Capital Injection, Monetary Policy, and Financial Accelerators*

Naohisa Hirakata,[a] Nao Sudo,[a] and Kozo Ueda[b]
[a]Bank of Japan
[b]Waseda University

We evaluate the implications of spread-adjusted Taylor rules and capital injection policies in response to adverse shocks to the economy, using a variant of the financial accelerator model. Our model comprises the two credit-constrained sectors that raise external finance under credit market imperfection: financial intermediaries (FIs) and entrepreneurs. With the model estimated using the U.S. data, we find that a spread-adjusted Taylor rule mitigates (amplifies) the impact of adverse shocks when the shock is accompanied by a widening (shrinking) of the corresponding spread. We formalize a capital injection policy as a positive (negative) amount of injection to either of the two sectors in response to an adverse shock (a favorable shock). In contrast to a spread-adjusted Taylor rule, a positive injection boosts the economy regardless of the type of shock. The capital injection to the FIs has a greater impact on the economy compared with that to the entrepreneurs. Our result shows support for adopting the spread-adjusted Taylor rules and capital injections, although welfare implication varies depending on the source of economic downturn and excessive responses aggravate welfare.

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1. Introduction

The financial turmoil that began in 2007 was propagated around the globe after the outbreak, causing a severe economic downturn in some countries, particularly the United States. The malfunctioning of financial intermediation played a central role in causing and then aggravating the macroeconomic stagnation. The deterioration of balance sheets at major banks and surges in banks' borrowing spread depressed economic activity,[1] and the resulting weakness in the economy further aggravated the credit condition of financial intermediaries (FIs).

In the United States, two classes of policy action were undertaken to address this deep recession. First, from the end of 2007 to the beginning of 2008, the Federal Reserve slashed its interest rate to nearly zero. According to Cúrdia and Woodford (2010b), this large reduction surpassed what was necessary according to the standard Taylor rule, possibly reflecting the developments in the financial sector. Second, since the end of 2008, the U.S. government injected public funds into major financial and non-financial institutions. For example, on October 28, 2008, Treasury Secretary Henry Paulson authorized the Troubled Asset Relief Program (TARP) capital injections for nine of the largest banks. These capital injection policies prevented the bankruptcy of private institutions by strengthening their balance sheets and restoring their ability to raise funds.[2]

In this paper, we investigate the relevance of the two classes of policy as stabilizers of the economy. The first class of policy is the

[1]For example, the LIBOR minus the OIS increased by more than 350 basis points in late 2008.

[2]See, for example, Bank of Japan (2009) and Black and Hazelwood (2012) for the details of initiatives regarding capital injections. Similarly to the case of the United States, from 2007 to 2009, many European banks were bailed out by their national governments through a range of initiatives including capital injections.

In addition to the policy rate reduction and capital injection, the Federal Reserve introduced several measures including the purchases of risky assets aiming to lower the premiums. It is notable that those Federal Reserve policies, often called quantitative or credit easing, are different from capital injection. While capital injection directly alters the size of equity of FIs on their liability side, such Federal Reserve policies alter the size and composition of the asset side of FIs' balance sheet by purchasing the FIs' assets and, in turn, indirectly raising the value of equity. See the discussion in Gagnon et al. (2010). For the policy action in the United Kingdom, see Cross, Fisher, and Weeken (2010).

spread-adjusted Taylor rule—a monetary policy rule that reduces (raises) the policy rate whenever a spread widens (shrinks). The second class of policy is capital injection by a government either to the FI sector or the entrepreneurial sector. The government transfers a positive (negative) amount of final goods from the household sector to either of the two sectors in response to an adverse shock (a favorable shock).

To explore the quantitative implication of these policies, we use a financial accelerator model developed by Hirakata, Sudo, and Ueda (henceforth, HSU) (2009). Drawing on the model of Bernanke, Gertler, and Gilchrist (henceforth, BGG) (1999), our economy comprises the credit-constrained FIs together with credit-constrained entrepreneurs. The FIs and the entrepreneurs raise external finance from the investors and the FIs, respectively, by paying an interest rate with borrowing spreads to the lenders. Due to informational friction in the credit market, these borrowing spreads are negatively related to the amount of net worth owned by the borrowers. HSU (2011) show, based on the U.S. data from the 1980s to the 2000s, that the model with credit-constrained FIs outperforms the model without them, indicating that chained credit contracts and shocks to the FI sector constitute an important element of the U.S. economy.

Our quantitative analysis in the current paper makes use of the estimation results of HSU (2011) in terms of the model parameters and size of structural shocks. We first investigate the impact of various types of adverse shocks in the economy where the standard Taylor rule is undertaken. The shocks include the financial shocks that primarily impact the credit market participants and are propagated to the rest of the economy through the credit market, as well as the widely analyzed macroeconomic shocks that directly influence the household's demand or production technologies. The responses of macroeconomic variables, particularly those of the credit spreads, differ according to the type of shocks. We then ask how the macroeconomic consequences of the shocks, including welfare implications, are altered by changing the policy from the standard Taylor rule to the spread-adjusted Taylor rules or the capital injection policies. To do this, we set weights attached to inflation and output gap in the policy rule to the optimal values and investigate if adding non-zero weights to the spreads in the rule improves the welfare.

The performance of the spread-adjusted Taylor rule conditional on a specific shock depends on how each type of shock influences the spread. Other things being equal, a wider spread in our model implies a higher cost of external finance, leading to an economic downturn. Under this rule, a widening of the borrowing spread is met by a cut in the policy rate, alleviating its adverse impact on the economy. The spread-adjusted Taylor rule therefore mitigates the recession when an adverse shock is accompanied by an increasing spread. Examples of this type of shock include adverse financial shocks and total factor productivity (TFP) shocks. On the contrary, in response to an adverse shock that reduces spread (e.g., an increase in investment adjustment cost), the rule leads to a monetary contraction followed by a further aggravation of the economy. From the welfare perspective, therefore, the spread-adjusted Taylor rule can achieve improvement relative to the standard Taylor rule so far as the class of shocks that render countercyclical movement of spread play a quantitatively dominant role in the economy. According to the estimation results of HSU (2011), shocks to investment adjustment cost explain only a limited portion of macroeconomic variations, and the rest of the shocks cause countercyclical spread movements. Consequently, in the economy where all shocks are prevalent, a positive weight is attached to the spread in the optimal monetary policy rule.

By contrast, capital injection policies boost the economy regardless of the type of shock. Since a larger net worth in the borrowing sectors enhances the financial intermediation by reducing the cost of external finance, these policies result in an economic expansion. In addition, we find that the capital injection to the FI sector has quantitatively a greater stimulus than a capital injection to the entrepreneurs. As demonstrated by HSU (2009, 2011), the FI sector is highly leveraged compared with the entrepreneurial sector in the United States, and a variation in the net worth in the former sector causes a disproportionately large impact on the economy. The welfare implication of these two injection policies, however, is similar. They achieve a welfare improvement to some shocks when the size of injection is minimal. A large welfare loss occurs as the size of injection increases, as injections themselves cause larger economic variations. When capital injection policy is conducted unconditional on the source of the shocks, welfare gain is achieved by injecting a moderate amount of capital to the FI sector and the entrepreneurial sector.

This paper is related to three strands of literature. The first strand comprises discussions about the spread-adjusted Taylor rule. The rule is first proposed by McCulley and Toloui (2008) and Taylor (2008) and theoretically analyzed by Cúrdia and Woodford (2010b). Our paper is close to Cúrdia and Woodford (2010b) in that we quantitatively evaluate the spread-adjusted Taylor rules in a dynamic stochastic general equilibrium (DSGE) framework. There are two key differences between our model and that of Cúrdia and Woodford (2010b). First, our model nests on a financial accelerator model à la BGG (1999) where credit spreads vary according to the endogenous development of the net worth in the borrowing sectors. Here, transmission channel through the net worth plays the essential role in implementing the monetary policy. Second, our model explicitly incorporates the FI sector that faces the credit market imperfection. Consequently, our economy includes more than one spread—in particular, that associated with the FIs' credit conditions. We therefore analyze not only the spread-adjusted Taylor rules targeting the spread between the ultimate lenders and borrowers in the economy but also those targeting the spread between the ultimate lenders and the FIs, and that between the FIs and the ultimate borrowers. As reported in Chari, Christiano, and Kehoe (2008) and Taylor and Williams (2009), a distinctive feature of the current turmoil was an upsurge in the FIs' borrowing spread. Our policy analysis is in line with these observations.

The second strand of literature concerns the importance of capital, or net worth, of the borrowing sector as a source of business-cycle fluctuations (BGG 1999, Chen 2001, Gilchrist and Leahy 2002, Aikman and Paustian 2006, and Meh and Moran 2010).[3] In the present paper, we investigate the importance of variations in net worth as a policy instrument in the wake of adverse shocks. Governments in OECD countries injected the capital to the FIs and

[3]BGG (1999) and Gilchrist and Leahy (2002) study the macroeconomic consequence of a disruption of entrepreneurial net worth based on the financial accelerator model. Chen (2001), Meh and Moran (2010), and Aikman and Paustian (2006) investigate the role of banks' net worth in the economic fluctuations by extending the model of Holmstrom and Tirole (1997).

entrepreneurs during the crisis to improve their balance sheets and stabilize the economy. We intend to gauge the effects of these policy actions in a DSGE framework.

The third strand is recent works on the effects of capital purchase or lending by the public sector (Gertler and Karadi 2011, Cúrdia and Woodford 2010a, and Del Negro et al. 2010) associated with the compositional change in the central bank's balance sheet. Gertler and Karadi (2011) develop a model in which the credit market imperfection prevents the banks from borrowing sufficient amounts of funds from the borrowers, and they show that there is room for direct lending by the central bank to private sectors. Cúrdia and Woodford (2010a), examining other unconventional monetary policies, draw similar conclusions regarding direct lending by the central bank. Del Negro et al. (2010) explore the consequence of government purchase of illiquid private assets in exchange for liquid government liabilities, and investigate the effectiveness of the policy. By contrast, our capital injection policy is the transfer of final goods from the household sector to the FI or entrepreneurial sector. This policy is not the direct lending by the government but indirectly increases lending to the private sectors by improving borrowers' balance sheets and mitigating the credit market imperfection.

The rest of the paper is organized as follows. In section 2, we briefly describe our economy. In section 3, we report the responses of the economy to various kinds of adverse shocks. In section 4, we study the consequences of the spread-adjusted Taylor rules and the capital injection policies during the financial crisis. In section 5, we conclude.

2. The Economy

The economy consists of credit markets and goods markets, and ten types of agents: a household, investors, FIs, entrepreneurs, capital goods producers, final goods producers, retail goods producers, wholesale goods producers, the monetary authority, and the government.

Our setting for the credit market is taken from HSU (2009, 2011). The participants of the markets are investors, FIs, and entrepreneurs. Investors collect deposits from a household, an ultimate lender in the economy, and invest what they collect as loans to the FIs. The FIs and entrepreneurs are both credit constrained. They earn positive profits, accumulating the net worth individually. The FIs are monopolistic lenders to the entrepreneurs, the ultimate borrowers in the economy. Because the FIs' net worth is smaller than the loans to the entrepreneurs, the FIs engage credit contracts with investors to raise the rest of the funds (IF contracts). The entrepreneurs carry out investment for their projects. Their net worth is again smaller than their needs for their investment project, and the entrepreneurs sign credit contracts with the FIs (FE contracts). Due to the asymmetric information, the two credit contracts are contingent on the borrowers' net worth.

