123 (0.108 , 0.138)	**Std. dev. of monetary shock**
σ_g	1 (4)	Invg	2.704 (2.306 , 3.216)	2.838 (2.452 , 3.221)	**Std. dev. of government expenditure shock**
σ_a	1 (4)	Invg	0.320 (0.213 , 0.432)	0.209 (0.157 , 0.259)	**Std. dev. of technology shock**
σ_{ς^c}	1 (4)	Invg	4.834 (4.604 , 5.000)	3.592 (2.159 , 4.999)	**Std. dev. of preferences shock**
σ_{ς^s}	1 (4)	Invg	2.353 (1.833 , 2.827)	_____	**Std. dev. of external finance premium shock**

The parameters related to prices and monetary policy 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 autoregresive 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 autorregresive 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.

4.2 Impulse response functions

Figure 1, below, shows the impulse response functions of output, investment, and the external finance premium to one standard deviation in the monetary policy shock. Figure 2 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 blue (dark) lines show the case of the financial accelerator, while the model without financial frictions is represented with the yellow (light) lines.

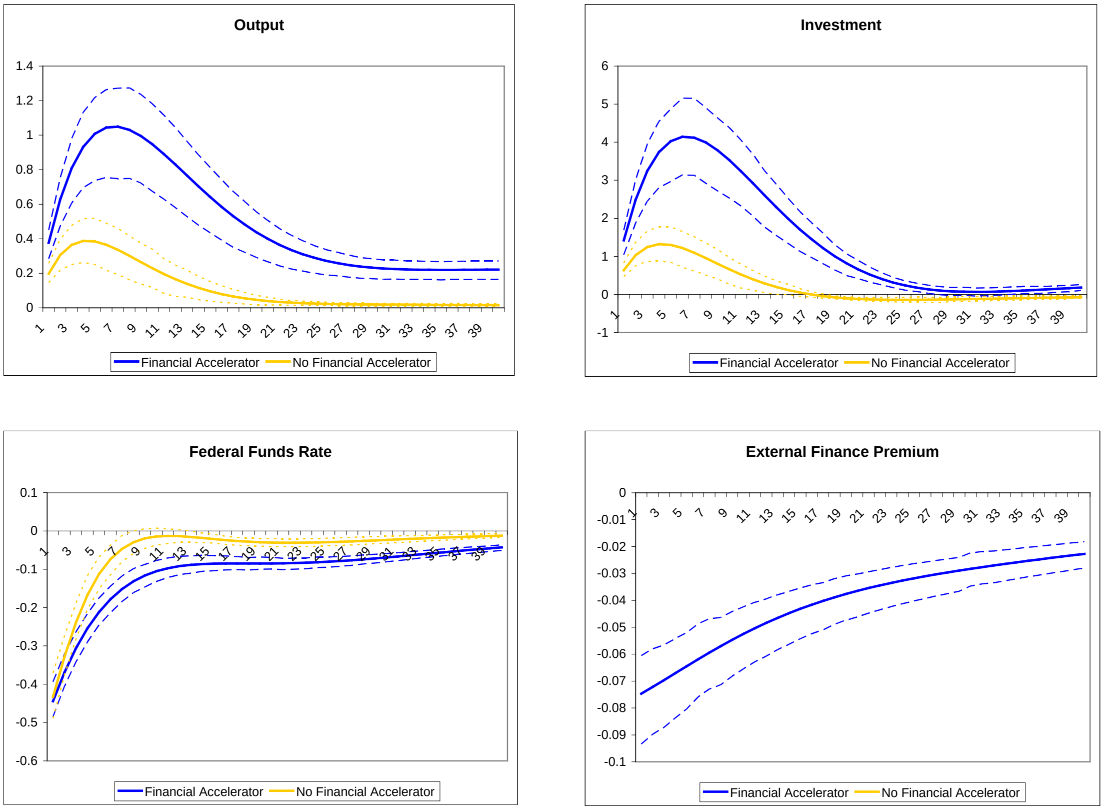
Before discussing the results it is important to remind that under the financial accelerator environment, an expansion in output causes an increase in the value of assets in place and a rise in the entrepreneurial net worth. As entrepreneurs' net worth expands relative to their borrowing, the external 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.

Figure 1 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 2 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.

