# Optimal Monetary Policy Under Financial Sector Risk[*]

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February 2012

## Abstract

Should a central bank respond directly to domestic or foreign financial market conditions when setting monetary policy in an open economy? Specifically, should a central bank put any weights on interbank lending spreads in its Taylor type policy rule? How may these weights be affected by the fact that the central bank may also respond directly to the nominal exchange rate? Using an open-economy model with risk and balance sheet effects in both the real and financial sectors, we find that optimal simple rules should put zero weights on fluctuations in the domestic and foreign interbank leading spreads that are the endogenous result of fluctuations due to productivity shocks. However, the central bank should adjust the policy rate in response to fluctuations in the spreads that occur because of exogenous financial shocks, though it should not be too aggressive in such easing policy. The fact that the central bank may also respond directly to the nominal exchange rate may significantly affect its optimal responses to the financial market conditions and other target variables; specifically the central bank faces a trade-off between exchange rate stabilization and financial stabilization following a domestic financial shock but faces no such trade-off following a foreign financial shock.

**JEL Classification:** E32; E44; E50; F40; G01

*Keywords:* Financial accelerator; Optimal monetary policy

# 1   Introduction

The past few years have witnessed how financial sector risks could be spread across countries' borders to cause a financial and economic calamity worldwide. This overwhelming episode has stimulated a surged interest in investigating whether and how monetary policy should respond to variations in financial market conditions. A popular view is that the central bank should include some interbank credit spreads in a Taylor type monetary policy rule. In his testimony on February 26, 2008 before the Committee on Financial Services of the U.S. House of Representatives, John B. Taylor argued that the intercept term in a Taylor type rule for monetary policy, that is, the natural rate of interest, should be adjusted downward in proportion to observed increase in the spread between the term Libor rate at three month maturity and an index of overnight federal funds rates expected for the same period. Similar views have been expressed by others, including Goodfriend and McCallum (2007), De Fiore and Tristani (2007), McCulley and Toloui (2008), Meyer and Sack (2008), Curdia and Woodford (2009 and 2010), Woodford (2010), and Mishkin (2010a and 2010b).

In this paper, we examine whether and how a Taylor type monetary policy rule should be modified in an open economy featuring financial frictions and/or financial sector risks. A defining feature of our model is a careful distinction between exogenous and endogenous changes in financial market conditions, which we capture by an interbank lending spread. An endogenous change in the interbank lending spread is one that occurs because of changes in non-financial economic variables which affect balance sheets and thus credit availability in the intermediary sector (for instance, a negative productivity shock could lead to increased bankruptcies in the real sector, and thus increased loans losses on the balance sheets of financial intermediaries). An exogenous change in the spread is one that occurs because of an exogenous "financial shock" that shifts the supply curve in the interbank lending market. Our main finding in the paper is that the central bank should adjust the risk free policy rate directly in response to exogenous variations in the domestic and foreign interbank leading spreads, but should not respond directly to any endogenous movements in the spreads. This result is robust, regardless of whether the central bank can also target the nominal exchange rate, whether there is home bias in consumption, or whether domestic entrepreneurs can borrow from foreign banks.

Another important finding in the paper that is closely related to the main result reported above has to do with how allowing the central bank to also target the nominal exchange rate may affect its optimal responses to movements in the interbank leading spreads. In an environment with home and foreign financial shocks, the policy prescription for exchange rate stabilization is to use an expansionary monetary policy following a foreign financial shock and a contractionary policy following a domestic financial shock. The policy prescription for financial stability is to use an expansionary monetary policy in response to both a home or a foreign financial shock. Thus following a home financial shock, there is a trade-off between exchange rate stability and financial stability, and when placing weight on the nominal exchange rate the central bank will want to

compensate by increasing its weight on the domestic interbank lending spread. The central bank faces no such trade-off following a foreign financial shock, and when placing weight on the nominal exchange rate, the central bank can relax its focus on the foreign interbank lending spread.