There are three goods in the economy: final goods, retail goods, and capital goods. Final goods are produced by competitive final goods producers using the Dixit-Stiglitz aggregator from the differentiated retail goods. Retail goods are produced by the monopolistic retail goods producers who set their goods prices following Calvo (1983). Each differentiated retail good is produced from the wholesale good. The wholesale goods are produced by competitive wholesale goods producers who own Cobb-Douglas production technology that converts capital goods and labor inputs into the wholesale goods. Capital goods are produced by capital goods producers, and labor inputs are supplied by households, the FIs, and the entrepreneurs.

2.1 Credit Market

2.1.1 Overview of the Two Types of Credit Contract

In each period, entrepreneurs conduct projects of size $Q(s^t)K(s^t)$, where s^t is the history of the state up to t, $Q(s^t)$ is the price of capital, and $K(s^t)$ is capital. Entrepreneurs hold the net worth, $N^E(s^t) < Q(s^t)K(s^t)$, and borrow funds, $Q(s^t)K(s^t) - N^E(s^t)$, from the FIs through the FE contracts. The FIs hold net worth, $N^{FI}(s^t) < Q(s^t)K(s^t) - N^E(s^t)$, and borrow funds, $Q(s^t)K(s^t) - N^{FI}(s^t) - N^E(s^t)$, from investors through the IF contracts. In both contracts, agency problems stemming from asymmetric information are present. That is, the FIs and the entrepreneurs are subject to idiosyncratic productivity shocks $\omega^{FI}(s^t)$ and $\omega^E(s^t)$, and the lenders cannot observe the realizations of these shocks without paying monitoring costs.[4]

The FIs choose the clauses of the two contracts to maximize their expected profits under the credit market imperfections. The first-order conditions to this problem give the following relationship between the net worth and the external finance premium $\mathrm{E}_t\left\{R^E\left(s^{t+1}\right)\right\}/R(s^t)^5$:

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

with

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

[4]One may interpret $\omega^{FI}(s^t)$ as idiosyncratic productivity shocks that are specific to a group of firms, such as those in the same industry or region. Suppose that there is an infinite number of industries (regions) that consist of an infinite number of firms and that each FI chooses either one of the industries (regions). Industry-specific (region-specific) shocks affect the individual FI's earning as if the FI is hit by the idiosyncractic productivity.

[5]See appendix 1 and 2 for details about the FIs' profit-maximization problem and functional forms of $G^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)$ and $G^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)$.

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

where $n^{FI}(s^t)$ and $n^E(s^t)$ are the ratios of net worth to aggregate capital in the two sectors, and $\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)$ and $\overline{\omega}^E\left(s^{t+1}|s^t\right)$ are the cut-off values for the FIs' idiosyncratic shock $\omega^{FI}\left(s^{t+1}\right)$ in the IF contract and for the entrepreneurial idiosyncratic shock $\omega^E\left(s^{t+1}\right)$ in the FE contract.

This equation (1) is the key equation of the model. Here, the external finance premium is influenced by the two net worth ratios through the three terms: (i) the ratio of total debt to aggregate capital, (ii) the share of profit in the IF contract going to the investors, and (iii) the share of profit in the FE contract going to the FIs. The term (1) expresses the capital investment leverage from the viewpoint of the household. Since the IF contracts and the FE contracts are chained, the household requires a higher return if either of the two net worth ratios is small. Consequently, the two net worth ratios work identically in this term. Terms (2) and (3) are the non-linear function of the two net worth ratios. A small net worth ratio of borrowers in either of the contracts is associated with a higher expected default probability, since it raises the leverage of the corresponding contracts. Given the presence of the participation constraint, this implies a larger lenders' share and the external finance premium.

It is notable that the financial intermediation and subsequent capital investment are not accomplished if either of the two contracts fails to hold. From the FIs' perspective, this implies that the two credit contracts are complements. Consequently, as shown numerically in HSU (2009), the external finance premium is disproportionately influenced by the smaller of the two net worth ratios. While both of the net worth ratios are negatively related to the external finance premium, the quantitative role of each net worth ratio is distinct from the other, depending on its relative size.

2.1.2 The Two Borrowing Rates and the Three Spreads

The borrowing rates that are charged to entrepreneurs and the FIs are determined according to the two contracts. The entrepreneurial borrowing rate, denoted by $Z^E\left(s^{t+1}|s^t\right)$, is the contractual interest rate that the non-defaulting entrepreneurs repay to the FIs:

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

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

$$\mathrm{E}_t\left[Z^{FI}\left(s^{t+1}|s^t\right)\right] \equiv \mathrm{E}_t\left[\frac{\overline{\omega}^{FI}\left(s^{t+1}|s^t\right) \Phi^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right) R^E\left(s^{t+1}|s^t\right) Q(s^t)K(s^t)}{Q(s^t)K(s^t) - N^{FI}(s^t) - N^E(s^t)}\right]. \tag{5}$$

Since our model consists of the FIs mediating between the investors and the entrepreneurs, a difference between the borrowing rate charged to the ultimate borrowers and the lending rate applied to the ultimate lender $\mathrm{E}_t\left[Z^E\left(s^{t+1}|s^t\right)\right] - R(s^t)$[6] is decomposed into the two components. In what follows, we call $\mathrm{E}_t\left[Z^E\left(s^{t+1}|s^t\right)\right] - R(s^t)$ the entrepreneurial borrowing spread and call its two components, $\mathrm{E}_t\left[Z^E\left(s^{t+1}|s^t\right)\right] - \mathrm{E}_t\left[Z^{FI}\left(s^{t+1}|s^t\right)\right]$ and $\mathrm{E}_t\left[Z^{FI}\left(s^{t+1}|s^t\right)\right] - R(s^t)$, the FIs' lending spread and the FIs' borrowing spread, respectively.

2.1.3 Dynamic Behavior of Net Worth

The FIs and the entrepreneurs accumulate their net worth using the earnings from the credit contracts. In addition, both FIs and entrepreneurs receive labor income $W^{FI}(s^t)$ and $W^E(s^t)$ by inelastically

[6]Among our three spreads, the spread $\mathrm{E}_t\left[Z^E\left(s^{t+1}|s^t\right)\right] - R(s^t)$ is the closest spread to the one discussed by Cúrdia and Woodford (2010b).

supplying a unit of labor to final goods producers. Assuming that each FI and entrepreneur survives to the next period with a constant probability γ^{FI} and γ^{E}, then the aggregate net worths of FIs and entrepreneurs evolve according to

$$N^{FI}\left(s^{t+1}\right) = \gamma^{FI} V^{FI}(s^t) + W^{FI}(s^t) + \varepsilon^{N^{FI}}(s^t), \tag{6}$$

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

where

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

Here, $\varepsilon^{N^{FI}}(s^t)$ and $\varepsilon^{N^{E}}(s^t)$ are the unexpected exogenous changes in the net worth that reflect an "asset bubble" or "irrational exuberance" in the borrowing sectors.[7] Their innovations are i.i.d. and normally distributed with mean zero and variances $\sigma^2_{N^{FI}}$ and $\sigma^2_{N^{E}}$, respectively. The FIs and entrepreneurs that fail to survive period t consume $\left(1-\gamma^{FI}\right)V^{FI}(s^t)$ and $\left(1-\gamma^{E}\right)V^{E}(s^t)$, respectively.

2.2 The Rest of the Economy

2.2.1 Household

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

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

subject to

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

[7]See Christiano, Motto, and Rostagno (2008) for an interpretation of net worth shocks.

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 $D\left(s^{t-1}\right)$ between time $t-1$ and t, $\Pi(s^t)$ 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 rate, the elasticity of leisure, and the utility weight on leisure, respectively. $e^B(s^t)$ is a preference shock with mean zero that provides a stochastic variation in the discount rate.

2.2.2 Final Goods Producer

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

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

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

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

2.2.3 Retail Goods Producers

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

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

where $y(h,s^t)$ for $h \in [0,1]$ are the wholesale goods used for producing the retail goods $Y(h,s^t)$ by the retail goods producers $h \in [0,1]$. The retail goods producers are price takers in the input market and choose their inputs, taking the input price $1/X(s^t)$ as given. 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:

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

Retailers are subject to nominal rigidity. They can change prices in a given period only with probability $(1-\xi)$, following Calvo (1983). The retail goods producers 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 retail goods producers by $P^{*}\left(h,s^{t}\right)$ and the demand curve the active retail goods producers 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 as follows:

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

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

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

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

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

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

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

2.2.4 Wholesale Goods Producers

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

$$\begin{aligned}\max_{y(s^t),K(s^{t-1}),H(s^t),H^{FI}(s^t),H^E(s^t)} & \frac{1}{X(s^t)} y(s^t) + Q(s^t)K\left(s^{t-1}\right)(1-\delta) \\ & - R^E(s^t)Q\left(s^{t-1}\right)K\left(s^{t-1}\right) - W(s^t)H(s^t) \\ & - W^{FI}(s^t)H^{FI}(s^t) - W^E(s^t)H^E(s^t),\end{aligned}$$

subject to

$$\begin{aligned} y(s^t) = {} & A\exp\left(e^A(s^t)\right) K\left(s^{t-1}\right)^{\alpha} H(s^t)^{(1-\Omega_F-\Omega_E)(1-\alpha)} \\ & \times H^{FI}(s^t)^{\Omega_{FI}(1-\alpha)} H^E(s^t)^{\Omega_E(1-\alpha)}, \quad (12)\end{aligned}$$

where $A\exp\left(e^A(s^t)\right)$ denotes the level of technology of wholesale production and $\delta \in (0,1]$, α, Ω_{FI}, 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.

2.2.5 Capital Goods Producers

The capital goods producers own the technology that converts final goods to capital goods. In each period, they purchase $I(s^t)$ 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 $Q(s^t)$. They then produce new capital goods $K(s^t), t$ using the technology F_I, and sell them in the competitive market at price $Q(s^t)$. Consequently, the capital goods producer's problem is to maximize the following profit function:

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

subject to

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

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 a shock to the adjustment cost.[8]

2.2.6 Government

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

$$G(s^t)=T(s^t). \tag{15}$$

[8]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 $\overline{Q}(s^t)$, is close to the price of the newly produced capital $Q(s^t)$ around the steady state.

2.2.7 Central Bank

The central bank sets the nominal interest rate $R^n(s^t)$ according to a standard Taylor rule

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

where $\overline{Y}(s^t)$ is the flexible-price equilibrium level of output, ϕ_π and ϕ_y are the policy weight on inflation rate $\pi(s^t)$ and the output gap $\left(\frac{Y(s^t)}{\overline{Y}(s^t)}\right)$, and $e^R(s^t)$ is the shock to the policy rule.[9] Note that while the nominal interest rate $R^n(s^t)$ is determined by the central bank, the real interest rate $R(s^t)$ is given by the following Fisher equation:

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

2.2.8 Resource Constraint

The resource constraint of the final goods is written as

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

where $e^G(s^t)$ is a shock to the government expenditure. Note that the fourth and fifth terms on the right-hand side of this equation represent the monitoring costs incurred by the FIs and investors, respectively. The last two terms are the final goods consumed by the FIs and entrepreneurs, respectively.