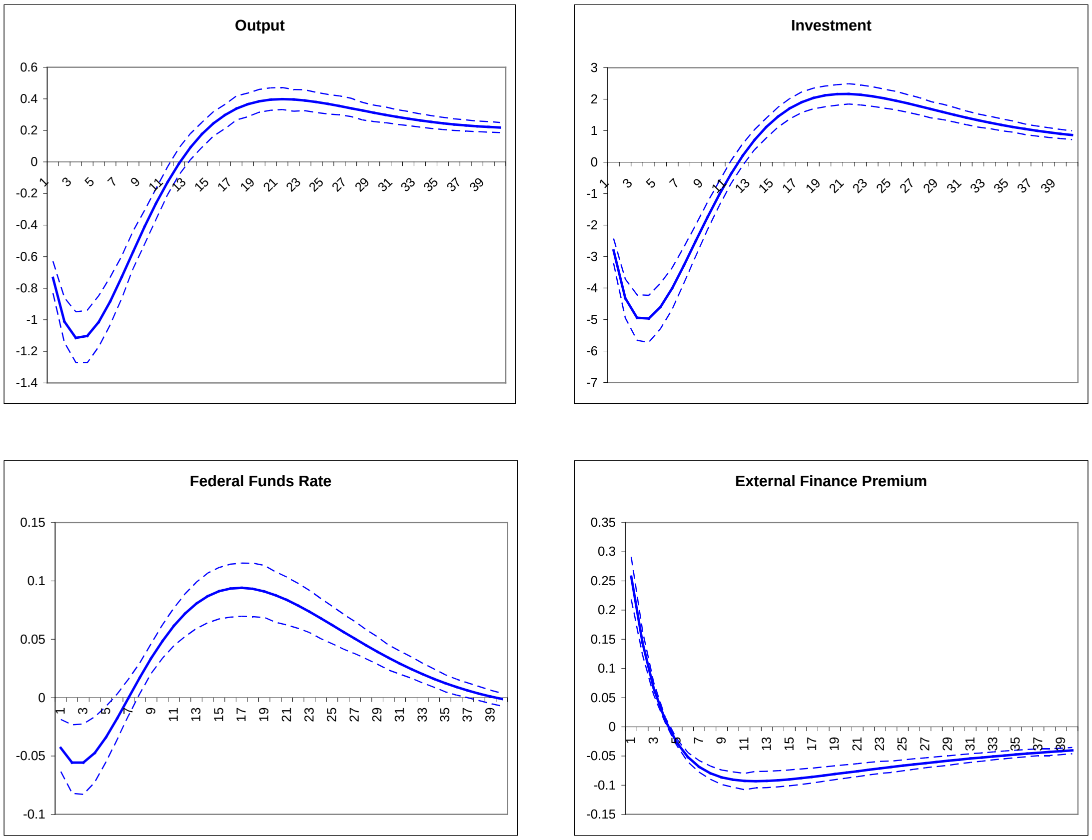
The real effect of this mechanism is quantitatively large –a 0.25% rise in the external finance premium causes a 0.73% decrease in output and a 2.8% decrease in investment.

Figure 1: 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 blue (dark) lines in each panel depict the financial accelerator case. The yellow (light) lines depict the responses generated by the model without the financial accelerator.

Figure 2: Model Responses to an External Finance Premium 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 blue (dark) lines in each panel depict the financial accelerator case. Here there are no yellow (light) lines as the model without the financial accelerator does not have financial shocks.

4.3 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. Appendix 3 presents the graphs for the five observable variables and five shocks in the financial accelerator case. Here we concentrate on the portion of the movement in the observable variables that can be credited to monetary policy and credit market innovations. Figure 3 shows the historical decomposition of monetary policy shocks in the cases with and without the financial accelerator, while Figure 4 focuses on the financial shocks.