Our paper is a study of optimal simple rules for central banks in an open-economy monetary model that features multiple sources of frictions and risks in both real and financial sectors. Estimated simple monetary policy rules typically take the form of a policy rate as a function of inflation and the output gap, as well as the lagged policy rate. Whereas stabilizing the variability in inflation and the output gap are the basic characteristics of the celebrated Taylor rule (e.g., Taylor, 1993), subsequent studies reveal substantial evidence of interest rate smoothing in monetary policy practice (e.g., Rudebusch, 1995; Clarida, Gali, and Gertler, 1998 and 2000; Orphanides, 2001). Arguments in favor of such policy rules have been made using structural models where the central bank's loss function consists of variations in inflation, the output gap, and interest rate (e.g., Woodford, 2003a). Desirability of such policy rules or their variants have been shown in models with sticky prices in one sector (e.g., Clarida, Gali, and Gertler, 1999; Goodfriend and King, 2001; Aoki , 2001), in multiple sectors (e.g., Mankiw and Reis, 2003; Huang and Liu, 2005), in multiple countries (e.g., Benigno, 2004; Clarida, Gali, and Gertler, 2002), and with both sticky prices and sticky wages (e.g., Erceg, Henderson, and Levin, 2000; Amato and Laubach, 2003). The importance of interest rate smoothing is especially emphasized by Woodford (2003b). The robustness of such simple policy rules have been shown in various modeling environments (e.g., Levin and Williams, 2003; Levin, Wieland, and Williams, 1999 and 2003; Levin, Onatski, Williams, and Williams, 2005; see Taylor and Williams, 2009b for a survey).

These models all feature a frictionless financial world and focus on a closed economy. In this paper, we examine how such simple monetary policy rules might need to be modified in an open economy featuring financial frictions and/or financial sector risks. Our model takes its root in the classic financial accelerator literature pioneered by Gertler (1988), Bernanke and Gertler (1989), Carlstrom and Fuerst (1997), Kiyotaki and Moore (1997), and Bernanke, Gertler, and Gilchrist (1999), among others. These papers incorporate frictions in finance for manufacturing firms, but they do not model financial intermediaries. Some recent studies incorporate financial intermediaries in modeling, but they abstract from frictions or risks in the financial sector. For instance, Christiano, Motto, and Rostagno (2008) model banks, but they do not allow for frictions or risks within the banking sector. A few recent papers like Meh and Moran (2010), Gertler and Karadi (2011), Gertler and Kiyotaki (2010), and Dib (2010) model financial frictions within the financial sector, in the form of collateral constraints, but they do not allow for financial sector risks. All of these studies focus on the mechanism of financial frictions in transmitting real or monetary shocks in a closed-economy setting.

Our model builds on Davis (2010) but is concerned about the design of optimal simple monetary policy rules in an open-economy monetary environment that features multiple sources of frictions and risks, in both real and financial sectors. The model has four important features. First, it incorporates financial intermediaries, and frictions and risks in both the manufacturing and financial

sectors. Thus, the model features balance sheet effects on both the demand and supply sides of the credit market. Second, it incorporates sticky wages, in addition to sticky prices, so monetary policy faces a nontrivial trade-off between different components of the central bank's objective even when the financial frictions and risks are muted, while in the baseline case the policy trade-off is multi-dimensional. Third, we consider an open-economy setting to take into account frictions and risks in not only domestic but international interbank lending markets for short-term unsecured loans. Last, and foremost, it distinguishes between endogenous and exogenous fluctuations in interbank lending spreads, the spread between the bank's cost of capital and the risk free rate. As we show, exogenous and endogenous fluctuations in the interbank spreads play fundamentally different roles in determining an optimal simple monetary policy rule.

Beginning with the standard case that abstracts from financial frictions and financial sector risks, we derive a simple optimal rule in terms of the respective responsiveness of policy rate to the variability in inflation and the output gap as well as lagged policy rate, much in line with the standard literature on optimal monetary policy. We then find that the presence of financial frictions calls for a greater degree of gradualism in the interest rate rule. This finding supports the classic view of Goodfriend (1987) and Cukierman (1991) in support of interest rate smoothing from the perspective of financial stability. In addition, policy also shifts weight from output gap stabilization to inflation stabilization in the presence of financial frictions. This is consistent with the finding by Lee (2010) who models financial frictions on the households' side, whereas we model financial frictions and risks on the sides of firms and banks.[1]

In contrast to the standard models that abstracts from financial frictions and financial sector risks, our model features more than one interest rate. Time varying spreads in our model have an allocative role. Issing (2006) and Goodhart (2007) suggest that such spreads may have implications for monetary policy practice. It is on this end we find it important to distinguish between what we term endogenous fluctuations in the spread from exogenous fluctuations.

