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Abstract

Recent financial turmoil and existing empirical evidence suggest that adverse shocks to the financial intermediary (FI) sector cause substantial economic downturns. The quantitative significance of these shocks to the U.S. business cycle, however, has not received much attention up to now. To determine the importance of these shocks, we estimate a sticky-price dynamic stochastic general equilibrium model with what we describe as chained credit contracts. In this model, credit-constrained FIs intermediate funds from investors to credit-constrained entrepreneurs through two types of credit contract. Using Bayesian estimation, we extract the shocks to the FIs' net worth. The shocks are cyclical, typically negative during a recession, such as the one that began in 2007. Their effects are persistent, lowering economic activity for several quarters after the recessionary trough. According to the variance decomposition, shocks to the FI sector are a main source of the spread variations, explaining 39% of the FIs' borrowing spread and 23% of the entrepreneurial borrowing spread. At the same time, these shocks play an important but not dominant role for investment, accounting for 15% of its variations.

Keywords: Monetary Policy; Financial Accelerators; Financial Intermediaries; Chained Credit Contracts

JEL classification: E31, E44, E52

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1 Introduction

The financial crisis that began in the fall of 2007 demonstrated that financial intermediaries (hereafter, FIs) play a crucial role in economic activity. Adverse shocks to the FI sector increase the borrowing costs for FIs by deteriorating their net worth. Consequently, the supply of funds to entrepreneurs tightens, leading to an investment decline and a further deterioration in the FIs' net worth. This account is consistent with the literature that focuses on the relationship between the FI sector and the aggregate economy. For example, Peek and Rosengren (1997, 2000), using a novel identification scheme for a loan supply shock, report that the worsening of FIs' net worth generates economic downturns.

However, there is as yet no body of literature determining how important the shocks to the FI sector are to the U.S. business cycle. While macroeconomists agree that shocks to the credit market are an important source of aggregate fluctuations, to the best of our knowledge only a limited number of studies have evaluated the relative impact of shocks to the FI sector.[1] In the existing models, shocks to entrepreneurial net worth are primarily focused on and shocks to the FIs' net worth are often neglected.

To assess the role of the shocks to the FIs' net worth, we estimate the financial accelerator model of Hirakata, Sudo, and Ueda (2009a, 2009b, hereafter HSU). Our model is built upon the financial accelerator model in Bernanke, Gertler, and Gilchrist (1999, hereafter BGG) where endogenous developments in the entrepreneurial net worth play an important role in amplifying and propagating exogenous shocks. The credit-constrained FIs intermediate funds from investors to credit-constrained entrepreneurs through two types of credit contracts: the FIs' borrowing contract with investors and the FIs' lending contract with entrepreneurs. Because the two contracts are chained, the borrowing cost for the entrepreneurs depends on the two contracts, and in turn, the net worth of the two credit-constrained sectors. Consequently, the financial accelerator effect is enhanced due to developments in the FIs' net worth along with the entrepreneurial net worth.

Based on HSU (2009a, 2009b), we distill the shocks to the FIs' net worth using a Bayesian technique. We employ a set of U.S. macroeconomic variables consisting of output, consump-

[1] See, for example, Gilchrist, Yankov, and Zakrajsek (2009) and Jermann and Quardini (2009). The notable exceptions are Christiano, Motto, and Rostagno (hereafter CMR, 2007, 2008), who analyze the shocks to the production functions of banks separately from the shocks to entrepreneurs. While other empirical work, such as Peek and Rosengren (1997, 2000), emphasizes the balance-sheet effect in the FI sector, the banks in CMR (2008) are competitive and do not own their net worth. In contrast, we focus on the shocks to FIs' net worth and their impact on the aggregate economy.

tion, investment, inflation, the policy rate, and the net worth of both the FI and entrepreneurial sectors.[2] The sample period runs from 1984Q1 to 2009Q2, and therefore covers the most recent turmoil in the credit market. We find that the estimated adverse shocks to the FIs' net worth typically take large negative values during the recession, and are positively correlated with a number of indicators of credit market stress.

A negative shock to the FIs' net worth causes an upsurge in borrowing spreads and a persistent decline in investment. In particular, during the several quarters since 2007, the shocks to the FIs' net worth have been unprecedentedly deep and persistent, contributing to a drastic widening in the borrowing spreads in that period. Their impacts on investment last long, lowering it for several quarters after the end of the recession.

The decomposition of the historical contributions of structural shocks suggests that the adverse shocks to the FI sector are one of the main sources of the variations in the borrowing spreads, and are an important but not dominant source of the variations in investment. They account for 39% of the variations in the FIs' borrowing spread and 23% of the variations in the entrepreneurial borrowing spread. At the same time, the relative contributions of these shocks to investment, output, and inflation, respectively, are 15%, 3%, and 4% of overall variations.

Research using the financial accelerator model commonly poses one or both of two questions.[3] The first concerns about the quantitative importance of the shocks originating in the credit market, and the second concerns the quantitative importance of the financial accelerator effect. For instance, in response to the first question, Nolan and Thoenissen (2009) report that shocks to the credit market account for 45% of the investment variations. In response to the second question, Christensen and Dib (2008) conclude that the financial accelerator mechanism brings the sticky-price dynamic stochastic general equilibrium (DSGE) model closer to the data. However, they also point out that its quantitative contribution is small.[4]

By adding to the model credit-constrained FIs and shocks to their net worth, we provide more extensive answers to the two questions. First, consistent with the existing literature, our result implies that shocks originating in the credit market substantially affect the macro-

[2] As discussed below, we conduct several sensitivity analyses of the choice of observable variables.

[3] See, for example, CMR (2008), Meier and Muller (2006), Christensen and Dib (2008), De Graeve (2008), and Nolan and Thoenissen (2009).

[4] Meier and Muller (2006) derive a similar conclusion that the financial accelerator effect is small by investigating impulse response functions to monetary policy shocks using U.S. data.

economy. However, a sizable amount of the estimated shocks to the credit market originates in the FI sector. Second, in comparing fit with the data, we find that our model, in which both FIs and entrepreneurs are credit constrained, outperforms the model in which only the entrepreneurs are credit constrained. Our comparison suggests that the financial accelerator mechanism linked to endogenous developments in the FIs' net worth is an important element in explaining the data.

The remainder of the paper is organized as follows. In Section 2, we describe our economy. In Section 3, we describe the estimation method and the results. Section 4 concludes.

2 The Economy

We consider an economy with a credit market and a goods market. The economy consists of 10 types of agents: investors, FIs, entrepreneurs, a household, final goods producers, retailers, wholesalers, capital goods producers, the government, and the monetary authority.

The setting for the credit market is taken from HSU (2009a). There are three types of participants in the credit market: investors, FIs, and entrepreneurs. Investors collect deposits from the household in a competitive market, and invest what they collect in loans to the FIs. FIs are the monopolistic lenders of funds to entrepreneurs. FIs own their net worth, but not sufficiently to finance their loans to the entrepreneurs. Therefore, they make credit contracts with investors to borrow the rest of the funds. Entrepreneurs invest in their projects, and also own their net worth, but not sufficiently to finance them. Thus, they make credit contracts with FIs to borrow the funds. Clearly, these two types of contracts are linked in the economy, and entrepreneurs cannot finance their projects if either of the credit contracts fails to hold.

Monopolistic FIs determine the borrowing rates of the credit contracts, thereby ensuring the participation constraints of entrepreneurs and investors. Agency problems arise from the asymmetric information between lenders and borrowers for both of the credit contracts, one between FIs and entrepreneurs (hereafter, FE contracts) and the other between investors and FIs (hereafter, IF contracts).[5] Consequently, the borrowing rates of the credit contracts

[5] Our setting thus contrasts with other banking models based on the moral hazard problems of FIs and entrepreneurs (Chen, 2001; Meh and Moran, 2004; and Aikman and Paustian, 2006). These studies all develop quantitative extensions of the model in Holmstrom and Tirole (1997) and illustrate the role of net worth in the banking sector. Importantly, in their model a rise in net worth mitigates the moral hazard problem, and affects aggregate investment by changing the incentive compatibility conditions. Our model, on the other hand, stresses the role of net worth in affecting the borrowing rates of the credit contracts.

change with the net worth of the borrowers.

We closely follow BGG (1999) for the setup of the goods market. There are four goods in the economy: final goods, retail goods, wholesale goods, and capital goods. Final goods are produced by final goods producers from differentiated retail goods through the Dixit-Stiglitz aggregator. Retail goods are produced from wholesale goods by monopolistic retail goods producers that set the prices of their goods following Calvo (1983). Wholesale goods are produced by competitive wholesalers that own a Cobb-Douglas production technology that converts capital and labor inputs into wholesale goods. Capital goods are produced by capital goods producers and sold to the entrepreneurs. In what follows, we briefly describe our setting of the credit market and fully explain the goods market.

2.1 The Credit Market

Overview of the two types of credit contract

In this section, we describe the framework of the credit contracts. In each period, entrepreneurs conduct projects with size $Q\left(s^t\right) K\left(s^t\right)$, where $Q\left(s^t\right)$ is the price of capital and $K\left(s^t\right)$ is capital. Entrepreneurs own their net worth, $N^E\left(s^t\right) < Q\left(s^t\right) K\left(s^t\right)$, and borrow funds, $Q\left(s^t\right) K\left(s^t\right) - N^E\left(s^t\right)$, from the FIs through the FE contracts. The FIs also own their net worth, $N^F\left(s^t\right) < Q\left(s^t\right) K\left(s^t\right) - N^E\left(s^t\right)$, and borrow funds, $Q\left(s^t\right) K\left(s^t\right) - N^F\left(s^t\right) - N^E\left(s^t\right)$, from investors through the IF contracts. In both contracts, agency problems stemming from asymmetric information are present. That is, the borrowers are subject to idiosyncratic productivity shocks and the lenders cannot observe the realizations of these shocks without paying additional costs.[6] Taking these credit market imperfections as given, the FIs choose the clauses of the two contracts that maximize their expected profits. Consequently, for a given riskless rate of the economy $R\left(s^t\right)$, the external finance premium $\mathrm{E}_t\left\{R^E\left(s^{t+1}\right)\right\}/R\left(s^t\right)$ is expressed by

Consequently, the theoretical relationship between the net worth of borrowers and their borrowing rates is explicitly given.

[6] The idiosyncratic productivity shocks for the FIs and the entrepreneurs are log-normally distributed with unit mean. In Subsection 3.5, we investigate the cases where stochastic process of these productivity shocks are time-variant.

$$
\begin{aligned}
\frac{\mathrm{E}_t\left\{R^E\left(s^{t+1}\right)\right\}}{R\left(s^t\right)} &= \overbrace{\Phi^F\left(\overline{\omega}_t^F\left(\frac{N^F\left(s^t\right)}{Q\left(s^t\right)K\left(s^t\right)}, \frac{N^E\left(s^t\right)}{Q\left(s^t\right)K\left(s^t\right)}\right)\right)^{-1}}^{\text{inverse of the share of profit going to the investors in the IF contract}} \\
&\times \overbrace{\Phi^E\left(\overline{\omega}_t^E\left(\frac{N^E\left(s^t\right)}{Q\left(s^t\right)K\left(s^t\right)}\right)\right)^{-1}}^{\text{inverse of the share of profit going to the FIs in the FE contract}} \\
&\times \overbrace{\left(1-\frac{N^F\left(s^t\right)}{Q\left(s^t\right)K\left(s^t\right)}-\frac{N^E\left(s^t\right)}{Q\left(s^t\right)K\left(s^t\right)}\right)}^{\text{ratio of the debt to the size of the capital investment}} \\
&\equiv F\left(n^F\left(s^t\right), n^E\left(s^t\right)\right), \qquad (1)
\end{aligned}
$$

with

$$
\begin{aligned}
\Phi^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right) &\equiv \overbrace{G^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)}^{\text{expected return from defaulting FIs}} \\
&+ \overbrace{\overline{\omega}^F\left(s^{t+1}|s^t\right)\int_{\overline{\omega}^F\left(s^{t+1}|s^t\right)}^{\infty} dF^F\left(\omega^F\right)}^{\text{expected return from nondefaulting FIs}} \\
&- \overbrace{\mu^F G^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)}^{\text{expected monitoring cost paid by investors}} \qquad (2)
\end{aligned}
$$

$$
\begin{aligned}
\Phi^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right) &\equiv \overbrace{G^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)}^{\text{expected return from defaulting entrepreneurs}} \\
&+ \overbrace{\overline{\omega}^E\left(s^{t+1}|s^t\right)\int_{\overline{\omega}^E\left(s^{t+1}|s^t\right)}^{\infty} dF^E\left(\omega^E\right)}^{\text{expected return from nondefaulting entrepreneurs}} \\
&- \overbrace{\mu^E G^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)}^{\text{expected monitoring cost paid by FIs}} \qquad (3)
\end{aligned}
$$

where $n_t^F\left(s^t\right)$ and $n_t^E\left(s^t\right)$ are the ratios of net worth to aggregate capital in the two sectors, $\overline{\omega}^F\left(s^{t+1}|s^t\right)$ and $\overline{\omega}^E\left(s^{t+1}|s^t\right)$ are the cutoff value for the FIs' idiosyncratic shock $\omega^F\left(s^{t+1}\right)$ in the IF contract, and that for the entrepreneurial idiosyncratic shock $\omega^E\left(s^{t+1}\right)$ in the FE contract.[7] Equation (1) is a key equation that links the net worth of the borrowing