[9]Similarly to Cúrdia and Woodford (2010b), the flexible-price equilibrium stands for the equilibrium in the economy where all prices are flexible and the distortion associated with credit market imperfections is present. Consequently, the output gap equals zero at the steady state.

2.2.9 Exogenous Shocks

In addition to the four macroeconomic shocks described above, the economy consists of four financial shocks. Closely following Christiano, Motto, and Rostagno (2008), we consider two kinds of shocks that occur among the credit market participants. The first shocks are once-and-for-all innovations to the FIs' and entrepreneurial net worth, $\varepsilon^{N^{FI}}(s^t)$ and $\varepsilon^{N^E}(s^t)$, as exhibited in equations (6) and (7).[10] The second shocks are associated with the idiosyncratic productivities $\omega^{FI}(s^t)$ and $\omega^E(s^t)$. We assume that $\log\omega^{FI}(s^t)$ and $\log\omega^E(s^t)$ are normally distributed with zero mean and the standard deviation of σ^{FI} and σ^E.

The dynamics of the macroeconomic shocks are given by

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

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

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

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

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

where ρ_A, ρ_I, ρ_B, ρ_G, and $\rho_R \in (0,1)$ are autoregressive roots of the exogenous variables, and $\varepsilon^A(s^t)$, $\varepsilon^I(s^t)$, $\varepsilon^B(s^t)$, $\varepsilon^G(s^t)$, and $\varepsilon^R(s^t)$ are innovations that are i.i.d. and normally distributed with mean zero and variances σ_A^2, σ_I^2, σ_B^2, σ_G^2, and σ_R^2.

2.3 Equilibrium Condition

An equilibrium consists of a set of prices, $\{P\left(h, s^t\right)$ for $h \in [0,1]$, $P(s^t)$, $X(s^t)$, $R(s^t)$, $R^E(s^t), W(s^t)$, $W^{FI}(s^t)$, $W^E(s^t)$, $Q(s^t)$, $R^E\left(s^{t+1}|s^t\right)$, $Z^{FI}\left(s^{t+1}|s^t\right)$, $Z^E\left(s^{t+1}|s^t\right)\}_{t=0}^{\infty}$, and the allocations $\{\overline{\omega}_i^{FI}\left(s^{t+1}|s^t\right)\}_{t=0}^{\infty}$, $\{\overline{\omega}_{j_i}^{E}\left(s^{t+1}|s^t\right)\}_{t=0}^{\infty}$, $\{N_i^{FI}(s^t)\}_{t=0}^{\infty}$, $\{N_{j_i}^{E}(s^t)\}_{t=0}^{\infty}$, $\{y(h, s^t)$, $Y(h, s^t)$ for $h \in [0,1]$, $Y(s^t)$, $C(s^t)$, $D(s^t)$, $I(s^t)$, $K(s^t)$,

[10]Our setting about the net worth shocks is similar to the specification employed in Gilchrist and Leahy (2002). By contrast, Christiano, Motto, and Rostagno (2008) and Nolan and Thoenissen (2009) incorporate the net worth shocks by assuming that the exit ratio of entrepreneurs γ^E fluctuates exogenously and leads to an unexpected change in the entrepreneurial net worth.

$H(s^t)\}_{t=0}^{\infty}$, for a given government policy $\{R^n(s^t), G(s^t), T(s^t)\}_{t=0}^{\infty}$, realization of exogenous variables $\{\varepsilon^A(s^t), \varepsilon^I(s^t), \varepsilon^B(s^t), \varepsilon^G(s^t), \varepsilon^R(s^t), \varepsilon^{N^{FI}}(s^t), \varepsilon^{N^E}(s^t)\}_{t=0}^{\infty}$ and initial conditions N_{-1}^{FI}, N_{-1}^{E}, K_{-1} such that for all t and h (i) a household maximizes its utility given the prices, (ii) the FIs maximize their profits given the prices, (iii) the entrepreneurs maximize their profits given the prices, (iv) the final goods producers maximize their profits given the prices, (v) the retail goods producers maximize their profits given the input prices, (vi) the wholesale goods producers maximize their profits given the prices, (vii) the capital goods producers maximize their profit given the prices, (viii) the government budget constraint holds, and (ix) markets clear.

3. Equilibrium Response to Disturbances

Before investigating the role of the spread-adjusted Taylor rules and capital injection policies, we explore how the present model behaves under the standard Taylor rule. To do the numerical simulations, we borrow the parameter values and sizes of shocks from HSU (2011) so that they are consistent with the U.S. data. See appendix 3 for details. In simulating the model, we first calculate the non-stochastic steady state where the inflation rate is zero and all of the endogenous variables remain constant. We then compute the approximated time path of the endogenous variables in response to each of the disturbances listed in section 2.2, by log-linearizing the model's equilibrium conditions around the non-stochastic steady state.

3.1 Baseline Simulation

We analyze the following six types of adverse shocks: (i) a disruption of net worth in the FI sector, (ii) a disruption of net worth in the entrepreneurial sector, (iii) an increase in the household's discount rate, (iv) a rise in the monetary policy rate, (v) a fall in productivity (total factor productivity [TFP]) of the wholesale-goods-producing sector, and (vi) an increase in the investment adjustment cost for the capital-goods-producing sector.

The first two shocks hit the credit market participants in the first place. These shocks touch neither the household's demand nor the production technologies, but instead are propagated to the macroeconomy through the movements in the borrowing spreads stemming from the credit market imperfection. By contrast, the last four shocks are macroeconomic shocks that have been regularly studied in the literature. Shocks (iii) and (iv) are shocks that influence the household's decision (hereafter referred to as demand shocks) and shocks (v) and (vi) are shocks to the production technologies (hereafter referred to as supply shocks).

3.1.1 Shocks to the Credit Market Participants

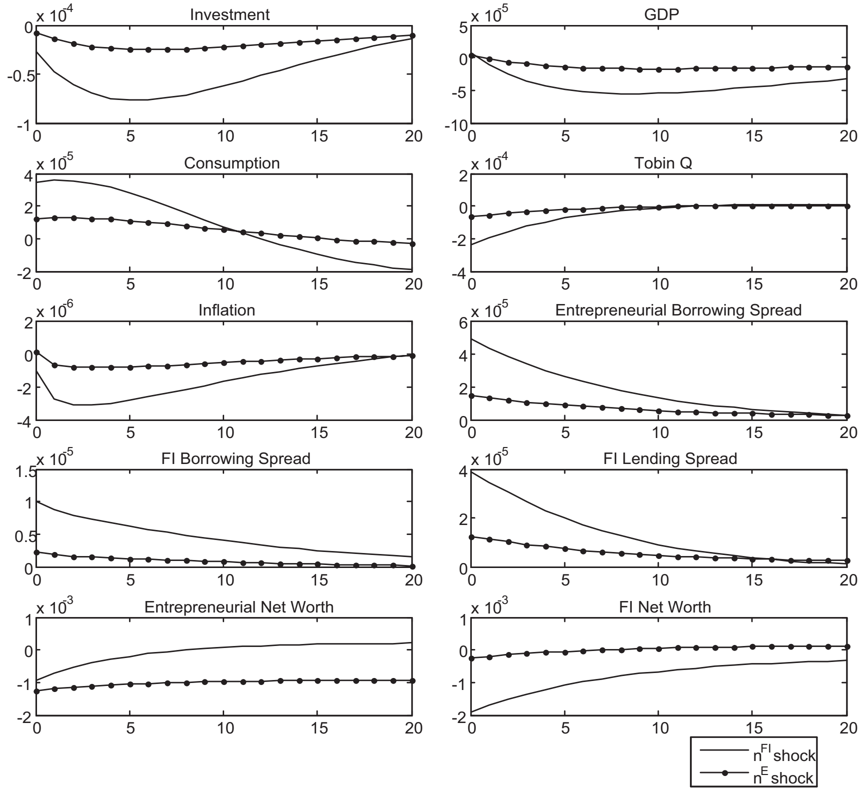
Figure 1 displays the response of key variables, investment $I(s^t)$, GDP $Y(s^t)$, consumption $C(s^t)$, Tobin's Q $Q(s^t)$, inflation $\pi(s^t)$, the entrepreneurial borrowing spread $\mathrm{E}_t\left[Z^E\left(s^{t+1}|s^t\right)\right] - R(s^t)$, the FIs' borrowing spread $\mathrm{E}_t\left[Z^{FI}\left(s^{t+1}|s^t\right)\right] - R(s^t)$, the FIs' lending spread $\mathrm{E}_t\left[Z^E\left(s^{t+1}|s^t\right)\right] - \mathrm{E}_t\left[Z^{FI}\left(s^{t+1}|s^t\right)\right]$, entrepreneurial net worth $N^E(s^t)$, and FIs' net worth $N^{FI}(s^t)$, to shocks to the credit market participants.

Those adverse shocks lead to the macroeconomic downturn through the widening of the credit spread stemming from credit market imperfection. A disruption of the net worth increases the external finance premium, as it implies higher leverage for each credit contract as well as for capital investment (the first term of equation (1)). Reflecting the increase in $R^E\left(s^{t+1}|s^t\right)$, the borrowing rates (4) and (5) also rise. Once the external finance premium increases, the wholesale goods producers employ fewer capital inputs, resulting in a drop in Tobin's Q. As shown in equations (6) and (7), a lower $Q(s^t)$ retards net worth accumulation in the two borrowing sectors, further widening the external finance premium according to equation (1).

The figures show that since the IF contracts and the FE contracts are chained and the two contracts work complementarily, the adverse shock that hits either of the two borrowing sectors results in the deterioration of the net worth of both sectors, leading to a macroeconomic downturn.[11]

[11] Admittedly, unconditional co-movement between investment and consumption is a key feature of the U.S. business cycles. Although HSU (2011) provide empirical support for the chained credit contracts and net worth shocks to the FIs, the model does not display the co-movement in response to the net worth shock. See Christiano, Motto, and Rostagno (2009) for a related discussion.