Endogenous fluctuations in the spreads are the essence of a financial accelerator model. For the paper's most interesting result, we find that when the conventional parameters of the Taylor rule, the coefficients on the lagged interest rate, the inflation rate, and the output gap, are chosen optimally, the central bank should ignore these endogenous fluctuations in the spreads. Since these fluctuations are the endogenous reactions to other macroeconomic variables in the model, these fluctuations in the spreads provide no new information that is not already contained in measures of the output gap and inflation. Since the conventional Taylor rule parameters were chosen optimally, the central bank has already found the optimal weighting of the information contained in the inflation rate and the output gap. Therefore putting any weight on a new term that contains no new information would be sub-optimal.

However this may not be true for exogenous fluctuations in the spreads. We define exogenous fluctuations in the spread as occurring because of some exogenous financial sector shocks, for

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[1]Recent welfare-based monetary policy evaluations in models with financial frictions on the households' side also include Iacoviello (2005) and Monacelli (2009).

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instance, a sudden tightening of the credit market that occurs because of a sudden increase in financial sector risk or uncertainty in the home or foreign country. This type of shock is documented by Taylor and Williams (2009a) who describe the sudden increase in interbank lending spreads at the beginning of the financial crisis in August 2007. Bordo and Haubrich (2010) document historical instances of these credit market shocks going back to 1875. Helbling et al. (2010) and Gilchrist, Yankov and Zakrajsek (2009) use econometric techniques to single out these credit shocks and demonstrate their importance in explaining the fluctuations in broader macro aggregates. Within the framework of a financial accelerator model, a number of recent papers, like Attah-Mensah and Dib (2008), Christiano et al. (2003 and 2008), Nolan and Thoenissen (2009), Jermann and Quadrini (2012), and Gilchrist, Ortiz, and Zakrajsek (2009) have introduced credit shocks into a DSGE model.

We find that fluctuations in the spreads that are caused by these exogenous credit shocks may contain new information that is not already found in measures of the output gap and the inflation rate. Thus the central bank may want to reduce the risk free policy rate in response to an exogenous increase in the interbank spread that is caused by a credit market shock originating either from home or abroad. This is to say that the central bank will want to react to exogenous fluctuations in both home and foreign interbank lending spreads. While the central bank will want to employ an accommodative monetary policy in response to a credit market shock, we find that the central bank will not want to fully accommodate the shock. To fully accommodate the shock would imply that the central bank would lower the risk free rate by 1% in response to a 1% exogenous increase in the spreads. We find that this degree of accommodation is too extreme. Optimal policy is for the central bank to reduce the risk free rate by less than one-for-one in response to an exogenous increase in the spreads. We show how allowing the central bank to also target the nominal exchange rate may affect its optimal responses to the interbank leading spreads and other target variables.

Our paper is related to an emerging literature of welfare-based monetary policy evaluations using models with financial frictions, including Moessner (2006), Faia and Monacelli (2007), De Fiore and Tristani (2007), Teranishi (2008), Sudo and Teranishi (2008), Curdia (2008), Curdia and Woodford (2009 and 2010), Faia and Iliopulos (2010), Merola (2010), and Kolasa and Lombardo (2011), among others. Besides our modeling details, such as the open-economy setup with both sticky prices and sticky wages, what distances our study from this literature is the incorporation of financial sector shocks, frictions in finance in both real and financial sectors, their distinguished roles, and the distinction between exogenous changes of domestic and foreign interbank spreads and endogenous movements in these spreads in determining simple optimal monetary policy rules.

This paper will proceed as follows. Section 2 presents the model that is used to assess the desirability of including interbank spreads in the central bank's policy function. The model is a multi-country new Keynesian model, with financial frictions introduced in both real and financial sectors that enable the model to move away from the irrelevance of balance sheets implied by the Modigliani and Miller (1958) theorem. The model is very similar to that presented in Davis (2010), but unlike the model in Davis (2010), the central bank's policy function is modified to

give the central bank the option of responding to financial market conditions and the nominal exchange rate. In addition, in this paper we introduce a new type of shock that is a direct shock to risk and uncertainty in the financial sector. This new type of shock provides the basis for the exogenous fluctuations in the interbank leading spreads that become so important when discussing optimal simple policy rules. Then the calibration of the model is discussed in section 3. The optimal parameters in the Taylor type rule as derived from simulations of the model are presented in section 4. First we discuss how the presence of financial frictions in the model induces the central bank to put more weight on interest rate smoothing in their Taylor rule function. Then we discuss whether or not the central bank will want to directly target interbank lending spreads and how allowing the central bank to also target the nominal exchange rate may affect its optimal responses to the interbank leading spreads and other target variables. Finally, section 5 concludes and offers some suggestions for further research.