[7]Similarly to BGG (1999) and CMR (2008), the aggregation problem of the FIs and the entrepreneurs becomes tractable thanks to the property of optimal credit contracts where the ratio of net worth to capital is the same within FIs and within entrepreneurs.

sectors to the external finance premium. The external finance premium is determined by three components: the share of profit in the IF contract going to the investors, the share of profit in the FE contract going to the FIs, and the ratio of total debt to aggregate capital. Lower profit shares going to the lenders cause a higher external finance premium through the first two terms of equation (1). Otherwise, the participation constraints of investors would not be met and financial intermediation fails. A higher ratio of the debt results in higher external costs, since it raises default probability of the IF contracts and investors require higher returns from the IF contracts to satisfy their participation constraint. The presence of the first two channels suggests that not only the sum of both net worths but also the distribution of the two net worths matter in determining the external finance premium.[8]

Borrowing rates

The two credit borrowing rates, namely, the entrepreneurial borrowing rate and the FIs' borrowing rate, are given by the FE and the IF contracts, respectively. The entrepreneurial borrowing rate, denoted by $Z^E\left(s^{t+1}|s^t\right)$, is given as the contractual interest rate that nondefaulting entrepreneurs repay to the FIs:

$$Z^E\left(s^{t+1}|s^t\right) \equiv \frac{\overline{\omega}^E\left(s^{t+1}|s^t\right) R^E\left(s^{t+1}|s^t\right) Q\left(s^t\right) K\left(s^t\right)}{Q\left(s^t\right) K\left(s^t\right) - N^E\left(s^t\right)}. \tag{4}$$

Clearly, the numerator stands for the amount that the nondefaulting entrepreneurs repay to the FIs, and the denominator for the amount of funds that entrepreneurs borrow from the FIs.

Similarly, the FIs' borrowing rate, denoted by $Z^F\left(s^{t+1}|s^t\right)$, is given by the contractual interest rate that nondefaulting FIs repay to the investors. That is

$$Z^F\left(s^{t+1}|s^t\right) \equiv \frac{\overline{\omega}^F\left(s^{t+1}|s^t\right) \Phi^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right) R^E\left(s^{t+1}|s^t\right) Q\left(s^t\right) K\left(s^t\right)}{Q\left(s^t\right) K\left(s^t\right) - N^F\left(s^t\right) - N^E\left(s^t\right)}, \tag{5}$$

In equation (5), the numerator is the amount that the nondefaulting FIs repay to the investors, and the denominator is the amount of funds that the FIs borrow from the investors.

Dynamic behavior of net worth

The net worth of FIs and entrepreneurs, $N^F\left(s^t\right)$ and $N^E\left(s^t\right)$, depends on their earnings from the credit contracts and their labor income. In addition to the profits stemming from entrepreneurial projects, both FIs and entrepreneurs inelastically supply a unit of labor to

[8] See Appendix A for the details of credit contracts. See Appendix B for the explicit forms of $G^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)$ and $G^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)$.

final goods producers and receive labor income $W^F(s^t)$ and $W^E(s^t)$. As we assume that each FI and entrepreneur survives to the next period with a constant probability γ^F and γ^E, then the aggregate net worths of FIs and entrepreneurs are given by

$$N^F(s^{t+1}) = \gamma^F V^F(s^t) + W^F(s^t), \tag{6}$$

$$N^E(s^{t+1}) = \gamma^E V^E(s^t) + W^E(s^t), \tag{7}$$

with

$$\begin{aligned} V^F(s^t) &\equiv \left(1 - \Gamma^F\left(\overline{\omega}^F(s^{t+1})\right)\right)\Phi^E\left(\overline{\omega}^E(s^{t+1}|s^t)\right)R^E(s^{t+1})\,Q(s^t)\,K(s^t), \\ V^E(s^t) &\equiv \left(1 - \Gamma^E\left(\overline{\omega}^E(s^{t+1})\right)\right)R^E(s^{t+1})\,Q(s^t)\,K(s^t). \end{aligned}$$

FIs and entrepreneurs that fail to survive at period t consume $(1-\gamma^F)V^F(s^t)$ and $(1-\gamma^E)V^E(s^t)$, respectively.[9]

2.2 The Rest of the Economy

Household

A representative household is infinitely lived, and maximizes the following utility function:

$$\max_{C(s^t),H(s^t),D(s^t)} \mathrm{E}_t \sum_{l=0}^{\infty} \exp(e^B(s^{t+l}))\beta^{t+l}\left\{\log C\left(s^{t+l}\right) - \chi\frac{H\left(s^{t+l}\right)^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}}\right\}, \tag{8}$$

subject to

$$C(s^t) + D(s^t) \leq W(s^t)\,H(s^t) + R(s^t)\,D(s^{t-1}) + \Pi(s^t) - T(s^t),$$

where $C(s^t)$ is final goods consumption, $H(s^t)$ is hours worked, $D(s^t)$ is real deposits held by the investors, $W(s^t)$ is the real wage measured by the final goods, $R(s^t)$ is the real risk-free return from the deposit $D(s^t)$ between time t and $t+1$, $\Pi(s^t)$ is dividend received from the ownership of retailers, and $T(s^t)$ is a lump-sum transfer. $\beta \in (0,1)$, η, and χ are the subjective discount factor, the elasticity of leisure, and the utility weight on leisure, respectively. $e^B(s^t)$ is a preference shock with mean one that provides the stochastic variation in the discount factor.

[9] See Appendix B for the definition of $\Gamma^F\left(\overline{\omega}^F(s^{t+1})\right)$ and $\Gamma^E\left(\overline{\omega}^E(s^{t+1})\right)$.

Final goods producer

The final goods $Y\left(s^t\right)$ are composites of a continuum of retail goods $Y\left(h, s^t\right)$. The final goods producer purchases retail goods in the competitive market, and sells the output to a household and capital producers at price $P\left(s^t\right)$. $P\left(s^t\right)$ is the aggregate price of the final goods. The production technology of the final goods is given by

$$Y\left(s^t\right) = \left[\int_0^1 Y\left(h, s^t\right)^{\frac{\epsilon-1}{\epsilon}} dh\right]^{\frac{\epsilon}{\epsilon-1}}, \tag{9}$$

where $\epsilon > 1$. The corresponding price index is given by

$$P\left(s^t\right) = \left[\int_0^1 P\left(h, s^t\right)^{1-\epsilon} dh\right]^{\frac{1}{1-\epsilon}}. \tag{10}$$

Retailers

The retailers $h \in [0, 1]$ are populated over a unit interval, each producing differentiated retail goods $Y\left(h, s^t\right)$, with production technology:

$$Y\left(h, s^t\right) = y\left(h, s^t\right), \tag{11}$$

where $y_t\left(h, s^t\right)$ for $h \in [0, 1]$ are the wholesale goods used for producing the retail goods $Y_t\left(h, s^t\right)$ by retailer $h \in [0, 1]$. The retailers are price takers in the input market and choose their inputs taking the input price $1/X\left(s^t\right)$ as given. However, they are monopolistic suppliers in their output market, and set their prices to maximize profits. Consequently, the retailer h faces a downward-sloping demand curve:

$$Y\left(h, s^t\right) = \left(\frac{P\left(h, s^t\right)}{P\left(s^t\right)}\right)^{-\epsilon} Y\left(s^t\right).$$

Retailers are subject to nominal rigidity. They can change prices in a given period only with probability $(1 - \xi)$, following Calvo (1983). Retailers who cannot reoptimize their price in period t, say $h = \overline{h}$, set their prices according to

$$P\left(\overline{h}, s^t\right) = \left[\pi\left(s^{t-1}\right)^{\gamma_p} \pi^{1-\gamma_p}\right] P\left(\overline{h}, s^{t-1}\right),$$

where $\pi\left(s^{t-1}\right)$ denotes the gross rate of inflation in period $t-1$, that is, $\pi\left(s^{t-1}\right) = P\left(s^{t-1}\right)/P\left(s^{t-2}\right)$. π denotes a steady state inflation rate, and $\gamma_p \in [0, 1]$ is a parameter that governs the size of price indexation. Denoting the price set by the active retailers by $P^*\left(h,s^t\right)$ and the demand curve the active retailer faces in period $t+l$ by $Y^*\left(h,s^{t+l}\right)$, retailer h's optimization problem with respect to its product price $P^*\left(h,s^t\right)$ is written in the following way:

$$\sum_{l=0}^{\infty}\xi E_t\Lambda\left(s^{t+l}\right)\left(\pi^{(1-\gamma_p)l}\left(\prod_{k=0}^{l-1}\pi^{\gamma_p}\left(s^{t+k}\right)\right)P^*\left(h,s^t\right)Y\left(h,s^{t+l}\right)\right.$$
$$\left.-\left(\frac{P\left(s^{t+l}\right)}{X\left(s^{t+l}\right)}\right)Y\left(h,s^{t+l}\right)\right)=0,$$

where $\Lambda\left(s^{t+l}\right)$ is given by

$$\Lambda\left(s^{t+l}\right)=\beta^{t+l}\left(\frac{C\left(s^t\right)}{C\left(s^{t+l}\right)}\right).$$

Using equations $(9),(10),$ and $(11),$ the final goods $Y\left(s^t\right)$ produced in period t are expressed with the wholesale goods produced in period t as the following equation:

$$y\left(s^t\right)=\int_0^1 y\left(h,s^t\right)dh=\left[\int_0^1\left(\frac{P_t\left(h,s^t\right)}{P\left(s^t\right)}\right)^{-\epsilon}dh\right]Y\left(s^t\right).$$

Moreover, because of stickiness in the retail goods price, the aggregate price index for final goods $P\left(s^t\right)$ evolves according to the following law of motion:

$$P\left(s^t\right)^{1-\epsilon}=(1-\xi)P^*\left(h,s^t\right)^{1-\epsilon}+\xi\left(\pi\left(s^{t-1}\right)^{\gamma_p}\overline{\pi}^{1-\gamma_p}P\left(s^{t-1}\right)\right)^{1-\epsilon}.$$

Wholesalers

The wholesalers produce wholesale goods $y_t\left(s^t\right)$ and sell them to the retailers with the relative price $1/X_t\left(s^t\right)$. They hire three types of labor inputs, $H\left(s^t\right)$, $H^F\left(s^t\right)$, and $H^E\left(s^t\right)$, and borrow capital $K\left(s^{t-1}\right)$. These labor inputs are supplied by the household, the FIs, and the entrepreneurs for wages $W\left(s^t\right)$, $W^F\left(s^t\right)$, and $W^E\left(s^t\right)$, respectively. Capital is supplied by the entrepreneurs with the rental price $R^E\left(s^t\right)$. At the end of each period, the capital is sold back to the entrepreneurs at price $Q\left(s^t\right)$. The maximization problem for the wholesaler is given by

$$\max_{y(s^t),K(s^{t-1}),H(s^t),H^F(s^t),H^E(s^t)}\frac{1}{X\left(s^t\right)}y_t\left(s^t\right)+Q\left(s^t\right)K\left(s^{t-1}\right)(1-\delta)$$
$$-R^E\left(s^t\right)Q\left(s^{t-1}\right)K\left(s^{t-1}\right)-W\left(s^t\right)H\left(s^t\right)$$
$$-W^F\left(s^t\right)H^F\left(s^t\right)-W^E\left(s^t\right)H^E\left(s^t\right),$$

subject to

$$y\left(s^{t}\right)=A\exp\left(e^{A}\left(s^{t}\right)\right)K\left(s^{t-1}\right)^{\alpha}H\left(s^{t}\right)^{(1-\Omega_{F}-\Omega_{E})(1-\alpha)}H^{F}\left(s^{t}\right)^{\Omega_{F}(1-\alpha)}H^{E}\left(s^{t}\right)^{\Omega_{E}(1-\alpha)},\tag{12}$$

where $A\exp\left(e^{A}\left(s^{t}\right)\right)$ denotes the level of technology of wholesale production and $\delta\in(0,1]$, α, Ω_F and Ω_E are the depreciation rate of capital goods, the capital share, the share of the FIs' labor inputs, and the share of entrepreneurial labor inputs, respectively.