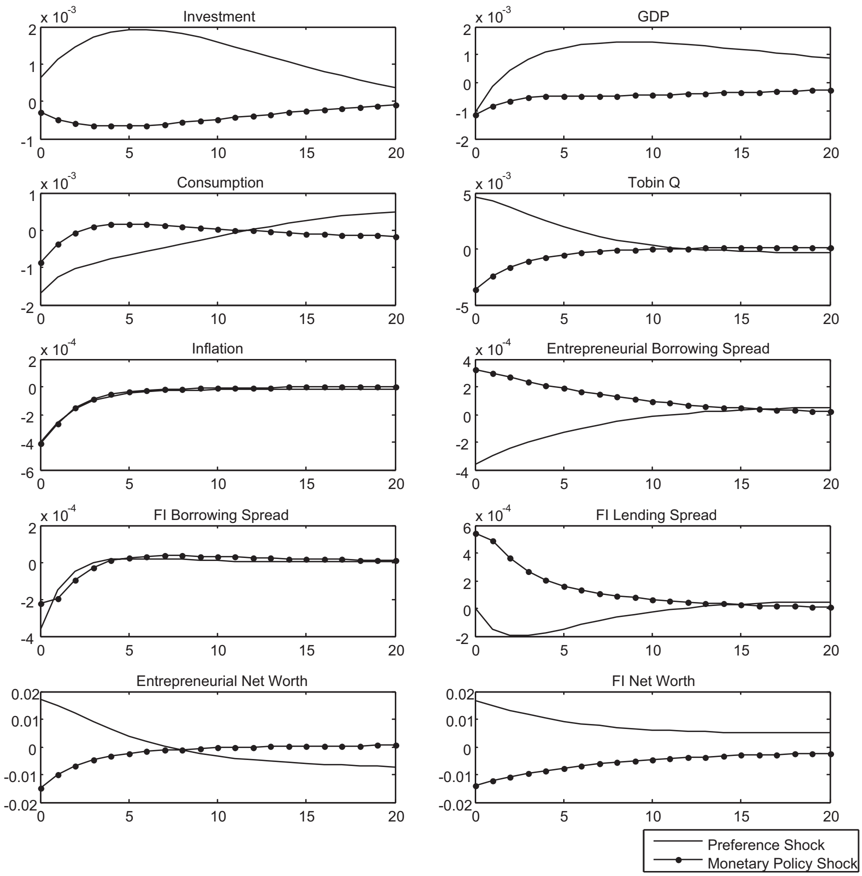
Figure 1. The Impulse Response of the Key Variables in Response to Negative Net Worth Shocks under the Standard Taylor Rule



3.1.2 Demand Shocks

Figure 2 displays the economic responses to the demand shocks. Both of the riskiness shocks and net worth shocks bring about the output decline and deflation with the impact, but they have opposite implications for the spread dynamics. On the one hand, when the discount rate rises, the household postpones consumption, increasing its saving. As a result, contemporaneous consumption and output fall, and investment increases. Tobin's Q rises, reflecting the increase in demand for capital goods, promoting the net worth accumulation, and reducing the three spreads.

Figure 2. The Impulse Response of the Key Variables in Response to a Positive Discount Rate Shock and a Contractionary Monetary Policy Shock under the Standard Taylor Rule



On the other hand, when the contractionary monetary policy shock occurs, the real interest rate surges, since the price responses are sluggish relative to the rise in the nominal interest rate. The high real interest rate makes investment costly. Tobin's Q declines as the demand for capital goods weakens, causing a deterioration in the net worth of the borrowing sectors. The entrepreneurial borrowing spread and the FIs' lending spread are widened by the shock.

Because the real interest rate rises by a greater amount than the FIs' borrowing rate, the FIs' borrowing spread shrinks.

3.1.3 Supply Shocks

While both the technology shock and investment adjustment cost shock reduce the investment and output in a similar manner, their impacts on the other variables differ substantially (figure 3). The lower technology causes a high marginal cost of producing goods, reducing the final goods production. As the demand for capital goods is weakened, Tobin's Q and net worth decline, resulting in a widening of the three spreads and a fall in investment. As the goods production becomes costly, consumption falls and inflation rises.[12]

By contrast, in response to the adverse investment adjustment cost shock, Tobin's Q increases, since the cost of producing capital goods from the final goods goes up. The demand for capital drops, and households move away from saving to consumption. Although the increase in Tobin's Q helps accumulate the net worth and improve the credit conditions of the borrowing sectors, these effects are weaker compared with the first channel, leading to an economic downturn.

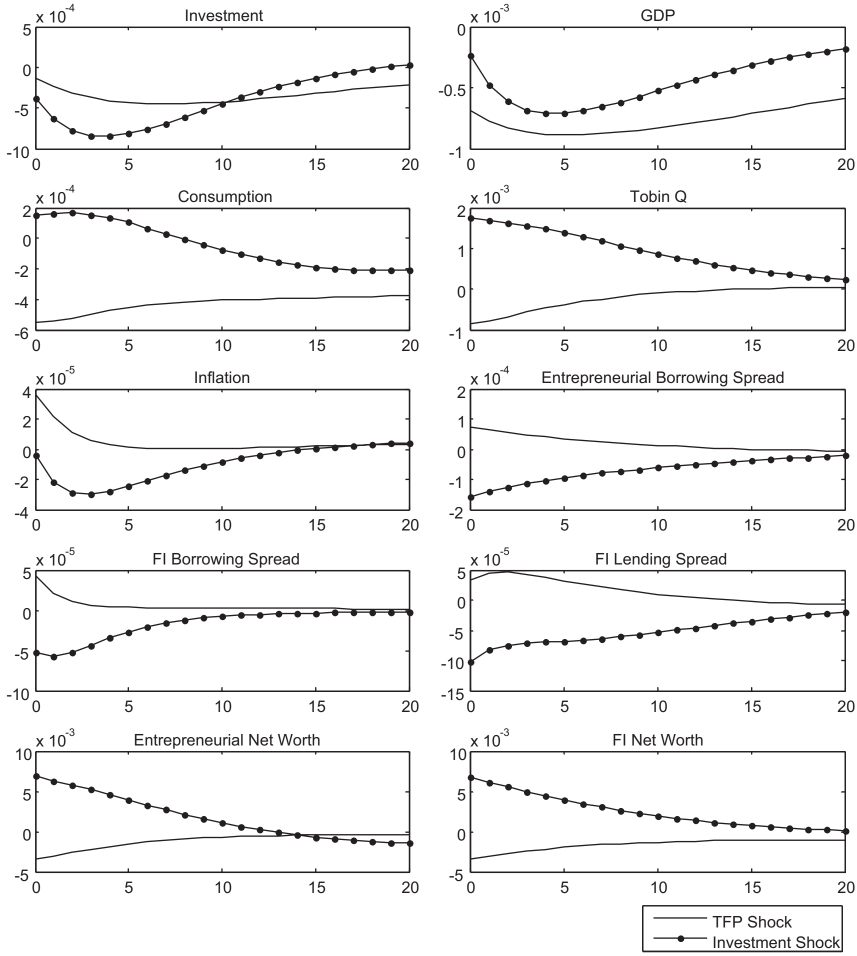
4. Policy Analysis

In considering the role of the spread-adjusted Taylor rules and capital injection policies, we begin by specifying these policies in detail. Since the model comprises the three spreads (the entrepreneurial borrowing spread and its components, the FIs' lending spread, and the FIs' borrowing spread) and the two net worths (the FIs' and entrepreneurial net worth), we study three classes of the spread-adjusted Taylor rule and two classes of the capital injection policy.

To grasp their implications for the macroeconomy, we compute how economic responses to a disturbance are altered when the central bank or government pursues either of these policies. We then ask whether these policies outperform the standard Taylor rule from the perspective of social welfare.

[12] This result contrasts with that of Cúrdia and Woodford (2010b). In their model, lower productivity causes lending volume to decrease, leading to a smaller spread.

Figure 3. The Impulse Response of the Key Variables in Response to a Negative Technology Shock and Positive Investment Adjustment Shock under the Standard Taylor Rule



4.1 Spread-Adjusted Taylor Rule

Following Cúrdia and Woodford (2010b), we define a spread-adjusted Taylor rule as a monetary policy rule that lowers the intercept of the standard Taylor rule by responding to a widening of the credit spread. Under this class of policy, a widening (shrinking) of the spread is systematically met by a cut (rise) in the interest rate, yielding an expansionary (contractionary) effect on the economy.

Since there are three spreads in the economy, the central bank is able to implement the following three types of spread-adjusted Taylor rules:

$$\text{Policy II: } \log R^n(s^t) = \left\{ \begin{array}{c} \phi_\pi \log \pi(s^t) + \phi_y \log\left(\frac{Y(s^t)}{Y^f(s^t)}\right) \\ -\phi_{II} \log\left(\frac{(\mathrm{E}_t\left[Z^E\left(s^{t+1}|s^t\right)\right] - R(s^t))}{\mathrm{E}[Z^E] - R}\right) \end{array} \right\}, \tag{24}$$

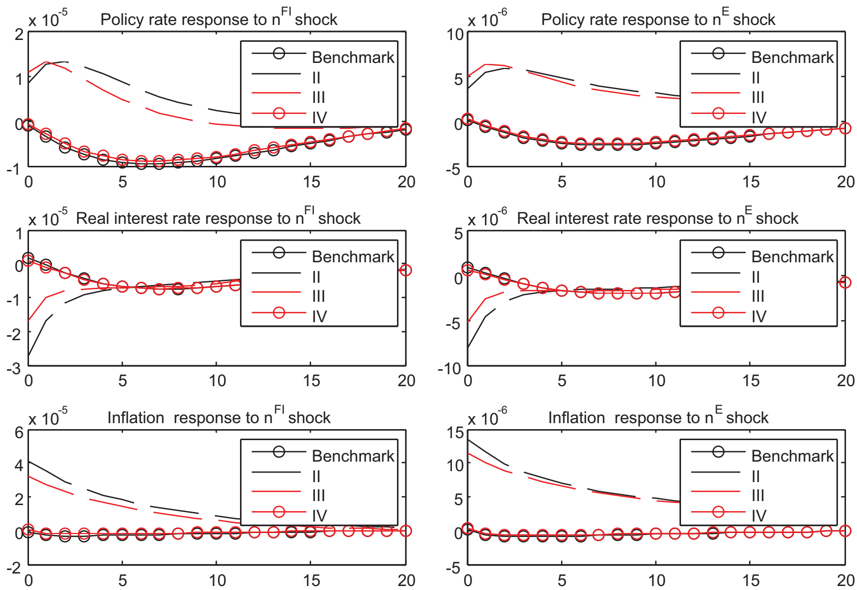
$$\text{Policy III: } \log R^n(s^t) = \left\{ \begin{array}{c} \phi_\pi \log \pi(s^t) + \phi_y \log\left(\frac{Y(s^t)}{Y^f(s^t)}\right) \\ -\phi_{III} \log\left(\frac{\mathrm{E}_t\left[Z^E(s^{t+1}|s^t)\right] - \mathrm{E}_t\left[Z^{FI}(s^{t+1})|s^t\right]}{\mathrm{E}[Z^E] - \mathrm{E}[Z^{FI}]}\right) \end{array} \right\}, \tag{25}$$

$$\text{Policy IV: } \log R^n(s^t) = \left\{ \begin{array}{c} \phi_\pi \log \pi(s^t) + \phi_y \log\left(\frac{Y(s^t)}{Y^f(s^t)}\right) \\ -\phi_{IV} \log\left(\frac{\mathrm{E}_t\left[Z^{FI}\left(s^{t+1}|s^t\right)\right] - R(s^t)}{\mathrm{E}[Z^{FI}] - R}\right) \end{array} \right\}, \tag{26}$$

where $\mathrm{E}\left[Z^E\right] - R$, $\mathrm{E}\left[Z^E\right] - \mathrm{E}\left[Z^{FI}\right]$, and $\mathrm{E}\left[Z^{FI}\right] - R$ are the steady-state values of each spread and non-negative coefficients ϕ_{II}, ϕ_{III}, and ϕ_{IV} are policy weights attached to the specific spreads.[13] Notice that policy II targets the entrepreneurial borrowing spread and attaches a non-zero weight only to ϕ_{II}, and policy III targets the FIs' lending spread and attaches a non-zero weight only to ϕ_{III}. Similarly, policy IV targets the FIs' borrowing spread and attaches a non-zero weight only to ϕ_{IV}.