## 2    Model

The model is a two country business cycle model. In each of the two symmetric countries there are five types of agents: firms, entrepreneurs, capital builders, banks, and households. There is also a central bank that sets the risk free nominal rate of interest.

Firms use capital and labor inputs to produce tradeable output that is used for consumption and investment. Each firm produces a differentiated good and sets prices according to a Calvo (1983) style price setting framework, thus giving rise to nominal price rigidity.

Entrepreneurs own physical capital and rent it to firms. This physical capital is financed partially through debt and partially through equity. In every period, an individual entrepreneur faces an idiosyncratic shock to the value of their physical capital assets. While these shocks have no direct aggregate effects, they introduce heterogeneity among entrepreneurs. The shock is uninsurable, and a fraction of entrepreneurs may experience an abnormally large shock to the value of their physical capital stock and be pushed into bankruptcy, while most will not. The uncertainty over which entrepreneurs will be pushed into bankruptcy and which will not is a type of financial friction in the real sector. The ratio of debt to equity on an entrepreneur's balance sheet determines their ability to withstand a shock to the value of their capital stock. Creditors use the entrepreneur's debt-equity ratio to determine the riskiness of lending to the entrepreneurial sector, giving rise to a default risk interest premium that depends on the debt-equity ratio.[2]

Capital builders purchase final goods from firms for physical capital investment. There are diminishing marginal returns to physical capital investment. In periods when investment is high, the marginal return of that investment in producing new physical capital is low, and vice versa. This gives rise to a procyclical relative value of physical capital.

Banks channel savings from households to firms in the form of working capital loans and to entrepreneurs in the form of physical capital loans. A bank finances its asset portfolio partially

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[2]The fact that this idiosyncratic shock is uninsurable provides the necessary violation of the complete markets assumption necessary to overcome the implications of the Miller and Modigliani (1958) theorem.

through equity and partially through debt, which is made up of deposits from domestic and foreign households.

Due to bankruptcies in the real sector, a portion of a bank's portfolio of physical capital loans will go into default in any given period. While these loan losses are not great enough to push the entire banking sector into insolvency, there is heterogeneity among banks with regards to their exposure to the set of non-performing loans. A few banks may be over-exposed to the set of bad loans, and they themselves may be pushed into insolvency. The uncertainty about which banks are over-exposed to the set of non-performing loans and which are not is a type of financial friction in the banking sector. The ratio of debt to equity on a bank's balance sheet determines their ability to absorb loan losses, so the debt-equity ratio determines the ex-ante riskiness of a particular bank. Thus the spread between interbank lending rates and the risk free rate is increasing in the leverage ratio of the banking sector.

Households supply labor to firms and consume final output. Furthermore they supply a differentiated type of labor and set wages according to a Calvo-style wage setting process, giving rise to nominal wage rigidity.

Finally, the central bank tries to stabilize output and prices by controlling the risk free nominal rate of interest. The central bank sets policy using a Taylor rule function combining the current period's inflation rate, output gap, and the lagged risk free nominal interest rate. We will also consider the case where the home and foreign interbank lending spreads are also part of the Taylor rule. When considering the central bank's optimal reaction to financial sector developments, specifically we are trying to find the optimal coefficients on the spreads in the Taylor rule.

In what follows, all variables are written in per capita terms and foreign variables are distinguished by an asterisk (*). The two countries are symmetric, so foreign equations have been omitted for brevity except where absolutely necessary.

## 2.1 Firms

In the home country, intermediate goods producing firms, indexed $i \in [0 \ n]$, combine capital and labor, $k_t(i)$ and $h_t(i)$ to produce a unique intermediate good $Y_t(i)$. The firm's production function is:

$$Y_t(i) = A_t h_t(i)^{1-\alpha} k_t(i)^\alpha - \phi \tag{1}$$

where $A_t$ is an exogenous country specific stochastic TFP parameter that is common to all firms and $\phi$ is a fixed cost parameter that is calibrated to ensure that firms earn zero profit in the steady state.