Capital goods producers

The capital goods producers own the technology that converts final goods to capital goods. In each period, the capital goods producers purchase $I\left(s^{t}\right)$ amounts of final goods from the final goods producers. In addition, they purchase $K\left(s^{t-1}\right)(1-\delta)$ of used capital goods from the entrepreneurs at price $Q\left(s^{t}\right)$. They then produce new capital goods $K\left(s^{t}\right)$, using the technology F_I, and sell them in the competitive market at price $Q\left(s^{t}\right)$. Consequently, the capital goods producer's problem is to maximize the following profit function:

$$\max_{I(s^{t})}\sum_{l=0}^{\infty}\mathrm{E}_{t}\Lambda\left(s^{t+l}\right)\left[Q\left(s^{t+l}\right)\left(1-F_{I}\left(I\left(s^{t+l}\right),I\left(s^{t+l-1}\right)\right)\right)I\left(s^{t+l}\right)-I\left(s^{t+l}\right)\right],\tag{13}$$

where F_I is defined as follows:

$$F_{I}\left(I\left(s^{t+l}\right),I\left(s^{t+l-1}\right)\right)\equiv\frac{\kappa}{2}\left(\frac{\exp(e^{I}(s^{t}))I\left(s^{t+l}\right)}{I\left(s^{t+l-1}\right)}-1\right)^{2}.$$

Note that κ is a parameter that is associated with investment technology with an adjustment cost, where $e^{I}(s^{t})$ is the shock to the adjustment cost.[10] Here, the development in the total capital available at period t is described as

$$K\left(s^{t}\right)=\left(1-F_{I}\left(I\left(s^{t}\right),I\left(s^{t-1}\right)\right)\right)I\left(s^{t}\right)+(1-\delta)K\left(s^{t-1}\right).\tag{14}$$

Government

[10] Equation (13) does not include a term for the purchase of the used capital $K\left(s^{t-1}\right)$ from the entrepreneurs at the end of the period. This is because we assume, following BGG (1999), that the price of old capital that the entrepreneurs sell to the capital goods producers, say $\overline{Q}\left(s^{t}\right)$, is close to the price of the newly produced capital $Q\left(s^{t}\right)$ around the steady state.

The government collects a lump-sum tax from the household $T\left(s^t\right)$, and spends $G\left(s^t\right)$. A budget balance is maintained for each period t. Thus, we have

$$G\left(s^t\right)\exp\left(e^G(s^t)\right) = T\left(s^t\right), \tag{15}$$

where $e^G(s^t)$ is the stochastic component of government spending.

Monetary authority

In our baseline model, the monetary authority sets the nominal interest rate $R^n\left(s^t\right)$, according to a standard Taylor rule with inertia:

$$R^n\left(s^t\right) = \theta R^n\left(s^{t-1}\right) + (1-\theta)\left(\phi_\pi \pi\left(s^t\right) + \phi_y \log\left(\frac{Y\left(s^t\right)}{Y}\right)\right) + e^R\left(s^t\right), \tag{16}$$

where θ is the autoregressive parameter of the policy rate, ϕ_π and ϕ_y are the policy weight on inflation rate of final goods $\pi\left(s^t\right)$ and the output gap $\log\left(\frac{Y(s^t)}{Y}\right)$, respectively, and $e^R(s^t)$ is the shock to the monetary policy rule. Because the monetary authority determines the nominal interest rate, the real interest rate in the economy is given by the following Fisher equation:

$$R\left(s^t\right) \equiv \mathrm{E}_t\left\{\frac{R^n\left(s^t\right)}{\pi\left(s^{t+1}\right)}\right\}. \tag{17}$$

Resource constraint

The resource constraint for final goods is written as

$$\begin{aligned}
Y\left(s^t\right) \quad = \quad & C\left(s^t\right) + I\left(s^t\right) + G\left(s^t\right)\exp\left(e^G(s^t)\right) \\
& + \mu^E G^E\left(\overline{\omega}^E\left(s^t\right)\right) R^E\left(s^t\right) Q\left(s^{t-1}\right) K\left(s^{t-1}\right) \\
& + \mu^F G^F\left(\overline{\omega}^F\left(s^t\right)\right) R^F\left(s^t\right)\left(Q\left(s^{t-1}\right) K\left(s^{t-1}\right) - N^E\left(s^{t-1}\right)\right) \\
& + C^F\left(s^t\right) + C^E\left(s^t\right).
\end{aligned} \tag{18}$$

Note that the fourth and the fifth terms on the right-hand side of the equation correspond to the monitoring costs incurred by FIs and investors, respectively. The last two terms are the FIs' and entrepreneurs' consumption.

Law of motion for exogenous variables

There are five equations for the shock processes, $e^A\left(s^t\right), e^I\left(s^t\right)$, $e^B\left(s^t\right), e^G\left(s^t\right)$, and $e^R\left(s^t\right)$, following processes as below:

$$e^{A}\left(s^{t}\right)=\rho_{A}e^{A}\left(s^{t-1}\right)+\varepsilon^{A}\left(s^{t}\right), \tag{19}$$

$$e^{I}\left(s^{t}\right)=\rho_{I}e^{I}\left(s^{t-1}\right)+\varepsilon^{I}\left(s^{t}\right), \tag{20}$$

$$e^{B}\left(s^{t}\right)=\rho_{\beta}e^{B}\left(s^{t-1}\right)+\varepsilon^{\beta}\left(s^{t}\right), \tag{21}$$

$$e^{G}\left(s^{t}\right)=\rho_{G}e^{G}\left(s^{t-1}\right)+\varepsilon^{G}\left(s^{t}\right), \tag{22}$$

$$e^{R}\left(s^{t}\right)=\rho_{R}e^{R}\left(s^{t-1}\right)+\varepsilon^{R}\left(s^{t}\right), \tag{23}$$

where ρ_A, ρ_I, ρ_B, ρ_G, and $\rho_R \in (0,1)$ are autoregressive roots of the exogenous variables, and $\varepsilon^{A}\left(s^{t}\right), \varepsilon^{I}\left(s^{t}\right), \varepsilon^{B}\left(s^{t}\right), \varepsilon^{G}\left(s^{t}\right)$, and $\varepsilon^{R}\left(s^{t}\right)$ are innovations that are mutually independent, serially uncorrelated, and normally distributed with mean zero and variances σ_A^2, σ_I^2, σ_β^2, σ_G^2, and σ_R^2, respectively.

In addition, we consider shocks to the credit market, following Gilchrist and Leahy (2002). We assume that both FIs and entrepreneurs face an unexpected disruption (rise) in their net worth, denoted by $\varepsilon^{N^F}\left(s^{t}\right)$, $\varepsilon^{N^E}\left(s^{t}\right)$. These innovations directly affect net worth accumulation through equations (6) and (7). As discussed in Nolan and Thoenissen (2009), we interpret these shocks to the net worth as a shock to the efficiency of the contractual relations in the IF contract and the FE contract, respectively.[11]

2.3 Equilibrium Condition

An equilibrium consists of a set of prices, $\{P\left(h,s^{t}\right)$ for $h\in[0,1]$, $P(s^t)$, $X(s^t)$, $R\left(s^{t}\right)$, $R^{F}\left(s^{t}\right), R^{E}\left(s^{t}\right), W\left(s^{t}\right), W^{F}\left(s^{t}\right), W^{E}\left(s^{t}\right), Q\left(s^{t}\right), R^{F}\left(s^{t+1}|s^{t}\right), R^{E}\left(s^{t+1}|s^{t}\right), Z^{F}\left(s^{t+1}|s^{t}\right)$, $Z^{E}\left(s^{t+1}|s^{t}\right)\}_{t=0}^{\infty}$, and the allocations $\{\overline{\omega}^{F}\left(s^{t+1}|s^{t}\right)\}_{t=0}^{\infty}$, $\{\overline{\omega}^{E}\left(s^{t+1}|s^{t}\right)\}_{t=0}^{\infty}$, $\{N^{F}\left(s^{t}\right)\}_{t=0}^{\infty}$, $\{N^{E}\left(s^{t}\right)\}_{t=0}^{\infty}$ $\{\{y(h,s^t)),\ Y(h,s^t)$ for $h\in[0,1]$, $Y\left(s^{t}\right)$, $C\left(s^{t}\right)$, $D\left(s^{t}\right)$, $I\left(s^{t}\right)$, $K\left(s^{t}\right)$, $H\left(s^{t}\right)$, $H^{F}\left(s^{t}\right)$, $H^{E}\left(s^{t}\right)\}\}_{t=0}^{\infty}$, for a given government policy $\{R^{n}\left(s^{t}\right), G_{t}\left(s^{t}\right), T\left(s^{t}\right)\}_{t=0}^{\infty}$, realization of exogenous variables $\{\varepsilon^{A}\left(s^{t}\right), e^{B}(s^t), e^{G}(s^t), e^{I}(s^t), \varepsilon^{R}\left(s^{t}\right), \varepsilon^{N^E}\left(s^{t}\right), \varepsilon^{N^F}\left(s^{t}\right)\}_{t=0}^{\infty}$ and initial conditions N_{-1}^F, N_{-1}^E, K_{-1} such that for all t and h:

[11] CMR (2008) and Nolan and Thoenissen (2009) assume that the exit ratio of entrepreneurs γ^E obeys the stochastic law of motion, generating an unexpected change in entrepreneurial net worth. CMR (2008) interprets these shocks as a reduced form of an "asset bubble" or "irrational exuberance."

(1) the household maximizes its utility given the prices;

(2) the FIs maximize their profits given the prices;

(3) the entrepreneurs maximize their profits given the prices;

(4) the final goods producers maximize their profits given the prices;

(5) the retail goods producers maximize their profits given the prices;

(6) the wholesale goods producers maximize their profits given the prices;

(7) the capital goods producers maximize their profits given the prices;

(8) the government budget constraint holds; and

(9) markets clear.

3 Estimation

Following Christensen and Dib (2008), we set some of the parameters to the values used in the existing studies. These include the quarterly discount factor β, the labor supply elasticity η, the capital share α, the quarterly depreciation rate δ, and the steady state share of government expenditure in total output G/Y. See Table 1 for the values of these parameters.

In addition, we calibrate six parameters for the credit contracts: the lenders' monitoring cost in the IF contract μ^F, the lenders' monitoring cost in the FE contract μ^E, the standard error of the idiosyncratic productivity shock in the FI sector σ^F, the standard error of the idiosyncratic productivity shock in the entrepreneurial sector σ^E, the survival rate of FIs γ^F, and the survival rate of entrepreneurs γ^E, so that the following six equilibrium conditions are met at the steady state:

(1) the risk spread, $R^E - R$, is 200 basis points annually;

(2) the ratio of net worth held by FIs to the aggregate capital, N^F/QK, is 0.1, a historical average in the U.S. economy;

(3) the ratio of net worth held by entrepreneurs to the aggregate capital, N^E/QK, is 0.5, a historical average in the U.S. economy;

(4) the annualized failure rate of FIs is 2%;

(5) the annualized failure rate of entrepreneurs is 2%;

(6) the spread between the entrepreneurial borrowing rate and the FIs' borrowing rate $Z^E - Z^F$ is 235 basis points annually, which is the historical average of the difference between the prime lending rate and the rate on six-month certificates of deposit for the estimation

period.

Equilibrium conditions (1), (3), and (5) are met in BGG (1999), also. As our model incorporates credit-constrained FIs, along with the credit-constrained entrepreneurs, our economy satisfies equilibrium conditions (2), (4), and (6). The six conditions above imply that the FIs' borrowing spread $Z^F - R$ equals 55 basis points annually, which is the average of the difference between the rate on six-month CDs and the six-month Treasury bill rate (TB rate) from for the estimation period.

We estimate the rest of parameters of the model using a Bayesian method. Estimated parameters are the frequency of price adjustment ξ, the degree of price indexation γ_p, a parameter that controls the capital adjustment cost κ, the coefficients of the policy rule θ, ϕ_π and ϕ_y, the autoregressive parameters of the shock process ρ_A, ρ_I, ρ_B, ρ_G, and ρ_R, the variances of these shocks σ_A^2, σ_I^2, σ_B^2, σ_G^2, and σ_R^2, as well as the variances of the shocks to net worth $\sigma_{N_F}^2$ and $\sigma_{N_E}^2$. To calculate the posterior distribution and to evaluate the marginal likelihood of the model, the Metropolis-Hastings algorithm is employed. To do this, a sample of 200,000 draws was created, neglecting the first 100,000 draws.[12]

3.1 Data

Our dataset includes seven time series for the U.S. economy from 1984Q1 to 2009Q2: namely, real GDP, real consumption, real investment, the log difference of the GDP deflator, the federal funds (FF) rate, the net worth of the FI sector and the net worth of the entrepreneurial sector. The last two variables are calculated from "corporate equities + equity in noncorporate business sector" held by the financial business sector and "corporate equities + equity in noncorporate business sector" held by the nonfinancial business sector, respectively. All of the variables other than the log difference of the GDP deflator and the FF rate are first differenced. Following CMR (2008), we impose the condition that the mean in the model coincides with the mean in the data. In estimating the model, we remove the sample mean of the growth rate of real GDP, real consumption, real investment and net worth, and the level of the FF rate, and the log difference of the GDP deflator. We depict all data series used in the estimation in Figure 1.