[13] It is notable from equations (24), (25), and (26) that the central bank targets the deviation of the spread from its steady-state value rather than the level of the spread. Since the steady-state values of spreads are determined by the factors that are independent of monetary policy, such as monitoring technology and the variance of borrowers' idiosyncratic shocks, we focus our attention on the endogenous deviation of the spread from its steady state. See Cúrdia and Woodford (2010b) for a related discussion.

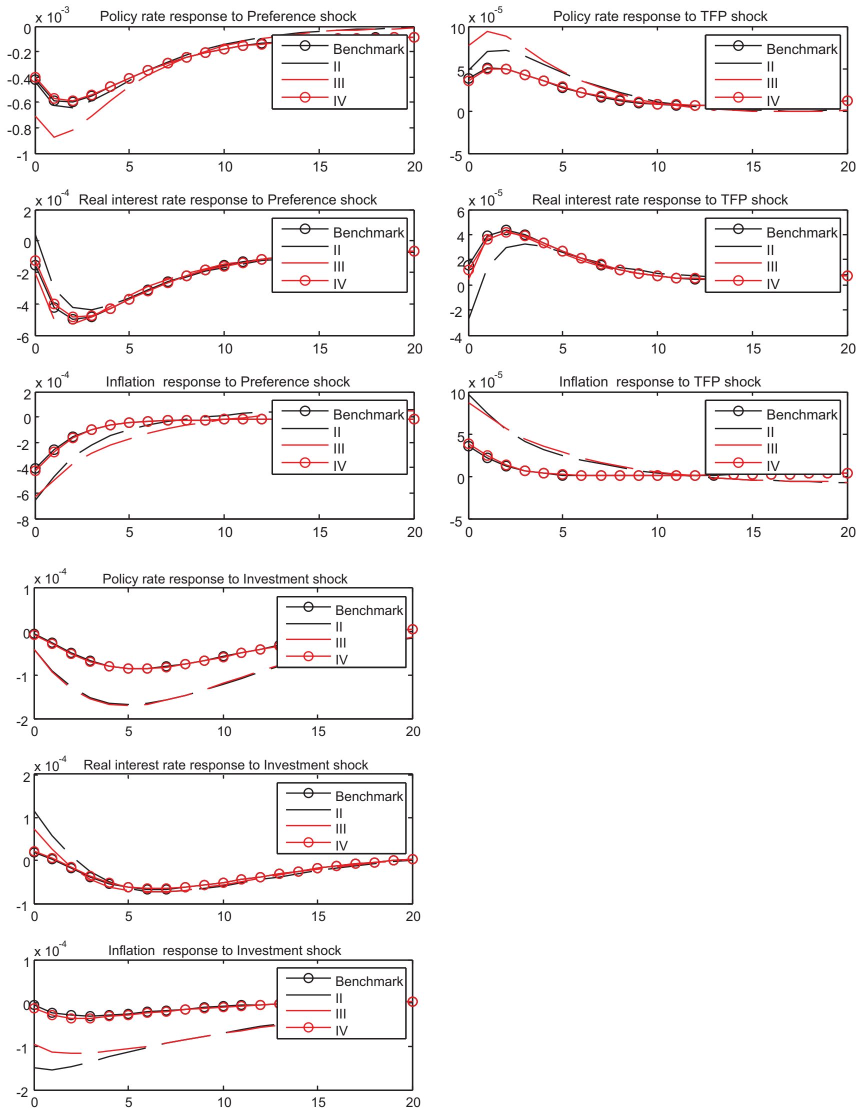
Figure 4. The Impulse Response of Policy Rates, Real Interest Rates, and Inflation to the Net Worth Shocks under Four Types of Monetary Policy Rule



Figures 4 and 5 demonstrate how the central bank under different policy rules reacts to shocks. To illustrate the difference between policies, we choose the standard Taylor rule given by equation (16) as our benchmark. In the quantitative simulation, we first search for weights attached to inflation and output gap, ϕ_π and ϕ_y, in the rule that gives the highest unconditional welfare of households. Here, we maintain the autoregressive parameter of the policy rule θ as 0.77. Based on the grid search by 0.01 unit for a range from 0.01 to 4.0, we find that a set $\{\phi_\pi = 4.0,\ \phi_y = 0.01\}$ is optimal under the economy where all shocks are present.[14] In implementing the simulation for the spread-adjusted Taylor rule, we set ϕ_{II}, ϕ_{III}, or ϕ_{IV} equal to 0.4 under each of the three policy rules, keeping the parameters

[14]Schmitt-Grohe and Uribe (2007) report $\phi_\pi = 3.0$ and $\phi_y = 0.01$ with $\theta = 0.84$ as the optimal policy rule parameters, where $\phi_\pi = 3.0$ is the largest value in their grid.

Figure 5. The Impulse Response of Policy Rates, Real Interest Rates, and Inflation to the Macroeconomic Shocks under Four Types of Monetary Policy Rule



for output gap and inflation the same as those under the benchmark simulation. We set a value, 0.4, which is sufficiently larger than zero, for the policy weight attached to the credit spread, to highlight how economic dynamics are altered when monetary policy rule changes from the standard Taylor rule to the spread-adjusted Taylor rule. In addition, we avoid choosing extremely large values, since, as we will explain below, the spread-adjusted Taylor rule with such a policy weight may lead to indeterminacy.

Other things being equal, a widening (shrinking) of credit spread causes a greater cut of the policy rate under the spread-adjusted Taylor rule than the benchmark, reducing (raising) the real interest rate more. As we see above, in response to an adverse FIs' net worth shock, for example, both the FIs' borrowing spread and the FIs' lending spread widen. If policy II is undertaken, the policy rate is lowered as the entrepreneurial borrowing spread increases. By contrast, if the standard Taylor rule is undertaken, the policy rate is irresponsive to the spread. Consequently, the decline of the real interest rate is larger under policy II than under the benchmark policy, and the deflationary pressure on the economy is mitigated more by policy II than by the benchmark policy.

When an adverse investment shock hits the economy, the real interest rate under policy II ascends more than that under the benchmark. As shown in figure 2, this type of adverse shock shrinks the spreads rather than widens them. When the spread-adjusted Taylor rules are undertaken, they lead to a further tightening of the policy rate, lowering the inflation rate more than the benchmark.

4.2 Capital Injection Policies

In contrast to the spread-adjusted Taylor rules, capital injection policies are formalized as a fiscal policy that involves a taxation of the household sector and a simultaneous transfer to either the FI sector or the entrepreneurial sector in the wake of a shock $\varepsilon^{\xi}\left(s^{t_0}\right)$ for $\xi = A, I, B, G, \sigma^E, \sigma^{FI}, N^{FI}$, and N^E, at period t_0.

Let $\left\{\tau\left(s^t|\varepsilon^{\xi}\left(s^{t_0}\right)\right)\right\}_{t=t_0}^{\infty}$ be the sequence of lump-sum tax revenue from the household conditional on a realization of a shock $\varepsilon^{\xi}\left(s^{t_0}\right)$. In addition, let $\left\{v^{FI}\left(s^t|\varepsilon^{\xi}\left(s^{t_0}\right)\right)\right\}_{t=t_0}^{\infty}$ and $\left\{v^{E}\left(s^t|\varepsilon^{\xi}\left(s^{t_0}\right)\right)\right\}_{t=t_0}^{\infty}$ be the sequence of final goods that is injected by the government to the FI sector and the entrepreneurial sector, respectively, conditional on the realization of the disturbance $\varepsilon^{\xi}(s^{t_0})$. Here, the capital injection into the FI sector (hereafter CIFN) can be defined as a set of lump-sum taxation $\tau\left(s^t|\varepsilon^{\xi}(s^{t_0})\right)$ and the equal size of injection $v^{FI}\left(s^t|\varepsilon^{\xi}(s^{t_0})\right)$ that satisfy $v^{FI}\left(s^t|\varepsilon^{\xi}(s^{t_0})\right) = \tau\left(s^t|\varepsilon^{\xi}(s^{t_0})\right)$ for $t \geq t_0$. Under CIFN, when $t = t_0$, for example, the net worth accumulation of the FI sector (6) is modified to

$$N^{FI}\left(s^{t_0}|\varepsilon^{\xi}\left(s^{t_0}\right)\right) = \gamma^{FI}V^{FI}\left(s^{t_0-1}\right) + W^{FI}\left(s^{t_0}|\varepsilon^{\xi}\left(s^{t_0}\right)\right) + \varepsilon^{N^{FI}}\left(s^t\right) + v^{FI}\left(s^{t_0}|\varepsilon^{\xi}\left(s^{t_0}\right)\right). \quad (27)$$

We define capital injection to the entrepreneurial sector (hereafter CIEN) in a similar way.

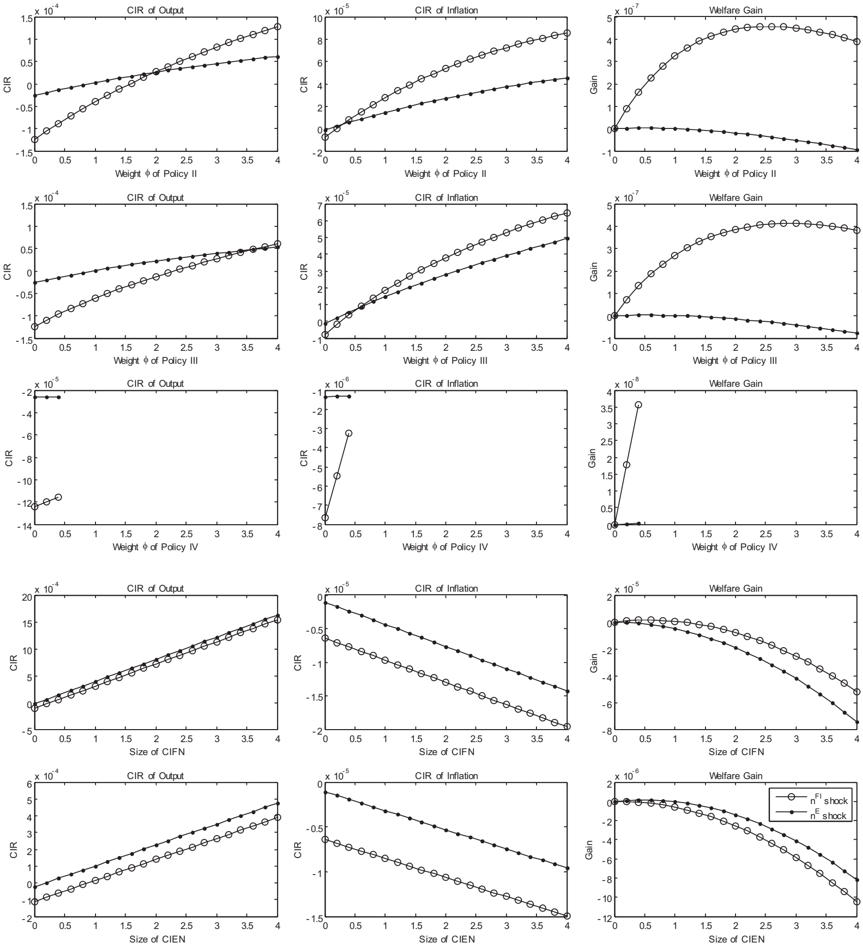
In the simulation exercises below, we assume that a positive (negative) final goods transfer by the government from the household to the FIs or entrepreneurs is undertaken whenever an adverse shock (good shock) is realized in the economy.[15] In addition, to simplify the analysis further, we focus on the case where $\left\{v^{FI}\left(s^t|\varepsilon^{\xi}(s^{t_0})\right)\right\}_{t=1+t_0}^{\infty}$ or $\left\{v^{E}\left(s^t|\varepsilon^{\xi}(s^{t_0})\right)\right\}_{t=1+t_0}^{\infty}$ is equalized to zero, so that the capital injection policy is a one-shot transfer that is implemented when the shock arrives, and so that no further transfer is conducted thereafter.