The output from firm $i$ can be sold to the domestic market or sold as imports in the foreign market:

$$Y_t(i) = y_t^d(i) + y_t^{m*}(i)$$

where $y_t^d(i)$ is output from firm $i$ that is sold domestically and $y_t^{m*}(i)$ is the output that is imported into the foreign country.

Intermediate goods from domestic and foreign firms are then combined into one aggregate final good. As in Chari, Kehoe, and McGrattan (2002), domestically supplied and imported intermediate goods are aggregated by the following:

$$y_t = \left[ (\gamma)^{\frac{1}{\rho}} \left[ \left( \int_0^n y_t^d(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \right]^{\frac{\rho-1}{\rho}} + \left( \gamma^f \right)^{\frac{1}{\rho}} \left[ \left( \int_n^1 y_t^m(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \right]^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \tag{2}$$

where $\sigma$ is the elasticity of substitution between domestic varieties and $\rho$ is the elasticity of substitution between home and foreign varieties.

From this aggregator function the demand in the home country for the intermediate good from domestic firm $i$, where $i \in [0\ n]$, as a function of aggregate demand is:

$$y_t^d(i) = \gamma(n)^{\frac{1-\rho}{1-\sigma}-1} \left( \frac{P_t^d(i)}{P_t^d} \right)^{-\sigma} \left( \frac{P_t^d}{P_t} \right)^{-\rho} y_t \tag{3}$$

Similarly, the demand in the home country for the intermediate good from foreign firm $i$, where $i \in (n\ 1]$, as a function of aggregate demand is:

$$y_t^m(i) = \gamma^f (1-n)^{\frac{1-\rho}{1-\sigma}-1} \left( \frac{P_t^m(i)}{P_t^m} \right)^{-\sigma} \left( \frac{P_t^m}{P_t} \right)^{-\rho} y_t \tag{4}$$

where $P_t^d(i)$ is the price in the domestic market for the intermediate good from firm $i$, $P_t^d = \left( \frac{1}{n} \int_0^n \left( P_t^d(i) \right)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$ is a price index of domestically produced intermediate goods, $P_t^m = \left( \frac{1}{1-n} \int_n^1 \left( P_t^m(i) \right)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$ is a price index of imported intermediate goods, and the aggregate price level is given by $P_t = \left[ \gamma(n)^{\frac{1-\rho}{1-\sigma}} \left( P_t^d \right)^{1-\rho} + \gamma^f (1-n)^{\frac{1-\rho}{1-\sigma}} \left( P_t^m \right)^{1-\rho} \right]^{\frac{1}{1-\rho}}$.

Firm $i$ can discriminate when setting prices for the domestic or foreign market. Thus they can set separate prices for the domestic and export markets. In period $t$, the firm will be able to change its price in the domestic market with probability $1 - \xi_p$. If the firm cannot change prices then they are reset automatically according to $P_t^d(i) = \pi_{t-1} P_{t-1}^d(i)$, where $\pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$.

Thus if allowed to change their domestic price in period $t$, the firm will set a price to maximize:

$$\max_{P_t^d(i)} E_t \sum_{\tau=0}^{\infty} \beta^\tau \left( \xi_p \right)^\tau \lambda_{t+\tau} \left\{ \Pi_{t,t+\tau} P_t^d(i) y_{t+\tau}^d(i) - MC_{t+\tau} y_{t+\tau}^d(i) \right\}$$

where $\lambda_t$ is the marginal utility of income in period $t$. As discussed in this paper's technical appendix, the firm that is able to change its domestic price in period $t$ will set its price to:

$$P_t^d(i) = \frac{\sigma}{\sigma-1} \frac{E_t \sum_{\tau=0}^{\infty} \beta^\tau \left( \xi_p \right)^\tau \lambda_{t+\tau} MC_{t+\tau} \left( \frac{\Pi_{t,t+\tau}}{P_{t+\tau}^d} \right)^{-\sigma} \left( \frac{P_{t+\tau}^d}{P_{t+\tau}} \right)^{-\rho} y_{t+\tau}}{E_t \sum_{\tau=0}^{\infty} \beta^\tau \left( \xi_p \right)^\tau \lambda_{t+\tau} \Pi_{t,t+\tau} \left( \frac{\Pi_{t,t+\tau}}{P_{t+\tau}^d} \right)^{-\sigma} \left( \frac{P_{t+\tau}^d}{P_{t+\tau}} \right)^{-\rho} y_{t+\tau}}$$

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If prices are flexible, and thus $\xi_p = 0$, then this expression reduces to:

$$P_t^d(i) = \frac{\sigma}{\sigma - 1} MC_t$$

which says that the firm will set a price equal to a constant mark-up over marginal cost.