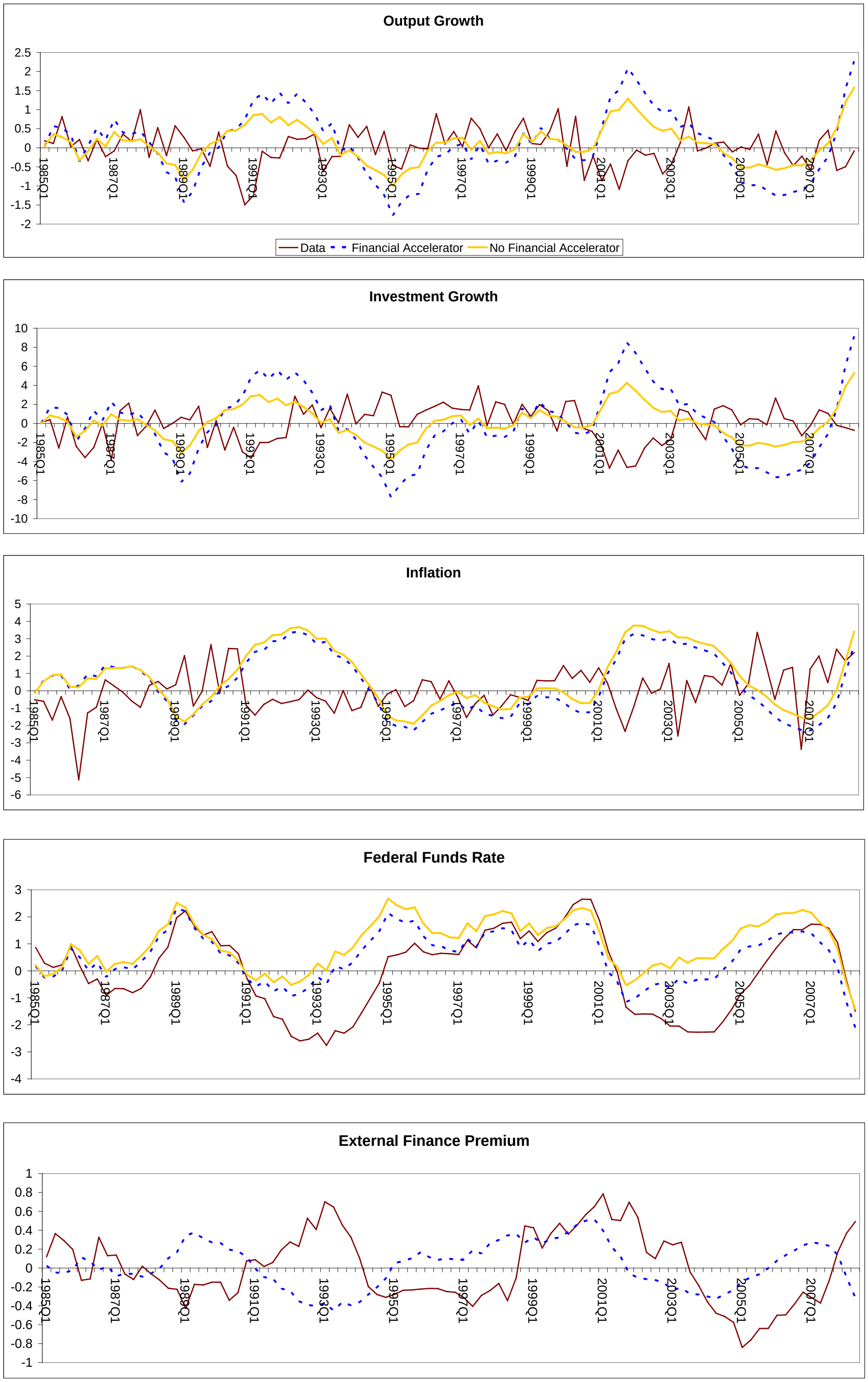
The effect of monetary policy shocks on the economy accord well with the historical record regarding the conduct of monetary policy since the mid-1980s. Monetary policy was tight in the late 1980s prior to the onset of the 1990-91 recession but was eased substantially during the economic downturn of the early 1990s. According to our estimates, tight monetary policy also contributed to the slowdown in business investment and output during the 1994-95 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 2005-07 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 4 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 1990-91 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 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.