[12] All estimations are done with Dynare.

3.2 Prior and Posterior Distribution of the Parameters

Table 2 reports the results of the parameter estimates with their prior distribution. The adjustment cost parameter for investment κ is normally distributed with a mean of 4.0 and a standard error of 1.5; the Calvo probability ξ is beta distributed with a mean of 0.5 and a standard error of 0.15; the degree of indexation to past inflation γ_p is beta distributed with a mean of 0.5 and a standard error of 0.2; the policy weight on the lagged policy rate θ is normally distributed with a mean of 0.75 and a standard error of 0.1; the policy weight on the inflation ϕ_π is normally distributed with a mean of 1.5 and a standard error of 0.125; and the policy weight on the output gap ϕ_y is normally distributed with a mean of 0.125 and a standard error of 0.05.

The priors on the stochastic processes of the exogenous shocks are set to follow an AR(1) process with autoregressive parameters ρ_A, ρ_I, ρ_B, ρ_G, and ρ_R, which are beta distributed with a mean of 0.5 and a standard deviation of 0.2. The variances of the innovations in exogenous variables σ_A^2, σ_I^2, σ_β^2, σ_G^2, $\sigma_{N_F}^2$, $\sigma_{N_E}^2$, and σ_R^2 are assumed to follow an inverse-gamma distribution with a mean of 0.01.

The last three columns in Table 2 display the posterior mean and the confidence intervals of the model parameters. For the investment adjustment cost, we obtain $\kappa = 7.21$. This value falls between the estimates of 0.65 (Meier and Muller, 2006) and 32.1 (Ireland, 2003) in existing studies. Our estimates of the degree of nominal price rigidity are $\xi = 0.79$ and $\gamma_p = 0.10$; these values are smaller than the findings in Meier and Muller (2006). The estimated monetary policy rule exhibits aggressive reaction to current inflation $\phi_\pi = 1.47$, with inertia of the interest rate $\theta = 0.74$, and mild reaction to current output $\phi_y = 0.04$. Table 2 also includes the shock processes of the seven exogenous variables. The government expenditure, productivity, and the preference processes are estimated to be persistent with AR(1) coefficients of 0.96, 0.92, and 0.88, respectively. The laws of motion for the investment adjustment cost and the monetary policy rate are relatively less persistent.

3.3 Impulse Responses

To illustrate the role played by the shocks to the FIs' net worth, we plot the economic responses to a one standard deviation negative shock to the net worth. An adverse shock to the net worth causes the downturn in the macroeconomy. The FIs' low net worth widens the two spreads, thereby reducing investment and output. Although the shock to the net worth is a one-time shock and therefore has no inertia, its impacts on the economy are persistent.

That is, as the demand for capital goods $K\left(s^t\right)$ is weakened, the capital price $Q\left(s^t\right)$ falls, leading to a further decrease in the investment owing to the endogenous declines in the entrepreneurial net worth as well as the FIs' net worth.

For the purpose of comparison, we also depict impulse responses to a one standard deviation negative shock to the entrepreneurial net worth. Time paths of the variables after the shock are similar to those after the shock to the FIs' net worth, but larger. As pointed out in HSU (2009a), for the same size of the shock, a shock to the FIs' net worth has a greater economic consequence than that to the entrepreneurial net worth. Since the estimated shocks to the entrepreneurial net worth are more volatile than those to the FIs' net worth, giving a larger standard deviation to the shocks to the entrepreneurial net worth, the one standard deviation shock to the entrepreneurial sector generates a more severe downturn than that to the FIs' net worth.

3.4 Shocks to the FI Sector and Their Contribution

Description of the time series of the shocks to the FIs' net worth

We now study how the shocks to the FIs' net worth affect the credit market and the real economy throughout the sample period. The solid line with white circles in Figure 3 displays the time series of the shocks (three quarters moving-averaged) with the National Bureau of Economic Research (NBER) business cycle periods. The realizations of these shocks are cyclical, typically taking large negative values during the recession. Particularly, during the several quarters since 2007, the exogenous net worth decline in the FI sector has been unprecedentedly deep and persistent.

Compared with the shocks to entrepreneurial net worth that are depicted by the solid line with black circles in the right scale of Figure 3, variations of shocks to the FIs' net worth are relatively moderate. Although the two shock series sometimes move differently over the sample period, they simultaneously drop substantially in the recession that began in 2007. Both series are negatively correlated with the financial indicators of credit market stress. For example, the contemporaneous correlations of each of the two shock series (the shocks to the FIs' net worth and those to the entrepreneurial net worth) and the BAA - AAA corporate bond rate are -0.50 and -0.53, respectively, indicating the link between the decline in the net worth in the borrowing sector and financial stress.[13]

[13] We also study the correlation of the time series of the two shock series and alternative financial indicators,

The role played by the shocks to the FIs' net worth

The shocks to the FIs' net worth bring about variations in both financial variables and real variables. In Figures 4 and 5, we depict the model-generated time path of the FIs' borrowing spread $Z^F\left(s^{t+1}|s^t\right) - R\left(s^t\right)$ and the entrepreneurial borrowing spread $Z^E\left(s^{t+1}|s^t\right) - R\left(s^t\right)$.[14] The two model-generated series have strong co-movement with the related indicator from the financial markets. The contemporaneous correlation between $Z^F\left(s^{t+1}|s^t\right) - R\left(s^t\right)$ and the three-month CD rate - FF rate is 0.64, and that between $Z^E\left(s^{t+1}|s^t\right) - R\left(s^t\right)$ and the BAA corporate bond rate - FF rate is 0.60, respectively.[15] A large portion of upsurge in the spreads, particularly in the FIs' borrowing spread since 2007, is attributed to the negative shocks to the FIs' net worth. The line with black circles is the model-generated spread when only shocks to the FIs' net worth are fed into the model. These time paths capture the general movements of the spreads' variations, including the current years.

Figure 6 displays the time path of investment; to see the relative importance of shocks to FIs' net worth, we decompose the investment variations into the contribution of each structural shock. To illustrate, we categorize these shocks into four broad categories. We include the total factor productivity (TFP) shock ε_t^A and the investment adjustment cost shock ε_t^I in "shocks to producers," the shocks to the entrepreneurial net worth shock ε_t^{NE} in "shocks to entrepreneurs," and the shocks to the FIs' net worth in "shocks to FIs." The rest of the shocks, including the preference shocks ε_t^B, the exogenous spending shocks ε_t^G, and the monetary policy shocks ε_t^R, we categorize as "other shocks."

The shocks to the FIs' net worth play a quantitatively important but not dominant role in investment variations. In particular, during the three recessionary episodes included in our sample period, these shocks drive down the investment substantially. As we discussed above, their impacts are persistent. In the recessions that began in 1990 and 2001, the shocks to FIs' net worth continued to lower investment, even several quarters after the trough of

such as BAA (or AAA) subtracted by the TB rate (or the FF rate). The correlation varies from -0.25 to -0.45, indicating the significant relationship.

[14] In the analysis for both model-implied series and the related actual data, we focus on their business-cycle components (six quarters to 32 quarters) and extract these components by applying the band-pass filter to the original series.

[15] Here, the three-month CD rate and the BAA corporate bond rate serve as the proxy for the FIs' borrowing rate and the entrepreneurial borrowing rate. Because $R\left(s^t\right)$ is defined as the policy rate divided by the aggregate price level in the model, we subtract each series by the FF rate. One other way is to subtract them by the TB rate. In this case, the contemporaneous correlations are then 0.37 and 0.56, respectively.

the recessions.

Variance decomposition

To summarize, we report the decomposition of the variations in the two spreads, investment, output, and inflation in Table 3.[16] The shocks to the FIs' net worth are a main source of variations in the spreads, particularly in the FIs' borrowing spread. About 40% and 20% of the FIs' borrowing spread and the entrepreneurial spread are attributed to these shocks. For the macroeconomic variables, these shocks contribute about 15% of investment variations, and play a comparatively minor role in the variations of other variables. Among the shocks that are responsible for the investment variations, the contribution of shocks to the FIs' net worth is about half of that to the entrepreneurial net worth, indicating that one-third of shocks originating from the credit market come from the FI sector rather than the entrepreneurial sector.

3.5 Sensitivity Analysis

We have seen up to now that shocks to the FI sector play a quantitatively important role, particularly in the U.S. investment variations. In our analysis, we have assumed that shocks originating in the FI sector take the form of exogenous change in the FIs' net worth, and that our benchmark dataset is sufficient to identify these shocks. In this section, we conduct sensitivity tests by incorporating another type of shock to the FI sector and by including the spread series in the dataset of estimation.

First, while most of the studies on banking shocks concentrate on the shocks that directly change FIs' net worth,[17] we consider a different type of exogenous shock, "riskiness shocks," along with the shocks to the net worth. CMR (2008) study the economy in which credit market imperfection is worsened by the exogenous increase in the variance of borrowers' idiosyncratic productivity called "riskiness." Realization of riskiness is independent of the net worth shocks, and captures the variations in the external finance premium that does not stem from the exogenous net worth variations. Closely following CMR (2008), we now assume that the standard deviations of idiosyncratic productivity shocks of borrowers are time-variant, so that σ_t^F and σ_t^E obey the laws of motion:

[16] In calculating the variance decompositions, we first calculate the volatility of the endogenous variable conditional on each of the shocks. We then sum these volatilities to calculate the share of each shock.

[17] See, for example, Chen (2001), Meh and Moran (2004), and Aikman and Paustian (2006).

$$\log\left(\frac{\sigma^F\left(s^t\right)}{\overline{\sigma}^F}\right)=\rho_{\sigma_F}\log\left(\frac{\sigma^F\left(s^{t-1}\right)}{\overline{\sigma}^F}\right)+\varepsilon^{\sigma_F}\left(s^t\right), \tag{24}$$

$$\log\left(\frac{\sigma^E\left(s^t\right)}{\overline{\sigma}^E}\right)=\rho_{\sigma_E}\log\left(\frac{\sigma^E\left(s^{t-1}\right)}{\overline{\sigma}^E}\right)+\varepsilon_t^{\sigma_E}\left(s^t\right), \tag{25}$$

where ρ_{σ_F} and ρ_{σ_E} are autoregressive parameters, $\varepsilon^{\sigma_F}\left(s^t\right)$ and $\varepsilon_t^{\sigma_E}\left(s^t\right)$ are the corresponding innovations, and $\overline{\sigma}^F$ and $\overline{\sigma}^E$ are the steady state values of riskiness. As shown in HSU (2009a, 2009b), a rise in either σ_t^F or σ_t^E increases the payment to the lender, causing a higher external finance premium and a downturn in investment, even when no shocks to net worth occur.

Second, we reformulate the estimation using the spread data. In the benchmark estimation, we do not employ spread series. This is because in constructing the series that corresponds to our two measures of spread $Z^F\left(s^t\right)-R\left(s^t\right)$ and $Z^E\left(s^t\right)-R\left(s^t\right)$, the indicators representing overall financial conditions of the FIs and entrepreneurs are called for. The data series that exactly match our model series, however, are not available. In fact, the choice of observable variables differs across the literature that estimates the financial accelerator model. For instance, while Christensen and Dib (2008) and De Graeve (2008) employ neither series, Nolan and Thoenissen (2009) use only net worth. On the other hand, CMR (2008) employ the BAA - AAA yield on corporate bonds as a measure of external finance premium in estimation, to distill shocks to the credit market. The second sensitivity check thus intends to see how our results change if spread series are added to the estimation.

We conduct two alternative formulations, estimation I and estimation II. In estimation I, we utilize the dataset $\{C_t,\, GDP_t,\, I_t,\, R_t^n,\, \pi_t,\, N_t^F, N_t^E,\, Z_t^F-R_t, Z_t^E-R_t\}_{t=1984Q1}^{2009Q2}$ for the estimation. In estimation II, we utilize the same dataset as that used in the benchmark estimation. For both estimations, we incorporate the riskiness shocks as well as the shocks to net worth in both of the sectors.

The results are shown in Table 4. The estimated impact of the shocks to the FI sector is robust to incorporating the other type of shock to the FI, and to including the spread data into the dataset. The contribution of shocks to FIs' net worth amounts to 18.49% and 15.03% in the investment variations in estimations I and II, respectively.[18]

[18] We have also calculated the variance decomposition for the other variables, output, inflation, the FIs' borrowing spread, and the entrepreneurial borrowing spread by estimation I and estimation II. Similarly to the outcomes obtained under benchmark estimation, the contribution of the shocks to the FI sector in the variations of output and inflation is at most 4%. For the two borrowing spreads, the shocks to the FI sector account for at least 20% of their variations.

3.6 Importance of Chained Credit Contracts

In contrast to the existing financial accelerator models, our model introduces the endogenous developments in the FIs' net worth and credit market imperfection that originates from them. To illustrate the implication of this additional source of the financial accelerator effect, we make two comparison analyses in this last subsection.