4.3 Quantititative Results

Figures 6–8 summarize the implication of the three spread-adjusted Taylor rules and the two capital injection policies to the macroeconomic dynamics and welfare when each of the eight exogenous shocks analyzed in section 3.1 occurs. Each figure comprises five rows and three columns. The panels in each row report the simulation outcomes under each of the five policies. The first and second columns display the two-year, cumulated sum of the impulse response of output and inflation after an adverse shock. The third column displays the second-order relative welfare loss, which is defined as the second-order change in the household's welfare (8) under each of the five

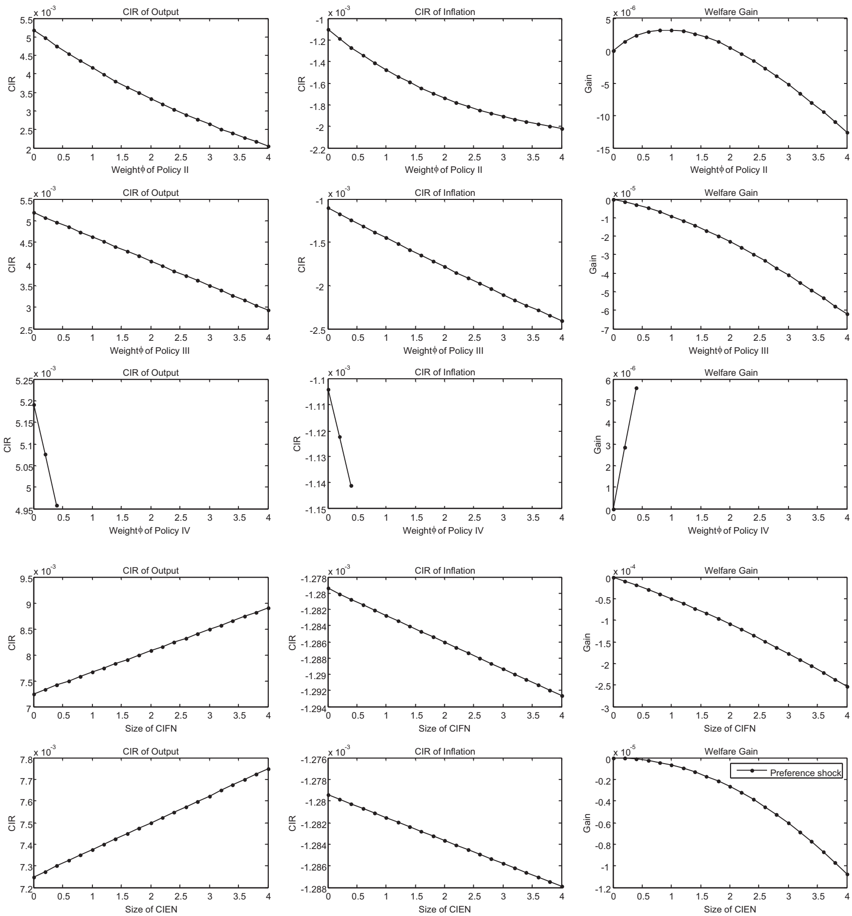
[15] As shown above, all shocks studied in section 3.1 deliver the short-run economic downturn. We therefore consider a transfer of household to the FIs or entrepreneurs in response to either of these shocks and a transfer in the reverse direction in response to a shock with an opposite sign. Our capital injection policy therefore acts countercyclically to a shock.

Figure 6. The Two-Year-Cumulative Sum of the Impulse Response (CIR) of Output and Inflation and Welfare Loss in Response to the Net Worth Shocks



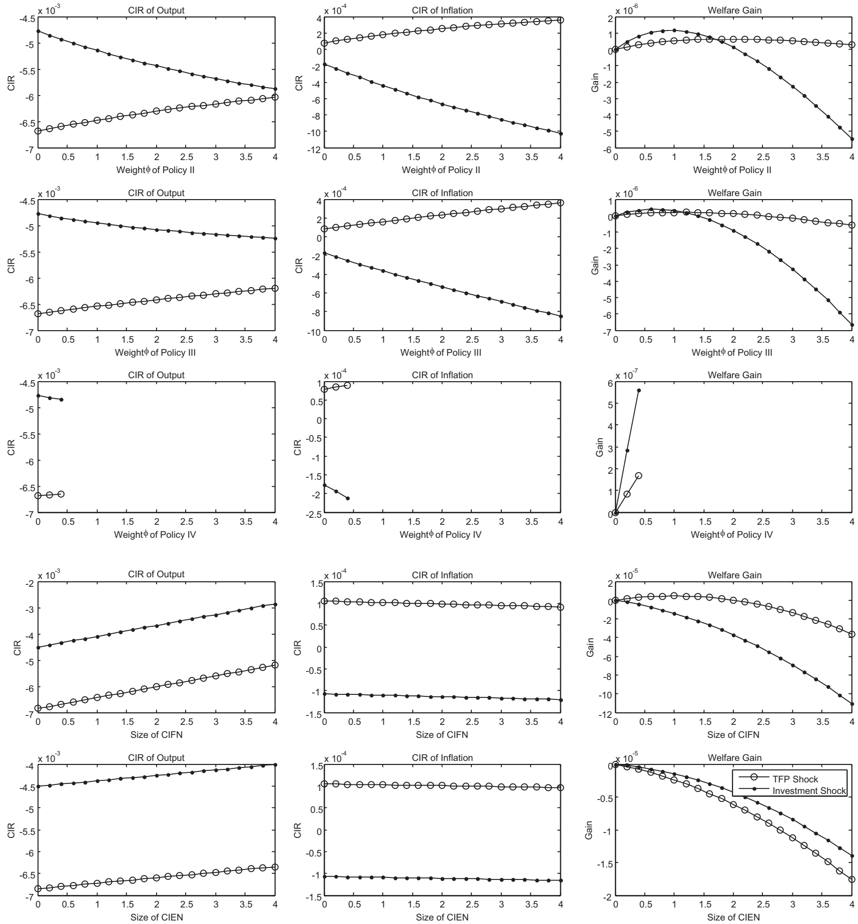
Notes: The first two columns display CIR in response to the FIs' net worth shock (line with white circle) and the entrepreneurial net worth shock (line with black circle). The third column displays the welfare loss relative to the standard Taylor rule.

Figure 7. The Two-Year-Cumulative Sum of the Impulse Response (CIR) of Output and Inflation and Welfare Loss in Response to the Discount Rate Shock



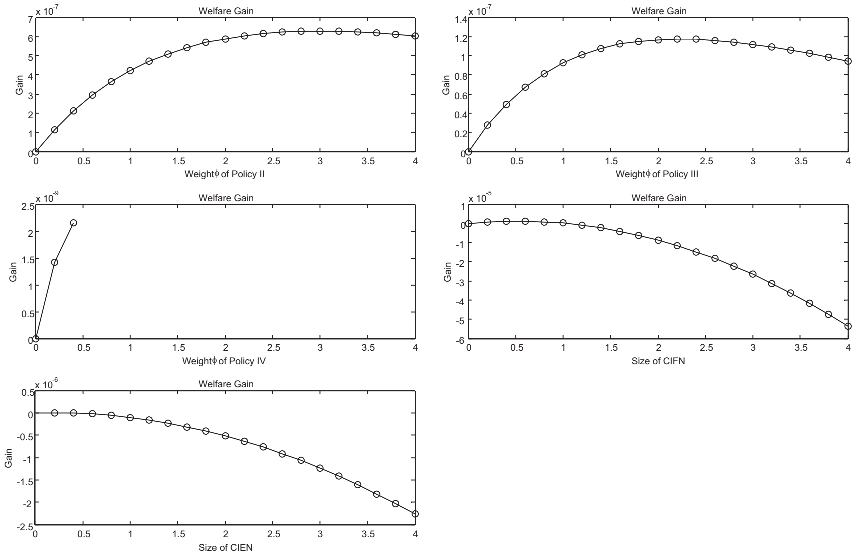
Notes: The first two columns display CIR in response to the discount rate shock. The third column displays the welfare loss relative to the standard Taylor rule.

Figure 8. The Two-Year-Cumulative Sum of the Impulse Response (CIR) of Output and Inflation and Welfare Loss in Response to the Shocks to the Production Technologies



Notes: The first two columns display CIR in response to the TFP shock (line with white circle) and the investment shock (line with black circle). The third column displays the welfare loss relative to the standard Taylor rule.

Figure 9. The Two-Year-Cumulative Sum of the Impulse Response (CIR) of Unconditional Welfare Loss



policies subtracted by that under the standard Taylor rule.[16] The x-axis depicts the size of policy weight attached to the spread for the spread-adjusted Taylor rule (the first three rows) and the size of capital injected for the capital injection policies (the last two rows). Notice that when the policy weight or the size of capital injection is zero, the policy is reduced to the basic Taylor rule.[17] In figure 9, we document the welfare implication of these policies when all shocks are present in the economy.

[16]To obtain the second-order response of welfare, we first derive the rational expectation solution of our model, up to the second order. Second, we give a once-and-for-all innovation to one of the eight disturbances in period 0, setting other innovations equal to zero, and calculate the second-order deviation of the welfare (8) from its steady-state level.

[17]The scale of the capital injection policies is 0.01 percent of the steady-state final goods output. The "4" in the x-axis, for example, indicates that final goods that amount to 0.04 percent of the steady-state output are injected into the borrowing sector. Compared with the size of public capital injections that were undertaken by the United States during the financial crisis (see, for example, Bank of Japan 2009), 0.04 percent of the output is small.

4.3.1 Spread-Adjusted Taylor Rules

The central bank's response to a spread under each of the three rules is dictated by the policy weight, ϕ_{II}, ϕ_{III}, and ϕ_{IV}. To illustrate the role of each policy, we study the equilibrium response of output, inflation, and welfare under a different size of policy weight.

The implication of a spread-adjusted Taylor rule depends on how the target spread reacts to shocks. Taking the entrepreneurial spread as an example, it widens in response to a disruption of net worth and a decline in TFP, and it shrinks in response to rises in the discount rate and investment adjustment cost. Consequently, under policy II, a higher weight of ϕ_{II} leads to an expansion in the first group of shocks and leads to a contraction in the second group of shocks.

Our simulation result also shows that a spread-adjusted Taylor rule may have an adverse effect in stabilizing the economy. Among the three spread-adjusted Taylor rules, policy IV falls into indeterminacy with a relatively small policy weight ϕ_{IV}. As suggested by figure 2, a cut in the nominal interest rate in response to a widening of the FIs' borrowing spread widens the FIs' borrowing spread further instead of diminishing it. Consequently, the equilibrium is not pinned down and destabilized.