Write the domestic price set by the firm that can reset prices in period $t$ as $\tilde{P}_t^d(i)$ to denote that it is an optimal price. Firms that can reset prices in period $t$ will all reset to the same level, so $\tilde{P}_t^d(i) = \tilde{P}_t^d$. Substitute this optimal price into the price index $P_t^d = \left(\frac{1}{n}\int_0^n \left(P_t^d(i)\right)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$. Since a firm has a probability of $1 - \xi_p$ of being able to change their price, then by the law of large numbers in any period $1 - \xi_p$ percent of firms will reoptimize prices, and the prices of $\xi_p$ percent of firms will be automatically reset using the previous periods inflation rate. Thus the domestic price index, $P_t^d$, can be written as:

$$P_t^d = \left(\xi_p \left(\Pi_{t-1,t} P_{t-1}^d\right)^{1-\sigma} + (1 - \xi_p)\left(\tilde{P}_t^d\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

The full details of this derivation as well as the derivation for prices set for the foreign market is located in the appendix.

The firm hires labor and capital inputs, where $W_t$ is the wage rate paid for labor input and $R_t$ is the capital rental rate, both of which the firm takes as given. Furthermore the firm must pay their wage bill at the beginning of the period, prior to production. To do so they borrow $b_t^{wc}(i) = W_t h_t(i)$. The firm's income after paying for capital and labor inputs is:

$$d_t^f(i) = P_t^d(i) y_t^d(i) + P_t^x(i) y_t^x(i) - W_t h_t(i) - R_t k_t(i) - r_t^{wc} b_t^{wc}(i) \tag{5}$$

where $P_t^x(i)$ is the export price for the intermediate good from firm $i$, and $r_t^{wc}$ is the interest rate on working capital loans. Since there is no default risk from lending working capital to firms, competition in the banking sector forces the rate on working capital loans down to the bank's own cost of capital, $r_t^{wc} = r_t^b$.

The aggregate income from all firms is returned to households as a lump sum payment, $d_t^f = \int_0^n d_t^f(i) di$.

The firm will choose $h_t(i)$ and $k_t(i)$ to maximize profit in (5) subject to the production function in (1). The working capital requirement implies that the cost of the labor input is $W_t(1 + r_t^{wc})$ and the cost of the capital input is $R_t$. Given these prices, the firm's demand for labor and capital inputs are:

$$
\begin{aligned}
h_t(i) &= (1 - \alpha)\frac{MC_t}{W_t(1 + r_t^{wc})} Y_t(i) \tag{6}\\
k_t(i) &= \alpha \frac{MC_t}{R_t} Y_t(i)
\end{aligned}
$$

where $MC_t = \frac{1}{A_t} \left( \frac{W_t(1+r_t^{wc})}{1-\alpha} \right)^{1-\alpha} \left( \frac{R_t}{\alpha} \right)^{\alpha}$.

## 2.2 Entrepreneurs

Entrepreneurs, indexed $j \in [0 \; n]$, buy capital from capital builders and rent it to firms. At the beginning of period $t$, entrepreneur $j$ has a stock of capital, $K_t(j)$, that he will rent to firms in period $t$ at a rental rate $R_t$. In equilibrium, the aggregate stock of capital supplied by all domestic entrepreneurs $j$ is equal to the aggregate stock of capital demanded by all domestic firms $i$, $\int_0^n K_t(j) \, dj = \int_0^n k_t(i) \, di$.

Entrepreneurs finance this stock of capital partially through debt. The entrepreneur borrows $b_t^e(j)$ from domestic banks to finance their capital stock $K_t(j)$. Thus the market value of the assets and liabilities for entrepreneur $j$ at the beginning of period $t$ are:

$$
\begin{aligned}
\text{Assets:} \quad & P_t^K K_t(j) \\
\text{Liabilities:} \quad & b_t^e(j)
\end{aligned}
\tag{7}
$$

where $P_t^K$ is the price of existing capital.