First, we examine if our model fits the data, compared with the model that abstracts from the credit market imperfection in the FI sector. To do this, we develop a model called the "BGG model" in which entrepreneurs are credit constrained but FIs are not.[19] We then estimate the BGG model and our benchmark model, using the same dataset $\{C_t,\ GDP_t,\ I_t,\ R_t^n,\ \pi_t, N_t^E\}_{t=1984Q1}^{2009Q2}$ for the two models.

The results of this estimation are shown in Table 5.[20] The value of the log-likelihood under the BGG model is significantly lower than that under the benchmark model, implying that the latter is more successful at predicting the data. This result indicates the importance of incorporating the credit-constrained FI sector, since the two models differ only in the FI sector.[21]

Second, we ask if introducing shocks to the FIs' net worth changes our understanding of the source of the investment variations. Early studies that abstract from the shocks originating in the credit market report that a bulk of economic variations is attributed to the shocks to the investment technology. According to Christensen and Dib (2008), more than 90% of investment variations originate in the shocks to investment efficiency. On the other hand, Nolan and Thoenissen (2009), based on the model that does not incorporate shocks to the investment technology, report that shocks originating in the credit market are important. Because our model has both shocks to the credit market and those to the investment adjustment technology, we can separate the former from the latter.

To illustrate the role played by the shocks to the FIs' net worth, we estimate one other

[19] This BGG model employs the same setting as the financial accelerator model of BGG (1999). The only difference is that we estimate some of the model parameters rather than calibrate them in our BGG model. A full description of the BGG model is provided in Appendix C. In estimating the model, we estimate parameters $\{\kappa,\ \xi,\ \gamma_p,\ \theta,\ \phi_\pi,\ \phi_y\}$ and shock processes $\{\rho_A,\ \rho_I,\ \rho_B,\ \rho_G,\ \rho_R,\ \sigma_A,\ \sigma_I,\ \sigma_B,\ \sigma_G,\ \sigma_R, ,\sigma_{N^E}\}$, using the dataset $\{C_t,\ GDP_t,\ I_t,\ \pi_t,\ R_t^n, N_t^E\}_{t=1984Q1}^{2009Q2}$. The rest of the parameters are calibrated to the U.S. economy.

[20] In estimating the benchmark model for Table 5, we do not use the data of the FIs' net worth, so that the outcomes are comparable between the BGG model and the benchmark model.

[21] Christensen and Dib (2008) conclude using the log-likelihood ratio test that their financial accelerator model outperforms the model that abstracts from the financial accelerator effect.

model, which we call the "Non-FA model,"[22] where no credit market imperfection prevails in the economy, along with the BGG model and the benchmark model by a Bayesian method.[23] Table 6 reports the variance decompositions of investment under the three models. Under the Non-FA model, a bulk of the variations comes from the shocks to investment adjustment cost ε_t^I. When shocks originating in the credit market are incorporated, however, the contribution of these shocks is reduced. The estimated contribution of ε_t^I is 54.42% and 35.24%, respectively, in the BGG model and the benchmark model. On the other hand, a significant portion of investment variations is attributed to the shocks originating in the credit market under the two models.

4 Conclusion

In this paper, we have quantitatively assessed the role played by the shocks to the FIs' net worth in the U.S. business cycle. To this end, we have estimated and simulated the financial accelerator model in HSU (2009a, 2009b), in which FIs along with entrepreneurs are credit constrained. In this model, once net worth in the FI sector falls, the cost of external finance increases, reducing investment. Consequently, endogenous developments in the FIs' net worth as well those in the entrepreneurial net worth become a key to the amplification and propagation mechanism in the economy.

Employing a Bayesian method, we have distilled the shocks to the FIs' net worth from the U.S. dataset that includes the FIs' net worth. These shocks typically take negative values during a recession, particularly during the one that began in 2007. According to the variance decomposition, these shocks are one of the main sources of the variations in the financial variables. They account for 39% of the FIs' borrowing spread and 23% of the entrepreneurial borrowing spread. At the same time, their role is important but not dominant in the variations of the macroeconomic variables. These shocks contribute 15% of investment variations, 3% of the output variations, and 4% of the inflation variations.

[22] We provide a full description of the Non-FA model in Appendix C. For the Non-FA model, we estimate parameters $\{\kappa, \xi, \gamma_p, \theta, \phi_\pi, \phi_y\}$ and shock processes $\{\rho_A, \rho_I, \rho_B, \rho_G, \rho_R, \sigma_A, \sigma_I, \sigma_B, \sigma_G, \sigma_R\}$, , using the data set $\{C_t, GDP_t, I_t, \pi_t, R_t^n\}_{t=1984Q1}^{2009Q2}$. The rest of the parameters are calibrated to the U.S. economy.

[23] In estimating the benchmark model for Table 6, we employ the full dataset including the FIs' net worth.

A Credit Contract

In this section, we discuss how the contents of the two credit contracts are determined by the profit maximization problem of the FIs. We first explain how the FIs earn profit from the credit contracts, and then explain the participation constraints of the other participants in the credit contracts.

In each period t, the expected net profit of an FI from the credit contracts is expressed by

$$\sum_{s^{t+1}} \Pi\left(s^{t+1}|s^t\right) \overbrace{\left[1-\Gamma^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)\right]}^{\text{share of FIs earnings received by the FI}} R^F\left(s^{t+1}|s^t\right)\left(Q_t\left(s^t\right)K\left(s^t\right)-N^E\left(s^t\right)\right), \tag{26}$$

where $\Pi\left(s^{t+1}|s^t\right)$ is a probability weight for state s^{t+1} for given state s^t. Here, the expected return on the loans to entrepreneurs, $R^F\left(s^{t+1}|s^t\right)$ is given by

$$\overbrace{\left[\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)-\mu^E G^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right]}^{\text{share of entrepreneurial earnings received by the FI}} R^E\left(s^{t+1}|s^t\right) Q\left(s^t\right) K\left(s^t\right)$$

$$\equiv R_t^F\left(s^{t+1}|s^t\right)\left(Q\left(s^t\right)K\left(s^t\right)-N^E\left(s^t\right)\right) \text{ for } \forall s^{t+1}|s^t. \tag{27}$$

This equation indicates that the two credit contracts determine the FIs' profits. In the FE contract, the FIs receive a portion of what entrepreneurs earn from their projects as their gross profit. In the IF contract, the FIs receive a portion of what they receive from the FE contract as their net profit, and pay the rest to the investors.

There is a participation constraint in each of the credit contracts. In the FE contract, the entrepreneurs' expected return is set to equal to the return from their alternative option. We assume that without participating in the FE contract, entrepreneurs can purchase capital goods with their own net worth $N^E\left(s^t\right)$. Note that the expected return from this option equals to $R^E\left(s^{t+1}\right)N^E\left(s^t\right)$. Therefore the FE contract is agreed by the entrepreneurs only when the following inequality is expected to hold:

$$\overbrace{\left[1-\Gamma_t^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right]}^{\text{share of entrepreneurial earnings kept by the entrepreneur}} R^E\left(s^{t+1}|s^t\right) Q\left(s^t\right) K\left(s^t\right)$$

$$\geq R^E\left(s^{t+1}|s^t\right)N^E\left(s^t\right) \text{ for } \forall s^{t+1}|s^t. \tag{28}$$

We next consider a participation constraint of the investors in the IF contract. We assume that there is a risk free rate of return in the economy $R\left(s^t\right)$, and investors may alternatively invest in this asset. Consequently, for investors to join the IF contract, the loans to the FIs must equal the opportunity cost of lending. That is

$$\overbrace{\left[\Gamma^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)-\mu^F G^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)\right]}^{\text{share of FIs' earnings received by the investors}} R^F\left(s^{t+1}|s^t\right)\left(Q\left(s^t\right)K\left(s^t\right)-N^E\left(s^t\right)\right)$$

$$\geq R\left(s^t\right)\left(Q\left(s^t\right)K\left(s^t\right)-N^F\left(s^t\right)-N^E\left(s^t\right)\right). \tag{29}$$

The FI maximizes its expected profit (26) by optimally choosing the variables $\overline{\omega}^F\left(s^{t+1}|s^t\right)$, $\overline{\omega}^E\left(s^{t+1}|s^t\right)$ and $K\left(s^t\right)$, subject to the investors' participation constraint (29) and entrepreneurial participation constraint (28). Combining the first-order conditions yields the following equation:

$$\begin{aligned}
0 = \sum_{s^{t+1}|s^t} \Pi\left(s^{t+1}|s^t\right)\Big\{&\left(1-\Gamma^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)\right)\Phi_t^E\left(s^{t+1}|s^t\right)R^E\left(s^{t+1}|s^t\right)\\
&+\frac{\Gamma'^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)}{\Phi'^F\left(s^{t+1}|s^t\right)}\Phi^F\left(s^{t+1}|s^t\right)\Phi^E\left(s^{t+1}|s^t\right)R_{t+1}^E\left(s^{t+1}|s^t\right)\\
&-\frac{\Gamma'^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)}{\Phi'^F\left(s^{t+1}|s^t\right)}R(s_t)\\
&+\frac{\left\{1-\Gamma^F\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)\right\}\Phi'^E\left(s^{t+1}|s^t\right)}{\Gamma'^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)}\left(1-\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right)R^E\left(s^{t+1}|s^t\right)\\
&+\frac{\Gamma'_B\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)\Phi^F\left(s^{t+1}|s^t\right)\Phi'^E\left(s^{t+1}|s^t\right)}{\Phi'^F\left(s^{t+1}|s^t\right)\Gamma'^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)}\left(1-\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right)R^E\left(s^{t+1}|s^t\right)\Big\}.
\end{aligned} \tag{30}$$

Using equations (27) and (29), we obtain the equation (1) in the text.

B Equilibrium Conditions of the Benchmark Model

In this appendix, we describe the equilibrium system of our benchmark model. We express it in five blocks of equations.

(1) **Household's Problem and Resource Constraint**

$$\frac{1}{C\left(s^{t}\right)}=E_{t}\left\{\beta \exp \left(e^{B\left(s^{t+1}\right)}\right) \frac{1}{C\left(s^{t+1}\right)} R_{t}\right\}, \tag{31}$$

$$W\left(s^{t}\right)=\chi H\left(s^{t}\right)^{\frac{1}{\eta}} C\left(s^{t}\right), \tag{32}$$

$$R_{t}=\mathrm{E}_{t}\left\{\frac{R_{t}^{n}}{\pi_{t+1}}\right\}, \tag{33}$$

$$\begin{aligned}
Y\left(s^{t}\right) = \; & C\left(s^{t}\right)+I\left(s^{t}\right)+G\left(s^{t}\right) \exp \left(e^{G}\left(s^{t}\right)\right) \\
& +\mu^{E} G_{t}^{E}\left(\overline{\omega}^{E}\left(s^{t}\right)\right) R^{E}\left(s^{t}\right) Q\left(s^{t-1}\right) K\left(s^{t-1}\right) \\
& +\mu^{F} G_{t}^{F}\left(\overline{\omega}^{F}\left(s^{t}\right)\right) R^{F}\left(s^{t}\right)\left(Q\left(s^{t-1}\right) K\left(s^{t-1}\right)-N^{E}\left(s^{t-1}\right)\right) \\
& +C^{F}\left(s^{t}\right)+C^{E}\left(s^{t}\right),
\end{aligned} \tag{34}$$

with

$$\begin{aligned}
C^{F}\left(s^{t}\right) & \equiv\left(1-\gamma^{F}\right)\left(1-\Gamma^{F}\left(\overline{\omega}^{F}\left(s^{t+1}\right)\right)\right) \Phi^{E}\left(\overline{\omega}^{E}\left(s^{t+1}\right)\right) R^{E}\left(s^{t+1}\right) Q\left(s^{t}\right) K\left(s^{t}\right), \\
C^{E}\left(s^{t}\right) & \equiv\left(1-\Gamma^{E}\left(\overline{\omega}^{E}\left(s^{t+1}\right)\right)\right) R^{E}\left(s^{t+1}\right) Q\left(s^{t}\right) K\left(s^{t}\right).
\end{aligned}$$