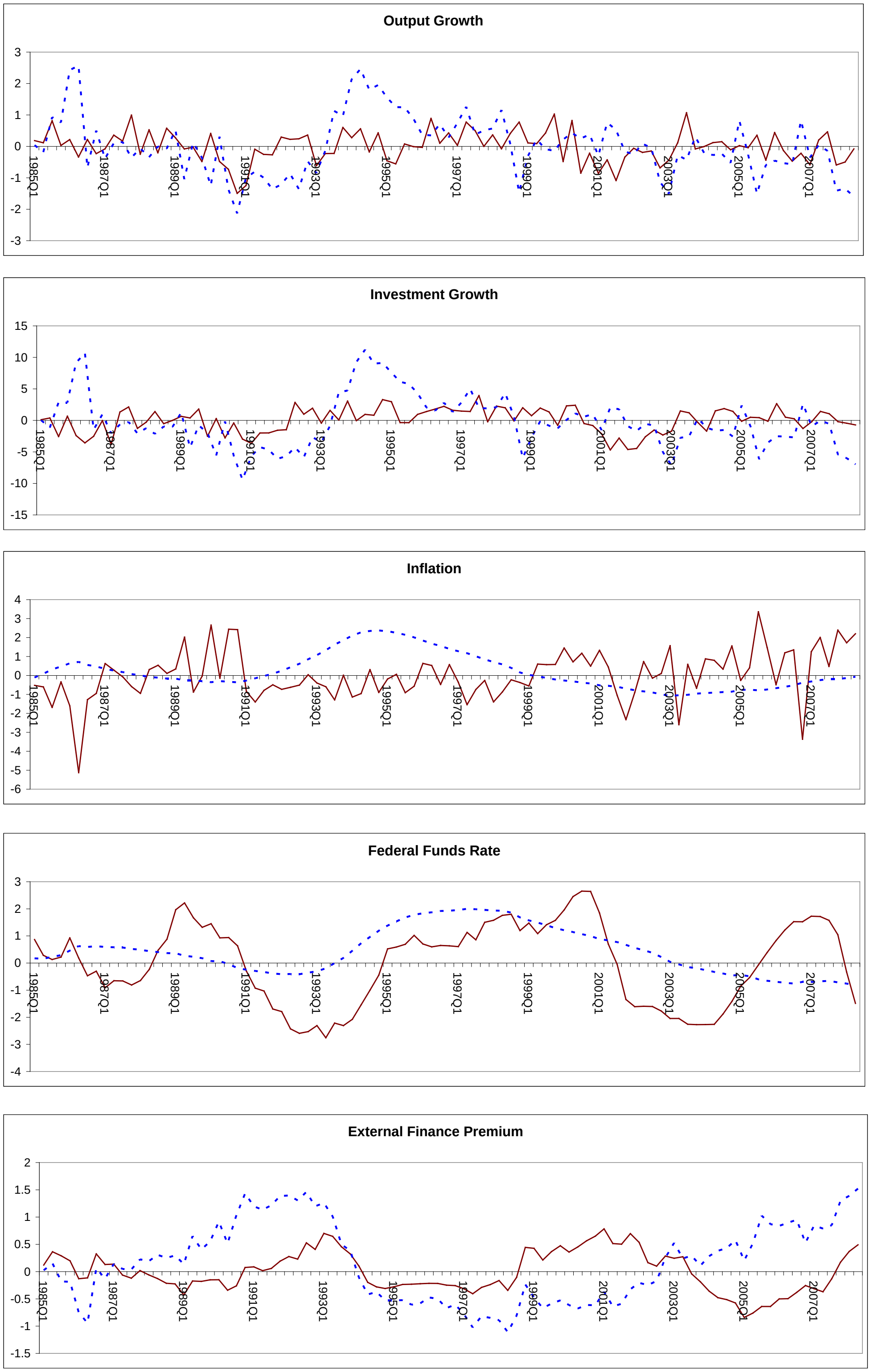
In summary, this relatively simple model of the financial accelerator- when estimated using both real and financial market data –does remarkably well at capturing much of the historical narrative regarding the conduct of monetary policy and developments in financial markets that led to the episodes of 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.

Figure 3: Historical Decomposition of Monetary Policy Shocks



Note: The solid brown (dark) line in each panel depicts the behavior of actual variables expressed in percentage point deviations from steady state. The dotted blue (dark) line in each panel depicts the estimated effect of monetary policy shocks (see text for details) under the financial accelerator model. The solid yellow (light) line in each panel depicts the estimated effect of monetary policy shocks in the model without the financial accelerator.

Figure 4: Historical Decomposition of Financial Shocks



Note: The solid brown (dark) line in each panel depicts the behavior of actual variables expressed in percentage point deviations from steady state. The dotted blue (dark) line in each panel depicts the estimated effect of monetary policy shocks (see text for details) under the financial accelerator model. Here there is no solid yellow (light) line as in the model without the financial accelerator there are no financial shocks.

4.4 Variance Decomposition

Table 2, below, 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.

In the version with financial factors, monetary innovations explain 12.5% of the output variance, while credit market innovations explain 15.1%[5]. Meanwhile, in the case of investment, 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.

Table 2: Asymptotic Variance Decomposition

Model with Financial Factors

shock \ variable	output	investment	inflation	interest rate	external finance premium
monetary	12.5	17.1	7.1	9.6	3.8
government	6.5	0.5	0.6	2.3	0.6
technology	51.3	53.0	52.0	42.2	11.1
discount factor	14.7	6.9	38.1	37.6	49.7
external finance premium	15.1	22.5	2.1	8.4	34.8

Model without Financial Factors

shock \ variable	output	investment	inflation	interest rate	external finance premium
monetary	18.5	26.1	10.6	10.4	
government	27.3	1.2	0.4	1.5	
technology	44.7	44.6	64.0	66.9	
discount factor	9.5	28.0	25.0	21.2	
external finance premium					

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

5. CONCLUSIONS

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 3 most recent recessions.