From the welfare perspective, within the range of parameterization of policy weights considered here, the three spread-adjusted Taylor rules can outperform the standard Taylor rule for all of the shocks, provided that the policy weight is appropriately chosen. In particular, a small deviation from the standard Taylor rule yields an improvement in welfare. In response to the shocks associated with the widened spread, the spread-adjusted Taylor rules mitigate the output decline at the cost of inflation, improving the social welfare. In response to the discount rate shock and investment adjustment shock, the policies achieve an improvement in welfare by moderating the variations in consumption, although these policy outcomes diminish as the weights increase. When all of the shocks are present in the economy, as is shown in figure 9, there is a welfare gain in giving a positive weight for all three rules.[18] Because welfare consequence of policy weights to the economy depends on which group

[18] Only responses of welfare are shown in the figure, since all types of the shocks are generated simultaneously.

of shocks play the dominant role in the economy, the resemblance of this figure to those depicted under the FIs' net worth shocks and TFP shocks indicates that they are important source of fluctuations in the U.S. economy compared with preference shocks or investment adjustment cost shocks.

4.3.2 Capital Injection Policies

To illustrate the role of capital injection policies, we simulate the model under different sizes of transfer, $v^{FI}\left(s^{t_0}|\varepsilon^{\xi}\left(s^{t_0}\right)\right)$ or $v^{E}\left(s^{t_0}|\varepsilon^{\xi}\left(s^{t_0}\right)\right)$. The policy implication of the capital injection policies to the economy is straightforward. As a positive capital injection to the borrowing sector helps reduce the spreads charged to the borrowers, the cost of external finance decreases. Consequently, declines in investment and output are mitigated and the inflation rate rises. In all of the figures, the cumulative sum of both output and inflation increases monotonically with the size of capital injection.

As far as capital injections of equal size are concerned, the CIFN boosts the economic activity more than does the CIEN, regardless of the type of shock. Even when the source of the economic downturn originates from the entrepreneurial sector, the CIFN has a large impact. This finding is consistent with the results obtained in section 3.1.

From the welfare perspective, the two capital injection policies bring about a similar consequence. Unlike the spread-adjusted Taylor rules, the capital injection policies underperform the standard Taylor rule on a number of occasions. For example, the CIFN does worse than the standard Taylor rule after a discount rate shock and an investment adjustment cost shock, regardless of the size of capital injection. The same is true for the CIEN when a TFP shock or investment adjustment cost shock occurs. In addition, when the size of capital injection is sufficiently large, these policies yield higher inflation and output variations, aggravating the social welfare compared with the standard rule. It is notable that capital injection policy is a policy rule that acts as positive (negative) net worth shock in the economy whenever an adverse shock (favorable shock) is realized. As a result, it increases economic fluctuation in response to some shocks, causing the welfare loss of the economy. This effect becomes substantial if the size of injection becomes large. When all shocks prevail and CIFN is conducted for every shock, as shown in figure 9, unconditional welfare increases by injecting a moderate amount of capital to the FI sector and the entrepreneurial sector, reflecting the fact that CIFN and CIEN is welfare improving to some of the shocks.

5. Conclusion

We explore the implication of the spread-adjusted Taylor rules and the capital injection policies in an economy where FIs and entrepreneurs are credit constrained under credit market imperfection. Our model is based on HSU (2009, 2011), in which three spreads and two net worths are present in the economy: (i) a spread between the borrowing rate charged to the entrepreneurs and the lending rate applied to the households, (ii) a spread charged to the entrepreneurs by the FIs, (iii) a spread between the borrowing rate charged to the FIs and the lending rate applied to the households, (iv) net worth held by the entrepreneurs, and (v) net worth held by the FIs.

To evaluate policies that target each of these spreads and net worths quantitatively, we compute the response of our model to a number of shocks that include widely analyzed macroeconomic shocks as well as those originating from the credit market participants, making use of the parameters estimated in HSU (2011) based on the U.S. data. After studying the economic impact of these shocks when the standard Taylor rule is undertaken, we ask how the impact is altered if an alternative policy is employed.

We find that under the spread-adjusted Taylor rules, the consequence of a shock may be reversed depending on the dynamics of the spread after the shock. When an adverse shock is accompanied by a widened (shrinking) spread, the adjustment makes the economic fluctuations more moderate (volatile) and inflationary (deflationary). From a welfare perspective, these policies dominate the standard Taylor rule in a certain range of policy weights. In our model, therefore, the adoption of some form of spread-adjusted Taylor rule is likely to be favorable compared with the standard Taylor rule, provided that the policy weight is carefully chosen.

In contrast to the spread-adjusted Taylor rules, we find that capital injection policies yield economic expansion and inflation regardless of the shocks. In addition, capital injection to the FI sector has a larger stimulative effect than that to the entrepreneurial sector. Unlike the spread-adjusted Taylor rules, capital injection policies do not outperform the standard Taylor rule in response to a number of shocks. Moreover, when the size of capital injection is sufficiently large, capital injection policies often deteriorate the social welfare.

Appendix 1. 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

$$\sum_{s^{t+1}} \Pi\left(s^{t+1}|s^t\right) \overbrace{\left[1-\Gamma_t^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)\right]}^{\text{share of FIs earnings received by the FI}} \times R^{FI}\left(s^{t+1}|s^t\right)\left(Q(s^t)K(s^t)-N^E(s^t)\right), \tag{28}$$

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, $R^{FI}\left(s^{t+1}|s^t\right)$, is given by

$$\overbrace{\left[\Gamma_t^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)-\mu^E G_t^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right]}^{\text{share of entrepreneurial earnings received by the FI}} R^E\left(s^{t+1}|s^t\right)Q(s^t)K(s^t) \equiv R^{FI}\left(s^{t+1}|s^t\right)\left(Q(s^t)K(s^t)-N^E(s^t)\right) \text{ for } \forall s^{t+1}|s^t. \tag{29}$$

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 equal to the return from their alternative option. Without participating in the FE contract, entrepreneurs can purchase capital goods with their own net worth $N^E(s^t)$. Note that the expected return from this option is equal to $R^E(s^{t+1})N^E(s^t)$. Therefore the FE contract is agreed to by the entrepreneurs only when the following inequality is expected to hold:

$$\overbrace{\left[1-\Gamma_t^E\left(\overline{\omega}^E(s^{t+1}|s^t)\right)\right]}^{\text{share of entrepreneurial earnings kept by the entrepreneur}} R^E(s^{t+1}|s^t)Q(s^t)K(s^t)$$
$$\geq R^E(s^{t+1}|s^t)N^E(s^t) \text{ for } \forall s^{t+1}|s^t. \tag{30}$$

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 $R(s^t)$, 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,

$$\overbrace{\left[\Gamma_t^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)-\mu^{FI}G_t^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)\right]}^{\text{share of FIs' earnings received by the investors}}$$
$$\times R^{FI}\left(s^{t+1}|s^t\right)\left(Q(s^t)K(s^t)-N^E(s^t)\right)$$
$$\geq R(s^t)\left(Q(s^t)K(s^t)-N^{FI}(s^t)-N^E(s^t)\right). \tag{31}$$

The FI maximizes its expected profit (28) by optimally choosing the variables $\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)$, $\overline{\omega}^E\left(s^{t+1}|s^t\right)$, and $K(s^t)$, subject to the investors' participation constraint (31) and entrepreneurial participation constraint (30). Combining the first-order conditions yields the following equation:

$$0=\sum_{s^{t+1}|s^t}\Pi\left(s^{t+1}|s^t\right)\left\{\left(1-\Gamma_t^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)\right)\right.$$
$$\times\Phi_t^E\left(s^{t+1}|s^t\right)R^E\left(s^{t+1}|s^t\right)$$
$$+\frac{\Gamma_t'^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)}{\Phi_t'^{FI}\left(s^{t+1}|s^t\right)}\Phi_t^{FI}\left(s^{t+1}|s^t\right)\Phi_t^E\left(s^{t+1}|s^t\right)R^E\left(s^{t+1}|s^t\right)$$
$$-\frac{\Gamma_t'^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)}{\Phi_t'^{FI}\left(s^{t+1}|s^t\right)}R(s^t)$$
$$+\frac{\left\{1-\Gamma_t^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)\right\}\Phi_t'^E\left(s^{t+1}|s^t\right)}{\Gamma_t'^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)}$$
$$\times\left(1-\Gamma_t^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right)R^E\left(s^{t+1}|s^t\right)$$

$$+\frac{\Gamma_t'^{FI}\left(\overline{\omega}^{FI}\left(s^{t+1}|s^t\right)\right)\Phi_t^{FI}\left(s^{t+1}|s^t\right)\Phi_t'^{E}\left(s^{t+1}|s^t\right)}{\Phi_t'^{FI}\left(s^{t+1}|s^t\right)\Gamma_t'^{E}\left(\overline{\omega}^{E}\left(s^{t+1}|s^t\right)\right)}$$
$$\times\left(1-\Gamma_t^{E}\left(\overline{\omega}^{E}\left(s^{t+1}|s^t\right)\right)\right)R^E\left(s^{t+1}|s^t\right)\Big\}. \tag{32}$$

Using equations (29) and (31), we obtain equation (1) in the text.

Appendix 2. Equilibrium Conditions of the Model

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

Household's Problem and Resource Constraint

$$\frac{1}{C(s^t)}=E_t\left\{\beta\exp\left(e^{B\left(s^{t+1}\right)}\right)\frac{1}{C\left(s^{t+1}\right)}R_t\right\}, \tag{33}$$

$$W(s^t)=\chi H(s^t)^{\frac{1}{\eta}}C(s^t), \tag{34}$$

$$R_t=\mathrm{E}_t\left\{\frac{R_t^n}{\pi_{t+1}}\right\}, \tag{35}$$

$$\begin{aligned}Y(s^t)=&\,C(s^t)+I(s^t)+G(s^t)\exp\left(e^G(s^t)\right)\\&+\mu^E G_t^E\left(\overline{\omega}^E(s^t)\right)R^E(s^t)Q(s^{t-1})K(s^{t-1})\\&+\mu^{FI}G_t^{FI}(\overline{\omega}^{FI}(s^t))R^{FI}(s^t)\left(Q(s^{t-1})K(s^{t-1})-N^E(s^{t-1})\right)\\&+C^{FI}(s^t)+C^E(s^t),\end{aligned} \tag{36}$$

with

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

Firms' Problems

$$Y(s^t)=\frac{A\exp\left(e^A(s^t)\right)K\left(s^{t-1}\right)^{\alpha}H(s^t)^{(1-\Omega_{FI}-\Omega_E)(1-\alpha)}H^{FI}(s^t)^{\Omega_F(1-\alpha)}H^E(s^t)^{\Omega_E(1-\alpha)}}{\Delta_p(s^t)}, \tag{37}$$