(2) **Firms' Problems**

$$Y\left(s^{t}\right)=\frac{A\exp\left(e^{A}\left(s^{t}\right)\right)K\left(s^{t-1}\right)^{\alpha}H\left(s^{t}\right)^{(1-\Omega_{F}-\Omega_{E})(1-\alpha)}H^{F}\left(s^{t}\right)^{\Omega_{F}(1-\alpha)}H^{E}\left(s^{t}\right)^{\Omega_{E}(1-\alpha)}}{\Delta_{p}\left(s^{t}\right)}, \tag{35}$$

with

$$\begin{aligned}
\Delta_{p}\left(s^{t}\right) &= (1-\xi)\left(\frac{K_{p}\left(s^{t}\right)}{F_{p}\left(s^{t}\right)}\right)^{-\epsilon}+\xi\left(\frac{\pi\left(s^{t-1}\right)^{\gamma_{p}}}{\pi\left(s^{t}\right)}\right)^{-\epsilon}\Delta_{p}\left(s^{t-1}\right),\\
F_{p}\left(s^{t}\right) &= 1+\xi\beta\exp\left(e^{B\left(s^{t+1}\right)}\right)\frac{C\left(s^{t}\right)Y\left(s^{t+1}\right)}{C\left(s^{t+1}\right)Y\left(s^{t}\right)}\left(\frac{\pi\left(s^{t}\right)^{\gamma_{p}}}{\pi\left(s^{t+1}\right)}\right)^{1-\epsilon}F_{p}\left(s^{t+1}\right),\\
K_{p}\left(s^{t}\right) &= \frac{\epsilon\left(s^{t}\right)}{\epsilon\left(s^{t}\right)-1}MC\left(s^{t}\right)+\xi\beta\exp\left(e^{B\left(s^{t+1}\right)}\right)\frac{C\left(s^{t}\right)Y\left(s^{t+1}\right)}{C\left(s^{t+1}\right)Y\left(s^{t}\right)}\left(\frac{\pi\left(s^{t}\right)^{\gamma_{p}}}{\pi\left(s^{t+1}\right)}\right)^{-\epsilon}K_{p}\left(s^{t+1}\right),
\end{aligned}$$

$$\begin{aligned}
H\left(s^{t}\right)W\left(s^{t}\right) &= A\exp\left(e^{A}\left(s^{t}\right)\right)K\left(s^{t-1}\right)^{\alpha}H\left(s^{t}\right)^{(1-\Omega_{F}-\Omega_{E})(1-\alpha)}H^{F}\left(s^{t}\right)^{\Omega_{F}(1-\alpha)}H^{E}\left(s^{t}\right)^{\Omega_{E}(1-\alpha)}\\
&\quad\cdot MC\left(s^{t}\right)(1-\alpha)\left(1-\Omega_{F}-\Omega_{E}\right),
\end{aligned} \tag{36}$$

$$R^{E}\left(s^{t}\right)=\frac{\alpha Y\left(s^{t}\right)/K\left(s^{t}\right)+Q\left(s^{t+1}\right)(1-\delta)}{Q\left(s^{t}\right)}, \tag{37}$$

$$\begin{aligned}
&Q\left(s^{t}\right)\left(1-0.5\kappa\left(\frac{I\left(s^{t}\right)\exp(e^{I}(s^{t}))}{I\left(s^{t-1}\right)}-1\right)^{2}\right)\\
&-Q\left(s^{t}\right)\left(\kappa\left(\frac{I\left(s^{t}\right)\exp(e^{I}(s^{t}))}{I\left(s^{t-1}\right)}\right)\left(\frac{I\left(s^{t}\right)\exp(e^{I}(s^{t}))}{I\left(s^{t-1}\right)}-1\right)\right)-1\\
=\ &\mathrm{E}_{t}\left\{\beta\exp\left(e^{B\left(s^{t+1}\right)}\right)\frac{C\left(s^{t}\right)Q\left(s^{t+1}\right)}{C\left(s^{t+1}\right)}\kappa\left(\frac{I\left(s^{t+1}\right)\exp(e^{I}(s^{t+1}))}{I\left(s^{t}\right)}\right)^{2}\left(\frac{I\left(s^{t+1}\right)}{I\left(s^{t}\right)}-1\right)\exp(e^{I}(s^{t+1}))\right\}.
\end{aligned} \tag{38}$$

(3) **FIs' Problems**

Equilibrium conditions for credit contracts are given by (29), (28) and (30), and the following equations:

$$G^F\left(\overline{\omega}_t^F\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^F - 0.5\sigma_F^2}{\sigma_F}} \exp\left(-\frac{v_F^2}{2}\right) dv_F, \tag{39}$$

$$G^E\left(\overline{\omega}_t^E\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^E - 0.5\sigma_E^2}{\sigma_E}} \exp\left(-\frac{v_E^2}{2}\right) dv_E, \tag{40}$$

$$G'^F\left(\overline{\omega}_t^F\right) = \left(\frac{1}{\sqrt{2\pi}}\right)\left(\frac{1}{\overline{\omega}_t^F \sigma_F}\right) \exp\left(-.5\left(\frac{\log \overline{\omega}_t^F - 0.5\sigma_F^2}{\sigma_F}\right)^2\right), \tag{41}$$

$$G'^E\left(\overline{\omega}_t^E\right) = \left(\frac{1}{\sqrt{2\pi}}\right)\left(\frac{1}{\overline{\omega}_t^E \sigma_E}\right) \exp\left(-.5\left(\frac{\log \overline{\omega}_t^E - 0.5\sigma_E^2}{\sigma_E}\right)^2\right), \tag{42}$$

$$\Gamma^F\left(\overline{\omega}_t^F\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^F - 0.5\sigma_F^2}{\sigma_F}} \exp\left(-\frac{v_F^2}{2}\right) dv_F + \frac{\overline{\omega}_t^F}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_t^F + 0.5\sigma_F^2}{\sigma_F}}^{\infty} \exp\left(-\frac{v_F^2}{2}\right) dv_F, \tag{43}$$

$$\Gamma^E\left(\overline{\omega}_t^E\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^E - 0.5\sigma_E^2}{\sigma_E}} \exp\left(-\frac{x^2}{2}\right) dx + \frac{\overline{\omega}_t^E}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_t^E + 0.5\sigma_E^2}{\sigma_E}}^{\infty} \exp\left(-\frac{v_E^2}{2}\right) dv_E, \tag{44}$$

$$\begin{aligned}
\Gamma'^F\left(\overline{\omega}_t^F\right) &= \frac{1}{\sqrt{2\pi}\overline{\omega}_t^F \sigma_F} \exp\left(-.5\left(\frac{\log \overline{\omega}_t^F - 0.5\sigma_F^2}{\sigma_F}\right)^2\right) dx \\
&\quad + \frac{1}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_t^F + 0.5\sigma_F^2}{\sigma_F}}^{\infty} \exp\left(-\frac{v_F^2}{2}\right) dv_F \\
&\quad - \frac{1}{\sqrt{2\pi}\sigma_F} \exp\left(-\frac{\left(\frac{\log \overline{\omega}_t^F + 0.5\sigma_F^2}{\sigma_F}\right)^2}{2}\right) dx,
\end{aligned} \tag{45}$$

$$\begin{aligned}
\Gamma'^E\left(\overline{\omega}_t^E\right) &= \frac{1}{\sqrt{2\pi}\overline{\omega}_t^E \sigma_E} \exp\left(-.5\left(\frac{\log \overline{\omega}_t^E - 0.5\sigma_E^2}{\sigma_E}\right)^2\right) dx \\
&\quad + \frac{1}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_t^E + 0.5\sigma_E^2}{\sigma_E}}^{\infty} \exp\left(-\frac{v_E^2}{2}\right) dv_E \\
&\quad - \frac{1}{\sqrt{2\pi}\sigma_E} \exp\left(-.5\left(\frac{\log \overline{\omega}_t^E + 0.5\sigma_E^2}{\sigma_E}\right)^2\right) dx,
\end{aligned} \tag{46}$$

$$\left[\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)-\mu^E G^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right]R^E\left(s^{t+1}|s^t\right)Q\left(s^t\right)K\left(s^t\right)$$

$$=R_t^F\left(s^{t+1}|s^t\right)\left(Q\left(s^t\right)K\left(s^t\right)-N^E\left(s^t\right)\right). \tag{47}$$

(4) **Laws of Motion of State Variables**

$$K\left(s^t\right)=\left(1-0.5\kappa\left(\frac{I\left(s^t\right)\exp(e^I(s^t))}{I\left(s^{t-1}\right)}\right)^2\right)I\left(s^t\right)+(1-\delta)K\left(s^{t-1}\right), \tag{48}$$

$$N^F\left(s^{t+1}\right)=\gamma^F V^F\left(s^t\right)+W^F\left(s^t\right), \tag{49}$$

$$N^E\left(s^{t+1}\right)=\gamma^E V^E\left(s^t\right)+W^E\left(s^t\right), \tag{50}$$

with:

$$\begin{aligned}
V^F\left(s^t\right) &\equiv \left(1-\Gamma^F\left(\overline{\omega}^F\left(s^{t+1}\right)\right)\right)\Phi^E\left(\overline{\omega}^E\left(s^{t+1}\right)\right)R^E\left(s^{t+1}\right)Q\left(s^t\right)K\left(s^t\right),\\
V^E\left(s^t\right) &\equiv \left(1-\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}\right)\right)\right)R^E\left(s^{t+1}\right)Q\left(s^t\right)K\left(s^t\right),\\
W^F\left(s^t\right) &\equiv (1-\alpha)\,\Omega_F Y\left(s^t\right),\\
W^E\left(s^t\right) &\equiv (1-\alpha)\,\Omega_E Y\left(s^t\right).
\end{aligned}$$

(5) **Policies and Shock Process**

Policies for the shock process are given by equations (15), (16), (19), (20), (21), (22) and (23).

C Equilibrium Conditions of Alternative Models

In addition to the benchmark model, we consider two alternative models for comparative convenience. The first is the "Non-FA model" in which no financial accelerator mechanism is incorporated. The equilibrium conditions under this model are given by equations (15), (16), (19), (20), (21), (22), (23), (31), (32), (33), (35), (36), (37), (38), and (48), and the following equations instead of equations (34) and (37) under the benchmark model, respectively:

$$Y\left(s^t\right) = C\left(s^t\right) + I\left(s^t\right) + G\left(s^t\right)\exp\left(e^G(s^t)\right), \tag{51}$$

$$R\left(s^t\right) = \mathrm{E}_t \frac{\alpha Y\left(s^t\right)/K\left(s^t\right) + Q\left(s^{t+1}\right)(1-\delta)}{Q\left(s^t\right)}. \tag{52}$$

The second model is the "BGG model" in which only entrepreneurs are credit constrained. The equilibrium conditions in this model are given by equations (7), (15), (16), (19), (20), (21), (22), (23), (31), (32), (33), (35), (36), (37), (38), (40), (42), (44), (46) and (48), and the following three equations instead of equations (30), (34) and (37) under the benchmark model, respectively:

$$\begin{aligned}0 = &\sum_{s^{t+1}|s^t} \Pi\left(s^{t+1}|s^t\right)\left(1-\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right)R^E\left(s^{t+1}|s^t\right)\\ &+\frac{\Gamma'^E\left(\overline{\omega}^F\left(s^{t+1}|s^t\right)\right)}{\Phi'^E\left(s^{t+1}|s^t\right)}\Phi^E\left(s^{t+1}|s^t\right)R^E_{t+1}\left(s^{t+1}|s^t\right) - \frac{\Gamma'^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)}{\Phi'^E\left(s^{t+1}|s^t\right)}\Phi^E\left(s^{t+1}|s^t\right)R(s_t),\end{aligned} \tag{53}$$

$$\begin{aligned}Y\left(s^t\right) &= C\left(s^t\right) + I\left(s^t\right) + G\left(s^t\right)\exp\left(e^G(s^t)\right)\\ &\quad+\mu^E G^E\left(\overline{\omega}^E\left(s^t\right)\right)R^E\left(s^t\right)Q\left(s^{t-1}\right)K\left(s^{t-1}\right) + C^E\left(s^t\right),\end{aligned} \tag{54}$$

with:

$$C^E\left(s^t\right) \equiv \left(1-\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}\right)\right)\right)R^E\left(s^{t+1}\right)Q\left(s^t\right)K\left(s^t\right),$$

$$\left[\Gamma^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right) - \mu^E G^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right]R^E\left(s^{t+1}|s^t\right)Q\left(s^t\right)K\left(s^t\right)$$

$$= R_t\left(s^{t+1}|s^t\right)\left(Q\left(s^t\right)K\left(s^t\right) - N^E\left(s^t\right)\right). \tag{55}$$