The end of the period the value of the non-depreciated capital stock for the average entrepreneur is $P_t^K(1-\delta)K_t$. However during the period, the individual entrepreneur $j$ receives an idiosyncratic draw that affects the relative price of their existing capital, so for entrepreneur $j$ the end of period value of their non-depreciated capital stock is:

$$
\omega_t^e(j) P_t^K(1-\delta)K_t(j)
$$

where $\omega_t^e(j)$ is a i.i.d. draw from a lognormal distribution on the interval $[0 \; \infty)$ with mean 1 and variance $\sigma_e^2$.

Since this draw has a mean 1, it has no effect on the aggregate capital stock. It simply introduces heterogeneity among entrepreneurs, and in any given period a fraction of entrepreneurs receive a draw that has a large adverse effect on the value of their existing capital (a small $\omega_t^e(j)$) and thus at the end of the period, the value of their liabilities exceeds the value of their assets.

During the period the entrepreneur rents his capital stock to firms for a rental rate of $R_t$. The entrepreneur finances this capital stock with a loan from the bank with an interest rate $r_t^e$. Thus at the end of the period, after the realization of $\omega_t^e(j)$, the nominal market value of entrepreneur $j$'s assets is $\omega_t^e(j) P_t^K(1-\delta)K_t(j) + R_t K_t(j)$. At the end of the period the nominal value of the entrepreneur's liabilities is $(1+r_t^e)b_t^e(j)$.

Thus, after the realization of $\omega_t^e(j)$, entrepreneur $j$ is bankrupt if:

$$
\omega_t^e(j) P_t^K(1-\delta)K_t(j) + R_t K_t(j) < (1+r_t^e)b_t^e(j)
\tag{8}
$$

Thus the threshold value of $\omega_t^e(j)$ below which the entrepreneur goes bankrupt in period $t$ and above which they continue operations is:

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$$\bar{\omega}_t^e = \frac{(1 + r_t^e) \frac{b_t^e(j)}{K_t(j)} - R_t}{P_t^K (1 - \delta)} \tag{9}$$

where $DA_t^e(j) = \frac{b_t^e(j)}{K_t(j)}$ is the ratio of the book value of debt to the book value of assets on an entrepreneur's balance sheet. The history of individual entrepreneur $j$ will influence the level of $b_t^e(j)$ and $K_t(j)$, but the ratio $DA_t^e(j) = \frac{b_t^e(j)}{K_t(j)}$ is equal across all entrepreneurs. This is a key result for aggregation, for it implies that the bankruptcy cutoff value $\bar{\omega}_t^e$ does not depend on an entrepreneur's history. More intuition behind this result is presented at the end of this section and a formal proof is presented in the appendix.

When deciding how much to lend to entrepreneurs going into next period and at what rate, banks factor in the fact that if entrepreneur $j$ does not default in period $t + 1$, creditors receive a return of $r_{t+1}^e$. If the entrepreneur defaults, creditors receive a share of the entrepreneur's remaining assets, less the bankruptcy cost $\mu^e$. The threshold value $\bar{\omega}_{t+1}^e$ in equation (9) determines whether or not an entrepreneur goes into default next period. Thus the payoff to creditors conditional of the realization of the shock $\omega_{t+1}^e(j)$ is:

$$
\begin{array}{ll}
(1 + r_{t+1}^e)(b_{t+1}^e(j)) & \text{if } \omega_{t+1}^e(j) \geq \bar{\omega}_{t+1}^e \\
(1 - \mu^e)[\omega_{t+1}^e(j)(1 - \delta) P_{t+1}^K K_{t+1}(j) + R_{t+1} K_{t+1}(j)] & \text{if } \omega_{t+1}^e(j) < \bar{\omega}_{t+1}^e
\end{array}
\tag{10}
$$

Perfect competition in the banking sector implies that the bank's expected profit is zero. So the interest rate the bank charges on physical capital loans, $r_{t+1}^e$, is set such that the expected return, after factoring in the cost of bankruptcy, is equal to the bank's cost of capital, $r_{t+1}^b$:

$$
\begin{aligned}
\left(1 + r_{t+1}^b\right) b_{t+1}^e(j) = & \int_0^{\bar{\omega}_{t+1}^e} (1 - \mu^e)\left(\omega_{t+1}^e(j)(1 - \delta) P_{t+1}^K K_{t+1}(j) + R_{t+1} K_{t+1}(j)\right) dF\left(\omega_{t+1}^e\right) \\
& + \int_{\bar{\omega}_{t+1}^e}^\infty \left(1 + r_{t+1}^e\right) b_{t+1}^e(j) dF\left(\omega_{t+1}^e\right)
\end{aligned}
$$

where $F\left(\omega_{t+1}^e\right)$ is the c.d.f. of the lognormal distribution of $\omega_{t+1}^e$.