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:

$$y_t = \frac{C}{Y}c_t + \frac{C^e}{Y}c_t^e + \frac{1}{Y}i_t + \frac{G}{Y}g_t \tag{22}$$

Marginal utility in the case of internal habit:

$$\lambda_t = \frac{1}{b^2\beta - bA(1+\beta) + A^2}[-(b^2\beta + A^2)c_t + bAc_{t-1} + bA\beta E_t\{c_{t+1}\} - bAa_t + bA\beta E_t\{a_{t+1}\}] \tag{23}$$

Consumption-savings:

$$\lambda_t = E_t\{\lambda_{t+1}\} - r_{t+1}^n - E_t\{\pi_{t+1}\} - E_t\{a_{t+1}\} - \zeta_{c,t} \tag{24}$$

Entrepreneurial consumption:

$$r_t^e = n_{t+1} \tag{25}$$

Definition of the external finance premium:

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

Determination of the external finance premium:

$$s_t = \chi\left(q_t - k_{t+1} + n_{t+1}\right) \tag{26}$$

Expected real rate of return on capital:

$$\begin{aligned} E_t\{R_{T+1}^K\} = & \frac{\left(1-\alpha\right)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A}{\left(1-\alpha\right)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A+(1-\delta)}\left(E_t\{y_{t+1}\} - k_{t+1} + E_t\{a_{t+1}\} + E_t\{mc_{t+1}\}\right) \\ & + \frac{(1-\delta)}{\left(1-\alpha\right)\frac{\varepsilon-1}{\varepsilon}\frac{Y}{K}A+(1-\delta)}E_t\{q_{t+1}\} - q_t \end{aligned} \tag{27}$$

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

$$q_t = (1+\beta)\psi A^2 i_t - \psi A^2 i_{t-1} - \beta\psi A^2 E_t\left\{i_{t+1}\right\} + \psi A^2 a_t - \beta\psi A^2 E_t\left\{a_{t+1}\right\} \tag{28}$$

Aggregate Supply

Aggregate supply of final goods:

$$y_t = \alpha\Omega h_t + (1-\alpha)k_t - (1-\alpha)a_t \tag{29}$$

Labor market equilibrium:

$$y_t - h_t + mc_t + \lambda_t = \gamma h_t \tag{30}$$

Phillips curve:

$$\pi_t = \frac{1}{1+\beta\rho_\pi}\frac{\left(1-\theta\right)\left(1-\beta\theta\right)}{\theta}mc_t + \frac{\beta}{1+\beta\rho_\pi}E_t\{\pi_{t+1}\} + \frac{\rho_\pi}{1+\beta\rho_\pi}\pi_{t-1} \tag{31}$$

Evolution of State Variables

Capital accumulation:

$$k_{t+1} = \left(1 - \frac{1-\delta}{A}\right) i_t + \frac{1-\delta}{A}(k_t - a_t) \tag{32}$$

Evolution of net worth:

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

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

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

Monetary Policy Rule and Shock Processes

The monetary policy rule follows:

$$r_t^n = \rho_{r^n} r_{t-1}^n + \left(1 - \rho_{r^n}\right)\left[\gamma_\pi \pi_t + \gamma_\pi \left(y_t - y_{t-1} + a_t\right)\right] + \varepsilon_t^{r^n} \tag{34}$$

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

$$g_t = \rho_g g_{t-1} + \varepsilon_t^g \tag{35}$$

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a \tag{36}$$

$$\zeta_{c,t} = \rho_{\zeta_c} \zeta_{c,t-1} + \varepsilon_t^{\zeta_c} \tag{37}$$

$$\zeta_{s,t} = \rho_{\zeta_s} \zeta_{s,t-1} + \varepsilon_t^{\zeta_s} \tag{38}$$