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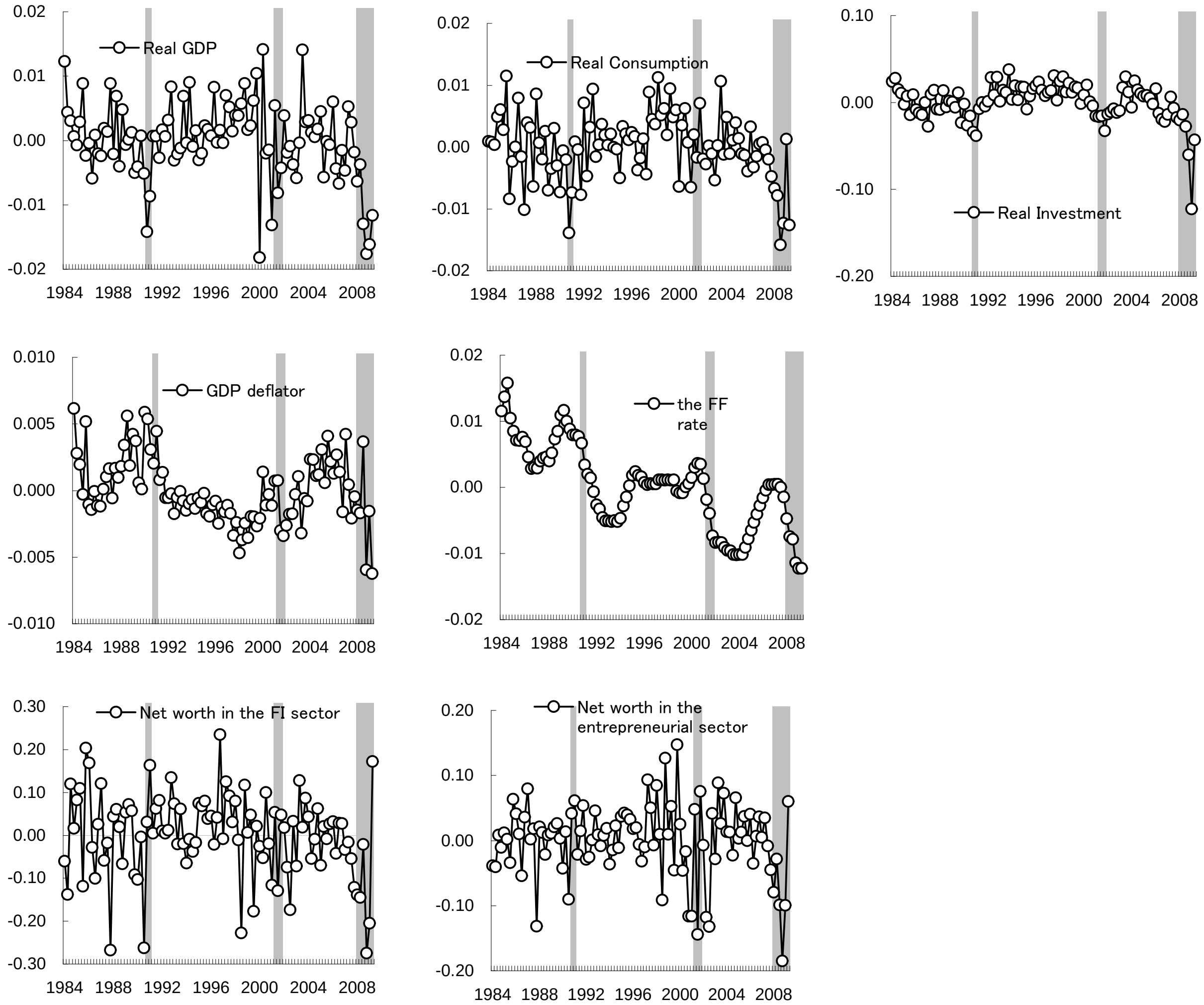

Figure 1: Time series of observables from 1984Q1 to 2009Q2. Variables except the FF rate are first differenced. Shaded quarters are the periods between the peak and trough of the NBER business cycle.

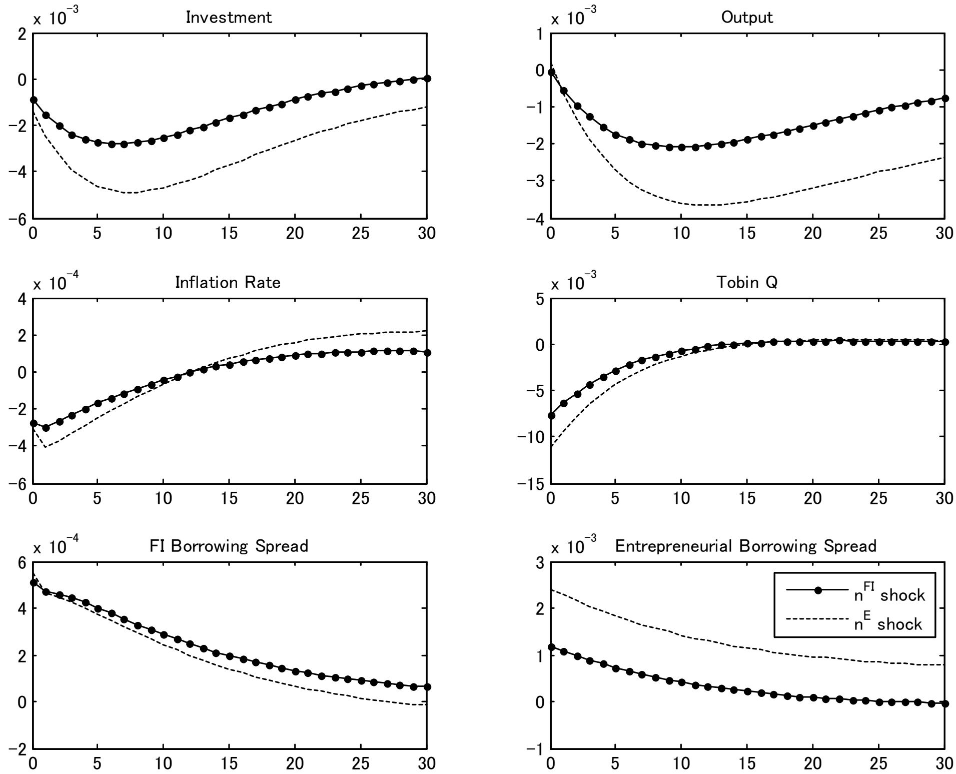

Figure 2: Impulse responses to the negative one standard deviation shock to the FIs' net worth (line with black circle) and those to the entrepreneurial net worth (dotted line).

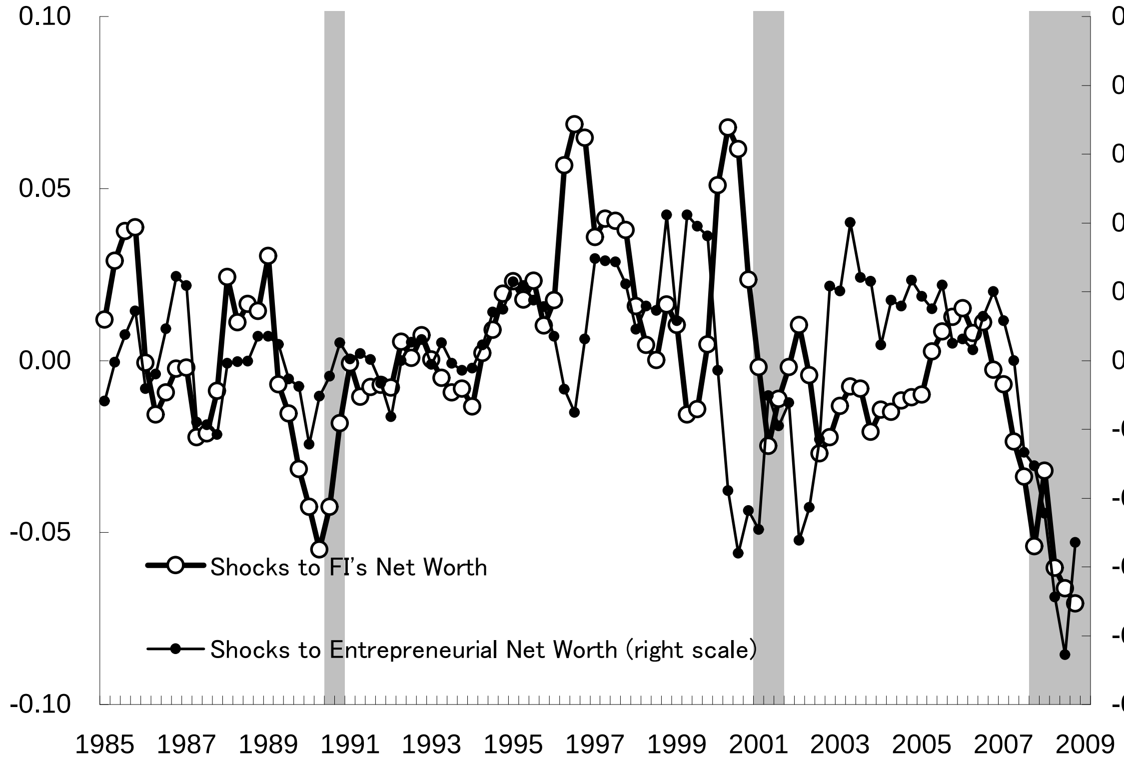

Figure 3: The estimated shocks to FIs' net worth and entrepreneurial net worth. Shaded quarters are those between the peak and trough of the NBER business cycle.

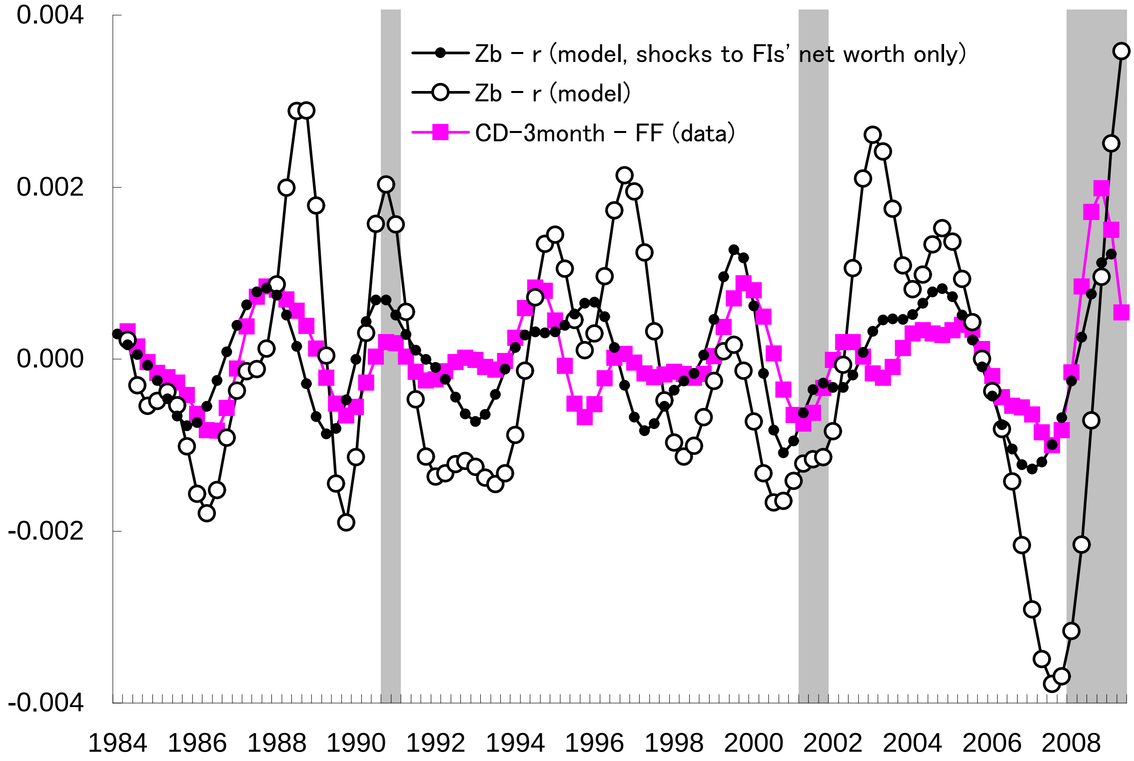

Figure 4: The model-generated series of the FIs' borrowing spread $Z^F\left(s^{t+1}|s^t\right) - R\left(s^t\right)$, and the spread between CD three-months and the FF rate. All series are filtered by the band pass filter. Shaded quarters are those between the peak and trough of the NBER business cycle.