with

$$\begin{aligned}
\Delta_p(s^t) &= (1-\xi)\left(\frac{K_p(s^t)}{F_p(s^t)}\right)^{-\epsilon} + \xi\left(\frac{\pi\left(s^{t-1}\right)^{\gamma_p}}{\pi(s^t)}\right)^{-\epsilon}\Delta_p\left(s^{t-1}\right),\\
F_p(s^t) &= 1+\xi\beta\exp\left(e^{B\left(s^{t+1}\right)}\right)\frac{C(s^t)Y\left(s^{t+1}\right)}{C\left(s^{t+1}\right)Y(s^t)}\left(\frac{\pi(s^t)^{\gamma_p}}{\pi\left(s^{t+1}\right)}\right)^{1-\epsilon}\\
&\quad\times F_p\left(s^{t+1}\right),\\
K_p(s^t) &= \frac{\epsilon}{\epsilon-1}MC(s^t)+\xi\beta\exp\left(e^{B\left(s^{t+1}\right)}\right)\\
&\quad\times\frac{C(s^t)Y\left(s^{t+1}\right)}{C\left(s^{t+1}\right)Y(s^t)}\left(\frac{\pi(s^t)^{\gamma_p}}{\pi\left(s^{t+1}\right)}\right)^{-\epsilon}K_p\left(s^{t+1}\right),\\
H(s^t)W(s^t) &= A\exp\left(e^A(s^t)\right)K\left(s^{t-1}\right)^{\alpha}H(s^t)^{(1-\Omega_{FI}-\Omega_E)(1-\alpha)}\\
&\quad\times H^{FI}(s^t)^{\Omega_{FI}(1-\alpha)}H^E(s^t)^{\Omega_E(1-\alpha)}\\
&\quad\times MC(s^t)(1-\alpha)\left(1-\Omega_{FI}-\Omega_E\right), \qquad (38)
\end{aligned}$$

$$R^E(s^t) = \frac{\alpha Y(s^t)/K(s^t)+Q\left(s^{t+1}\right)(1-\delta)}{Q(s^t)}, \qquad (39)$$

$$\begin{aligned}
&Q(s^t)\left(1-0.5\kappa\left(\frac{I(s^t)\exp(e^I(s^t))}{I\left(s^{t-1}\right)}-1\right)^2\right)\\
&\quad-Q(s^t)\left(\kappa\left(\frac{I(s^t)\exp(e^I(s^t))}{I\left(s^{t-1}\right)}\right)\left(\frac{I(s^t)\exp(e^I(s^t))}{I\left(s^{t-1}\right)}-1\right)\right)-1\\
&=\mathrm{E}_t\left\{\beta\exp\left(e^{B\left(s^{t+1}\right)}\right)\frac{C(s^t)Q\left(s^{t+1}\right)}{C\left(s^{t+1}\right)}\kappa\left(\frac{I\left(s^{t+1}\right)\exp(e^I(s^{t+1}))}{I(s^t)}\right)^2\right.\\
&\quad\left.\times\left(\frac{I\left(s^{t+1}\right)}{I(s^t)}-1\right)\exp(e^I(s^{t+1}))\right\}. \qquad (40)
\end{aligned}$$

FIs' Problems

Equilibrium conditions for credit contracts are given by (30), (31), and (32), and the following equations:

$$G_t^{FI}\left(\overline{\omega}_t^{FI}\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^{FI} - 0.5\left(\sigma_t^{FI}\right)^2}{\sigma_t^{FI}}} \exp\left(-\frac{v_{FI}^2}{2}\right) dv_{FI}, \tag{41}$$

$$G_t^{E}\left(\overline{\omega}_t^{E}\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^{E} - 0.5\left(\sigma_t^{E}\right)^2}{\sigma_t^{E}}} \exp\left(-\frac{v_{E}^2}{2}\right) dv_{E}, \tag{42}$$

$$G_t'^{FI}\left(\overline{\omega}_t^{FI}\right) = \left(\frac{1}{\sqrt{2\pi}}\right)\left(\frac{1}{\overline{\omega}_t^{FI}\sigma_t^{FI}}\right) \times \exp\left(-.5\left(\frac{\log \overline{\omega}_t^{FI} - 0.5\left(\sigma_t^{FI}\right)^2}{\sigma_t^{FI}}\right)^2\right), \tag{43}$$

$$G_t'^{E}\left(\overline{\omega}_t^{E}\right) = \left(\frac{1}{\sqrt{2\pi}}\right)\left(\frac{1}{\overline{\omega}_t^{E}\sigma_t^{E}}\right) \exp\left(-.5\left(\frac{\log \overline{\omega}_t^{E} - 0.5\left(\sigma_t^{E}\right)^2}{\sigma_t^{E}}\right)^2\right), \tag{44}$$

$$\Gamma_t^{FI}\left(\overline{\omega}_t^{FI}\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^{FI} - 0.5\left(\sigma_t^{FI}\right)^2}{\sigma_t^{FI}}} \exp\left(-\frac{v_{FI}^2}{2}\right) dv_{FI} + \frac{\overline{\omega}_t^{FI}}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_t^{FI} + 0.5\left(\sigma_t^{FI}\right)^2}{\sigma_t^{FI}}}^{\infty} \exp\left(-\frac{v_{FI}^2}{2}\right) dv_{FI}, \tag{45}$$

$$\Gamma_t^{E}\left(\overline{\omega}_t^{E}\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_t^{E} - 0.5\left(\sigma_t^{E}\right)^2}{\sigma_t^{E}}} \exp\left(-\frac{x^2}{2}\right) dx + \frac{\overline{\omega}_t^{E}}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_t^{E} + 0.5\left(\sigma_t^{E}\right)^2}{\sigma_t^{E}}}^{\infty} \exp\left(-\frac{v_{E}^2}{2}\right) dv_{E}, \tag{46}$$

$$\Gamma_t'^{FI}\left(\overline{\omega}_t^{FI}\right) = \frac{1}{\sqrt{2\pi}\overline{\omega}_t^{FI}\sigma_t^{FI}} \exp\left(-.5\left(\frac{\log \overline{\omega}_t^{FI} - 0.5\left(\sigma_t^{FI}\right)^2}{\sigma_t^{FI}}\right)^2\right) dx$$

$$+\frac{1}{\sqrt{2\pi}}\int_{\frac{\log\overline{\omega}_t^{FI}+0.5(\sigma_t^{FI})^2}{\sigma_t^{FI}}}^{\infty}\exp\left(-\frac{v_{FI}^2}{2}\right)dv_{FI}$$

$$-\frac{1}{\sqrt{2\pi}\sigma_t^{FI}}\exp\left(-\frac{\left(\frac{\log\overline{\omega}_t^{FI}+0.5\left(\sigma_t^{FI}\right)^2}{\sigma_t^{FI}}\right)^2}{2}\right)dx, \quad (47)$$

$$\Gamma_t'^E\left(\overline{\omega}_t^E\right)=\frac{1}{\sqrt{2\pi}\overline{\omega}_t^E\sigma^E}\exp\left(-.5\left(\frac{\log\overline{\omega}_t^E-0.5\left(\sigma^E\right)^2}{\sigma_E}\right)^2\right)dx$$

$$+\frac{1}{\sqrt{2\pi}}\int_{\frac{\log\overline{\omega}_t^E+0.5(\sigma^E)^2}{\sigma^E}}^{\infty}\exp\left(-\frac{v_E^2}{2}\right)dv_E$$

$$-\frac{1}{\sqrt{2\pi}\sigma^E}\exp\left(-.5\left(\frac{\log\overline{\omega}_t^E+0.5\left(\sigma^E\right)^2}{\sigma^E}\right)^2\right)dx, \quad (48)$$

$$\left[\Gamma_t^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)-\mu^E G_t^E\left(\overline{\omega}^E\left(s^{t+1}|s^t\right)\right)\right]R^E\left(s^{t+1}|s^t\right)Q(s^t)K(s^t)$$
$$=R_t^{FI}\left(s^{t+1}|s^t\right)\left(Q(s^t)K(s^t)-N^E(s^t)\right). \quad (49)$$

Laws of Motion of State Variables

$$K(s^t)=\left(1-0.5\kappa\left(\frac{I(s^t)\exp(e^I(s^t))}{I\left(s^{t-1}\right)}\right)^2\right)I(s^t)$$
$$+(1-\delta)K\left(s^{t-1}\right), \quad (50)$$
$$N^{FI}\left(s^{t+1}\right)=\gamma^{FI}V^{FI}(s^t)+W^{FI}(s^t), \quad (51)$$
$$N^E\left(s^{t+1}\right)=\gamma^E V^E(s^t)+W^E(s^t), \quad (52)$$

with

$$V^{FI}(s^t)\equiv\left(1-\Gamma_t^{FI}(\overline{\omega}^{FI}(s^{t+1}))\right)\Phi_t^E(\overline{\omega}^E(s^{t+1}))R^E(s^{t+1})Q(s^t)K(s^t),$$
$$V^E(s^t)\equiv\left(1-\Gamma_t^E\left(\overline{\omega}^E(s^{t+1})\right)\right)R^E\left(s^{t+1}\right)Q(s^t)K(s^t),$$

$$W^{FI}(s^t) \equiv (1-\alpha)\Omega_{FI}Y(s^t),$$
$$W^{E}(s^t) \equiv (1-\alpha)\Omega_{E}Y(s^t).$$

Policies and Shock Process

Policies and the shock process are given by equations (15), (16), (19), (20), (21), (23), and the two net worth shocks.

Appendix 3. Parameterization

This appendix provides parameterization of the variables associated with households, wholesalers, capital goods producers, retailers, final goods producers, government, and monetary authority. Following calibration in BGG (1999) and Christiano, Motto, and Rostagno (2008) as well as estimation by HSU (2011), we choose values for these parameters, listed in table 1. The parameters of the variables related to the credit contracts are described in tables 2 and 3. Shock processes are estimated as shown in table 4.

Table 1. Parameters

Parameter	Value	Description
β	.99	Discount Rate
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
G/Y	0.2	Share of Government Expenditure at Steady State
ξ	.7966	Probability that Price Cannot Be Adjusted
κ	6.3767	Adjustment Cost of Investment
γ_p	.0803	Degree of Price Indexation
θ	.7678	Autoregressive Parameter for Policy Rate
ϕ_π	1.5158	Policy Weight on Inflation
ϕ_y	.0488	Policy Weight on Output Gap

Note: Figures are quarterly unless otherwise noted.

Table 2. Steady-State Conditions under Prior Means

Variable	Value	Description
$R^E - R$	.02/4	Return to Capital Minus the Risk-Free Rate
$F\left(\overline{\omega}^F\right)$	.03/4	Default Probability in the IF Contract
$F\left(\overline{\omega}^E\right)$	.03/4	Default Probability in the FE Contract
n^{FI}	.1	FIs' Net Worth Ratio
n^E	.5	Entrepreneurial Net Worth Ratio
$(Z^E - Z^{FI})/(Z^{FI} - R)$	337/58	The Spread between the FIs' Lending Rate and the FIs' Borrowing Rate Divided by the Spread between the FIs' Borrowing Rate and the Risk-Free Rate

Table 3. Estimated Posterior Means

Parameter	Value	Description
μ_{FI}	.0651	Monitoring Cost Associated with FIs
μ_E	.0150	Monitoring Cost Associated with Entrepreneurs
σ^{FI}	.0818	S.E. of FIs' Idiosyncratic Productivity
σ^E	.2650	S.E. of Entrepreneurial Idiosyncratic Productivity
γ^{FI}	.9628	Survival Rate of FIs
γ^E	.9842	Survival Rate of Entrepreneurs

Table 4. Shock Processes

Parameter	Value
ρ_B	.9026
ρ_I	.8051
ρ_A	.9515
ρ_G	.9610
ρ_R	.2441
σ_B	.0021
σ_I	.0067
σ_G	.0047
σ_A	.0098
σ_R	.0017
σ_N^{FI}	.0692
σ_N^E	.2627

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