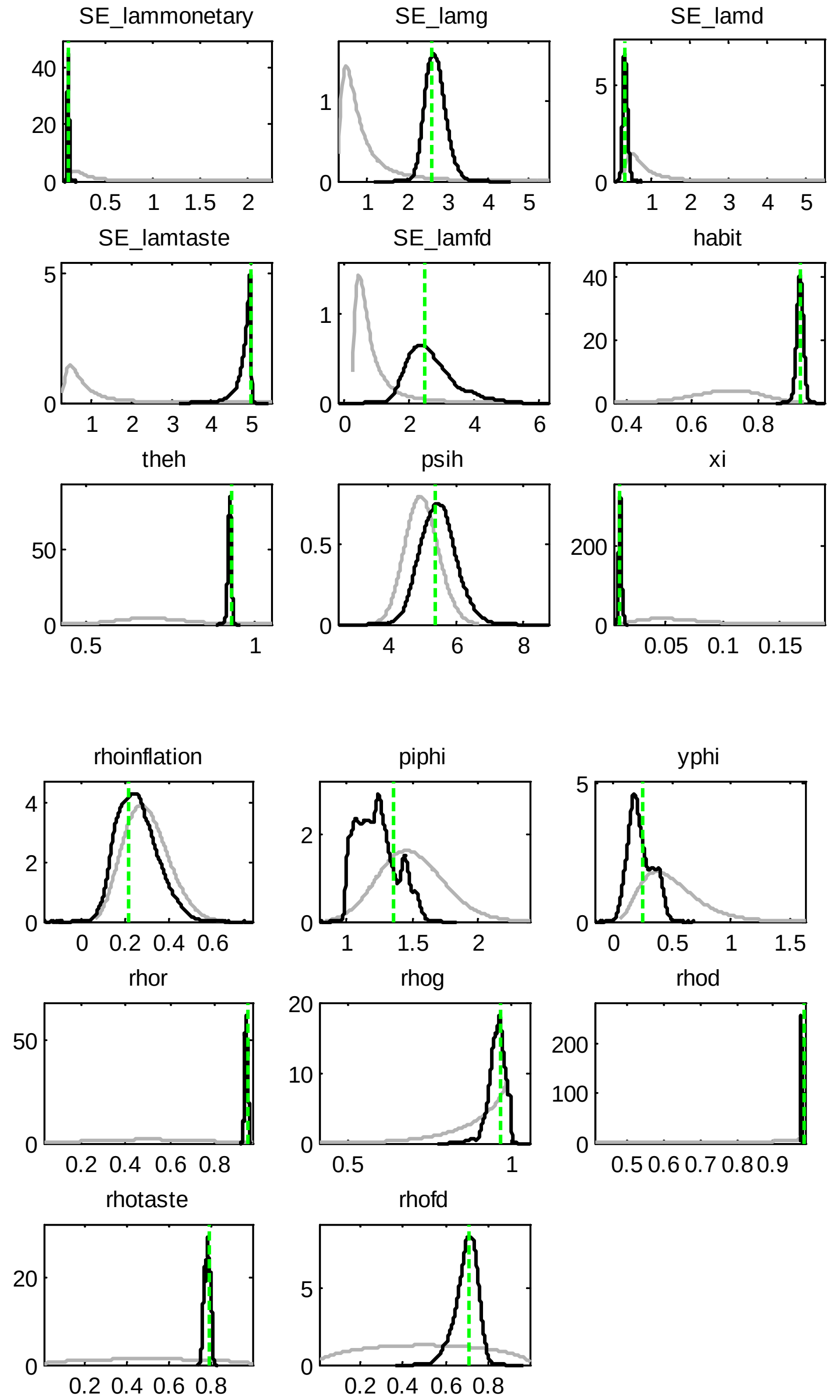
while the monetary policy shock is i.i.d.:

$$\zeta_{r^n,t} = \varepsilon_t^{r^n} \tag{39}$$

APPENDIX 2. PRIOR AND POSTERIOR DISTRIBUTIONS

Figure 5 presents the prior (light) and posterior (dark) distributions for the parameters estimates, along with the posterior mode (vertical line).

Figure 5


SE_lammonetary
40 20 0
0.5 1 1.5 2
SE_lamg
1 0
1 2 3 4 5
SE_lamd
5 0
1 2 3 4 5
SE_lamtaste
5 0
1 2 3 4 5
SE_lamfd
1 0
0 2 4 6
habit
40 20 0
0.4 0.6 0.8
theh
50 0
0.5 1
psih
0.5 0
4 6 8
xi
200 0
0.05 0.1 0.15
rhoinflation
4 2 0
0 0.2 0.4 0.6
piphi
2 0
1 1.5 2
yphi
5 0
0 0.5 1 1.5
rhor
50 0
0.2 0.4 0.6 0.8
rhog
20 10 0
0.5 1
rhod
200 100 0
0.5 0.6 0.7 0.8 0.9
rhotaste
20 0
0.2 0.4 0.6 0.8
rhofd
5 0
0.2 0.4 0.6 0.8

APPENDIX 3. SHOCK DECOMPOSITION

Figures 6 to 10 report the contribution of each shock to the observed data for the financial accelerator case. For example, Figure 6 shows the contribution of monetary policy, government expenditure, technology, taste (preferences), and credit (external finance premium) shocks to explain demeaned output growth. Figures 7 to 10 report the results for investment growth, 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 6