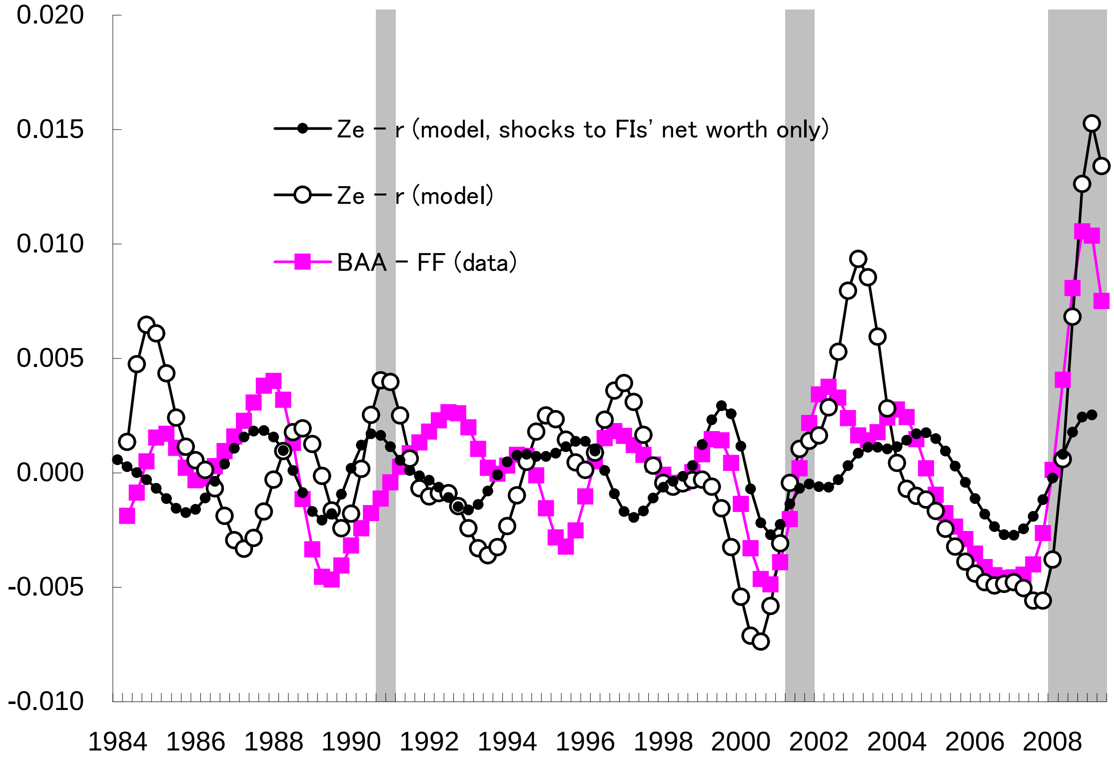

Figure 5: The model-generated series of the entrepreneurial borrowing spread $Z^E\left(s^{t+1}|s^t\right) - R\left(s^t\right)$, and the spread between BAA rated corporate bonds and the FF rate. All series are filtered by the band pass filter. Shaded quarters are those between the peak and trough of the NBER business cycle.

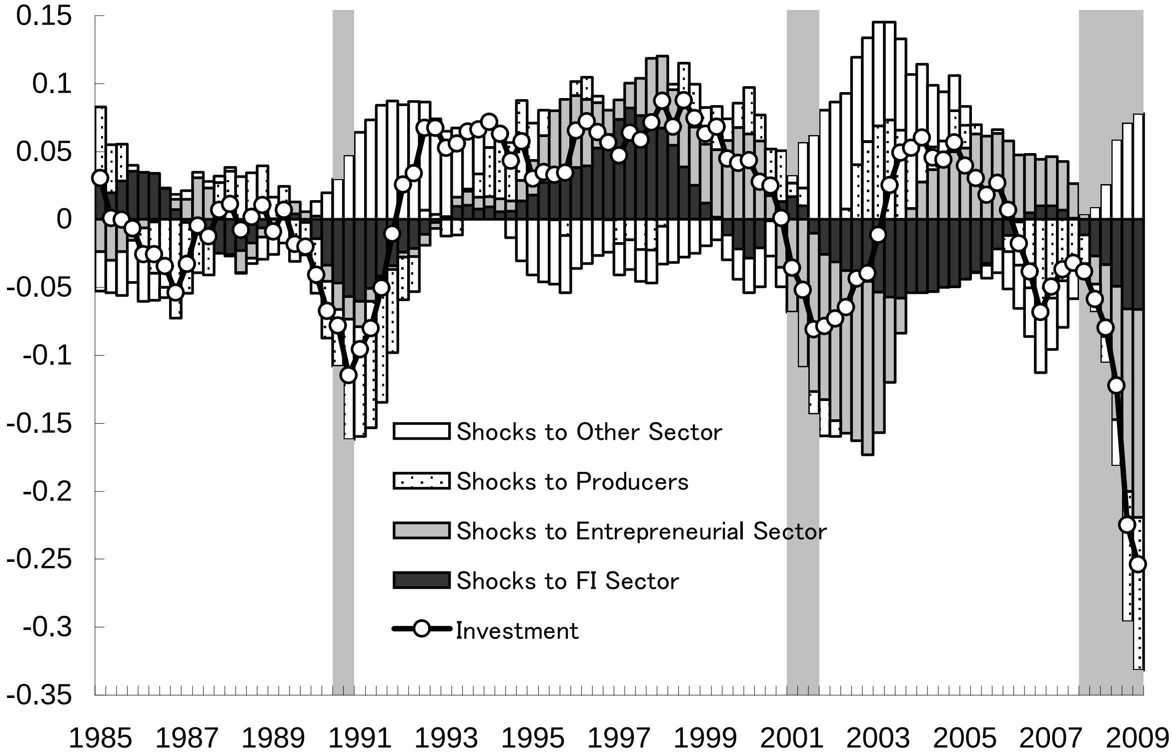

Figure 6: Historical decomposition of U.S. aggregate investment. (year-on-year % change, deviation from trend growth) Shaded periods are those between the peak and trough of the NBER business cycle.

Table 1A: Parameters[24]

Parameter	Value	Description
β	.99	Discount factor
δ	.025	Depreciation rate
α	.35	Capital share
R	$.99^{-1}$	Risk free rate
ϵ	6	Degree of substitutability
η	3	Elasticity of labor
χ	.3	Utility weight on leisure
GY^{-1}	.2	Share of government expenditure at steady state

[24] Figures are quarterly unless otherwise noted.

Table 1B: Calibrated Parameters[25]

Parameter	Value	Description
σ_F	0.107366	S.E. of FIs' idiosyncratic productivity at steady state
σ_E	0.312687	S.E. of entrepreneurial idiosyncratic productivity at steady state
μ_F	0.033046	bankruptcy cost associated with FIs
μ_E	0.013123	bankruptcy cost associated with entrepreneurs
γ_F	0.963286	Survival rate of FIs
γ_E	0.983840	Survival rate of entrepreneurs

Table 1C: Steady State Conditions

Condition	Description
$R = .99^{-1}$	Risk-free rate is the inverse of the subjective discount factor.
$Z^E = Z^F + .023^{.25}$	Premium for entrepreneurial borrowing rate is $.023^{.25}$.
$Z^F = R + .006^{.25}$	Premium for FIs' borrowing rate is $.006^{.25}$.
$F\left(\overline{\omega}^F\right) = .02$	Default probability in the IF contract is .02.
$F\left(\overline{\omega}^E\right) = .02$	Default probability in the FE contract is .02.
$n^F = .1$	FIs' net worth/capital ratio is set to .1
$n^E = .5$	Entrepreneurial net worth/capital ratio is set to .5.

[25] Figures are quarterly unless otherwise noted.

Table 2: Parameter Estimates

	Prior distribution			Posterior distribution		
	Distr.	Mean	St. Dev.	Mean	5%	95%
ξ	Beta	0.5	0.15	0.7866	0.7100	0.8712
κ	Normal	4	1.5	7.2085	5.4124	9.0542
γ_p	Beta	0.5	0.2	0.1042	0.0123	0.2017
θ	Beta	0.75	0.1	0.7427	0.6971	0.7921
ϕ_π	Normal	1.5	0.125	1.4671	1.3100	1.6223
ϕ_y	Normal	0.125	0.05	0.0404	0.0124	0.0660
ρ_B	Beta	0.5	0.2	0.8757	0.8403	0.9131
ρ_I	Beta	0.5	0.2	0.6867	0.5839	0.7965
ρ_A	Beta	0.5	0.2	0.9204	0.8654	0.9717
ρ_G	Beta	0.5	0.2	0.9558	0.9330	0.9807
ρ_R	Beta	0.5	0.2	0.2080	0.0922	0.3253
σ_B	Inv. Gamma	0.01	2	0.0022	0.0016	0.0029
σ_I	Inv. Gamma	0.01	2	0.0079	0.0061	0.0095
σ_G	Inv. Gamma	0.01	2	0.0043	0.0038	0.0048
σ_A	Inv. Gamma	0.01	2	0.0098	0.0070	0.0131
σ_R	Inv. Gamma	0.01	2	0.0018	0.0016	0.0021
σ_{N_E}	Inv. Gamma	0.01	2	0.1790	0.1588	0.1999
σ_{N_F}	Inv. Gamma	0.01	2	0.0407	0.0354	0.0453
Log likelihood	2172.43255					

Table 3: Variance Decomposition

Category		$var\left(Z_t^E - R_t\right)$	$var\left(Z_t^F - R_t\right)$
Shocks to Producers and Entrepreneurs	ε_t^A	0.89	10.48
	ε_t^I	2.79	5.45
	$\varepsilon_t^{N_E}$	57.60	17.71
	sum	61.28	33.64
Shocks to FI	$\varepsilon_t^{N_F}$	22.83	39.11
Other Shocks	ε_t^b	0.46	15.97
	ε_t^g	0.14	0.15
	ε_t^r	15.29	11.12
	sum	15.89	27.25

Category		$var\left(I_t\right)$	$var\left(GDP_t\right)$	$var\left(\pi_t\right)$
Shocks to Producers and Entrepreneurs	ε_t^A	4.61	27.26	42.67
	ε_t^I	30.79	9.68	2.89
	$\varepsilon_t^{N_E}$	37.13	6.27	4.43
	sum	72.53	43.21	49.99
Shocks to FI	$\varepsilon_t^{N_F}$	15.32	3.16	4.28
Other Shocks	ε_t^b	3.86	29.94	27.68
	ε_t^g	0.06	12.08	0.07
	ε_t^r	8.23	11.60	17.98
	sum	12.15	53.63	45.73

Note: The estimated share of variance accounted for by each shock is reported. Numbers are the average of 1984Q2 to 2009Q2.

Table 4: Sensitivity of Variance Decomposition of Investment

Category		Benchmark	Estimation I	Estimation II
Shocks to	ε_t^A	4.61	1.56	4.47
Producers and	ε_t^I	30.79	27.60	34.22
Entrepreneurs	$\varepsilon_t^{N_E}$	37.13	30.65	34.64
	$\varepsilon_t^{\sigma_E}$		0.58	0.00
	sum	72.53	59.80	73.34
Shocks to	$\varepsilon_t^{N_F}$	15.32	18.32	14.98
FI Sector	$\varepsilon_t^{\sigma_F}$		1.08	0.00
	sum	15.32	19.40	14.98
Other Shocks	ε_t^b	3.86	0.57	3.53
	ε_t^g	0.06	0.08	0.06
	ε_t^r	8.23	19.57	8.10
	sum	12.15	20.21	11.68

Note: The estimated share of variance accounted for by each shock is reported. Numbers are the average of 1984Q2 to 2009Q2.

Table 5: Likelihood Comparison

	Benchmark: Chained BGG			BGG		
Log likelihood	**2117.9**			**2113.1**		
	Posterior distribution			Posterior distribution		
	Mean	5%	95%	Mean	5%	95%
ξ_p	0.6427	0.5626	0.7147	0.6631	0.5906	0.7246
κ	7.1747	5.5340	9.2229	5.6593	3.8576	7.6968
γ_p	0.2504	0.0581	0.4429	0.2082	0.0294	0.3905
θ	0.6235	0.5615	0.6882	0.6392	0.5822	0.7046
ϕ_π	1.8519	1.7030	2.0254	1.7896	1.6158	1.9401
ϕ_y	0.0057	-0.0263	0.0364	-0.0007	-0.0293	0.0255
ρ_B	0.8782	0.8465	0.9156	0.8721	0.8386	0.9051
ρ_I	0.5328	0.4158	0.7452	0.6015	0.4922	0.7257
ρ_A	0.9751	0.9576	0.9937	0.9726	0.9543	0.9919
ρ_G	0.9464	0.9236	0.9744	0.9450	0.9216	0.9684
ρ_R	0.5283	0.4362	0.6107	0.5113	0.4159	0.5998
σ_B	0.0019	0.0014	0.0023	0.0020	0.0015	0.0024
σ_I	0.0099	0.0074	0.0117	0.0090	0.0070	0.0108
σ_G	0.0044	0.0039	0.0049	0.0044	0.0040	0.0049
σ_A	0.0069	0.0058	0.0078	0.0071	0.0061	0.0082
σ_R	0.0019	0.0016	0.0022	0.0018	0.0016	0.0021
σ_{N_E}	0.1876	0.1658	0.2092	0.1984	0.1761	0.2204
σ_{N_F}	0.0187	0.0020	0.0303			

Table 6: Variance Decomposition of Investment under Different Models

Category		Non FA	BGG	Chained BGG
Shocks to	ε_t^A	13.19	12.08	4.02
Producers and	ε_t^I	74.81	54.42	35.24
Entrepreneurs	$\varepsilon_t^{N_E}$		19.38	33.98
	sum	88.00	85.89	73.24
Shocks to	$\varepsilon_t^{N_F}$			15.07
FI Sector	sum			
Other Shocks	ε_t^b	11.81	13.32	3.33
	ε_t^g	0.00	0.02	0.05
	ε_t^r	0.19	0.77	8.30
	sum	12.00	14.11	11.66

Note: The estimated share of variance accounted for by each shock is reported. Numbers are the average of 1984Q2 to 2009Q2.