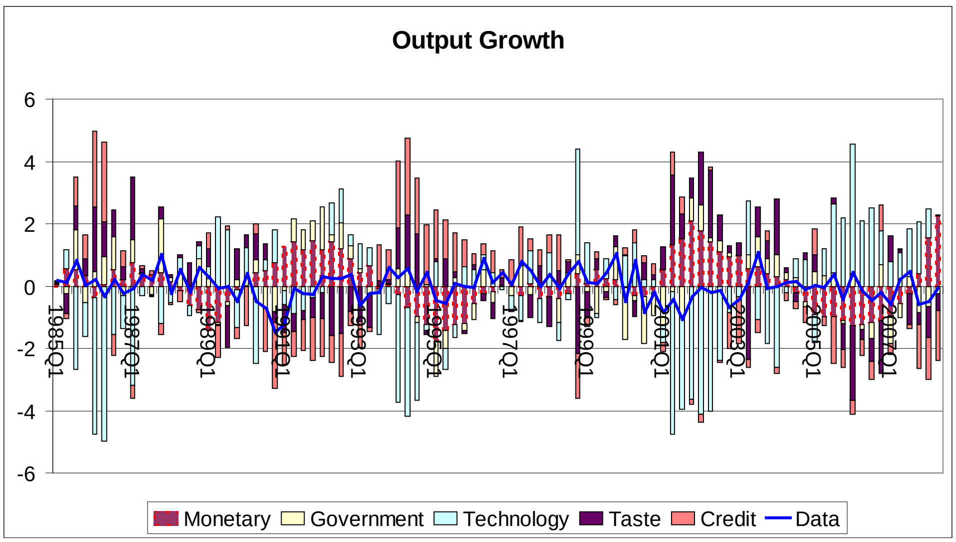


Figure 7

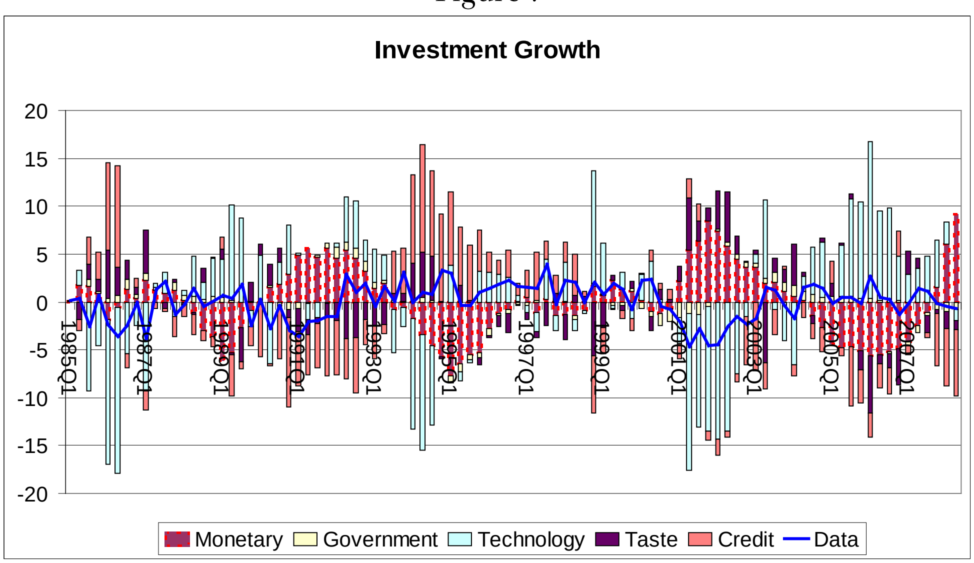


Figure 8

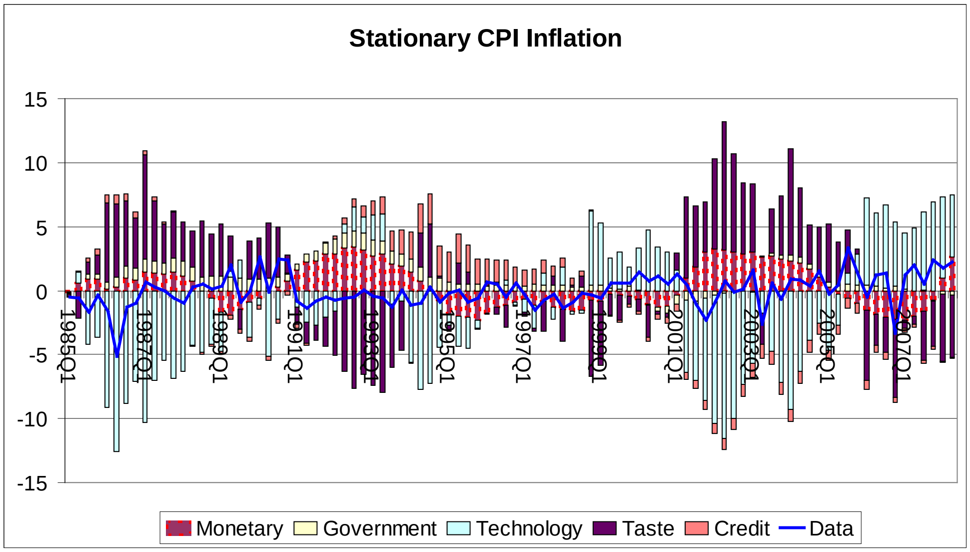


Figure 9

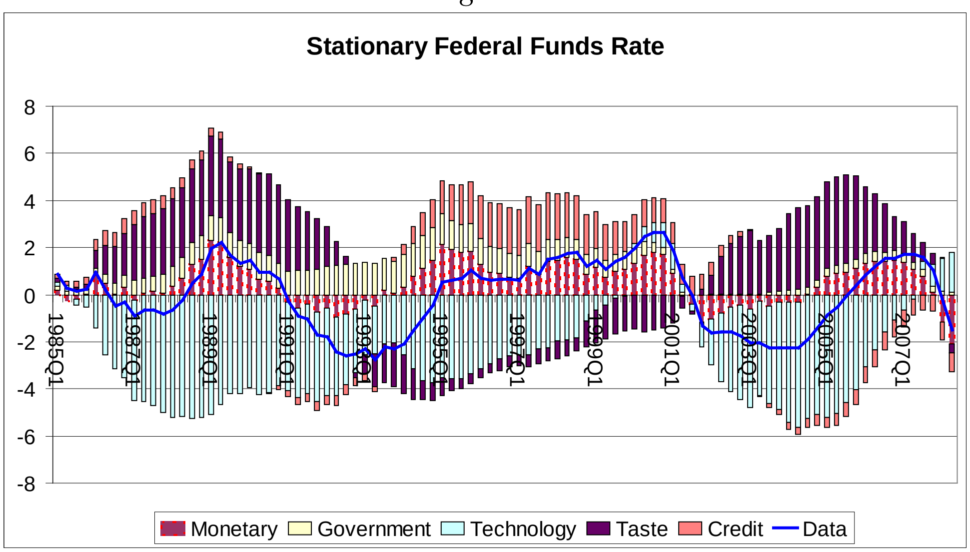
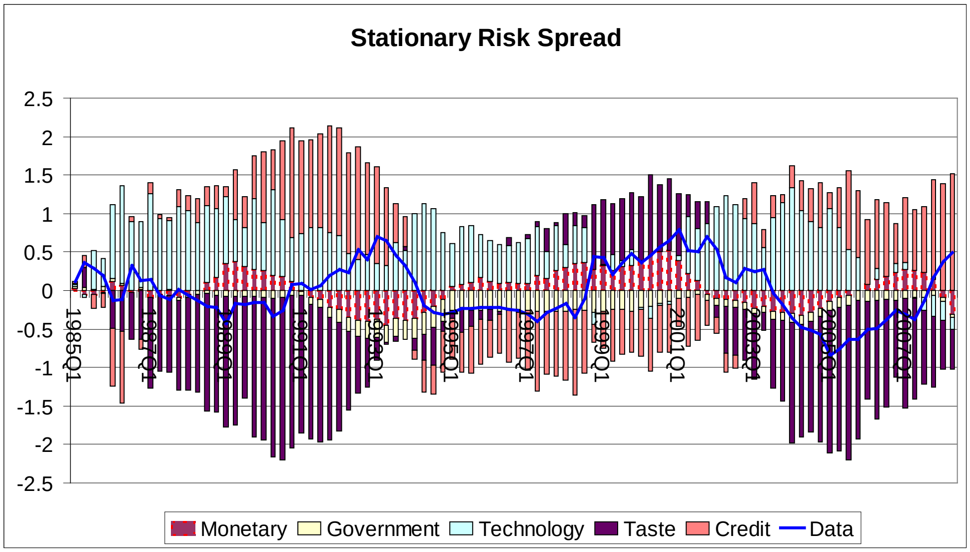


Figure 10



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