Thus the interest rate charged by banks for physical capital loans is:

$$
1 + r_{t+1}^e = \frac{\left(1 + r_{t+1}^b\right)}{1 - F\left(\bar{\omega}_{t+1}^e\right)} - \frac{(1 - \mu^e)\left[R_{t+1} F\left(\bar{\omega}_{t+1}^e\right) + (1 - \delta) P_{t+1}^K \int_0^{\bar{\omega}_{t+1}^e} \omega_{t+1}^e dF\left(\omega_{t+1}^e\right)\right]}{\left(1 - F\left(\bar{\omega}_{t+1}^e\right)\right) \frac{b_{t+1}^e(j)}{K_{t+1}(j)}} \tag{11}
$$

where $F\left(\bar{\omega}_{t+1}^e\right)$ is the fraction of manufacturing firms that declare bankruptcy.

Holding all else equal, this interest rate, $r_{t+1}^e$, is increasing in $F\left(\bar{\omega}_{t+1}^e\right)$. If there are financial frictions in the entrepreneurial sector, $F\left(\bar{\omega}_{t+1}^e\right)$ is increasing in $\bar{\omega}_{t+1}^e$. $\bar{\omega}_{t+1}^e$ is increasing in the manufacturing firm's debt-asset ratio. Thus when there are financial frictions in the entrepreneurial sector, the interest rate on physical capital loans is increasing in the level of debt on an

entrepreneur's balance sheet.

The cutoff value of $\omega_{t+1}^e(j)$ in equation (9) combined with the interest rate expression in (11) demonstrates the feedback loop associated with financial frictions in the entrepreneurial sector. When the price of existing capital, $P_{t+1}^K$ falls, the cutoff value $\bar{\omega}_{t+1}^e$ rises. This implies that more firms will receive draws of $\omega_{t+1}^e(j)$ below this cutoff value and be forced into bankruptcy. When more firms go into bankruptcy, $F\left(\bar{\omega}_{t+1}^e\right)$ increases, and $r_{t+1}^e$ increases as banks now demand a higher interest rate to compensate for the increased bankruptcy risk. This higher $r_{t+1}^e$ means higher interest expenses and lower profit for the entrepreneur, which leads to a further increase in the cutoff value $\bar{\omega}_{t+1}^e$.

The end of period net worth for the entrepreneur that survives is the entrepreneur's profit in time $t$ plus the value of their non-depreciated capital stock:

$$\tilde{N}_t^e(j) = R_t K_t(j) - (1 + r_t^e) b_t^e(j) + \omega_t^e(j) P_t^K (1 - \delta) K_t(j)$$

The entrepreneur will pay a dividend to shareholders of $d_t^e(j)$ and begin the next period with net worth $N_{t+1}^e(j) = \tilde{N}_t^e(j) - d_t^e(j)$. Entrepreneurs that declare bankruptcy in period $t$ pay no dividend and drop out of the market, they are replaced with new entrepreneurs, which are endowed with start up capital of $\bar{N}^e$. Thus the net worth of the entrepreneurial sector at the beginning of next period is:

$$
\begin{aligned}
N_{t+1}^e &= \int_0^{\bar{\omega}_t^e} N_{t+1}^e(j) \, dF(\bar{\omega}_t^e) + \int_{\bar{\omega}_t^e}^\infty N_{t+1}^e(i) \, dF(\bar{\omega}_t^e) \quad (12) \\
&= \bar{N}^e F(\bar{\omega}_t^e) + (R_t K_t - (1 + r_t^e) b_t^e - d_t^e)(1 - F(\bar{\omega}_t^e)) + P_t^K (1 - \delta) K_t \int_{\bar{\omega}_t^e}^\infty \omega_t^e \, dF(\bar{\omega}_t^e)
\end{aligned}
$$

At the beginning of any period, entrepreneurs have different levels of net worth $N_{t+1}(j)$ that will depend on the entrepreneur's history of idiosyncratic shocks $\omega_t^e(j)$.

The entrepreneur will acquire capital up to the point where the interest rate on bank loans is equal to the expected return to holding a unit of capital:

$$r_{t+1}^e = E_t \left( \frac{R_{t+1} + \omega_{t+1}^e(j)(1 - \delta) P_{t+1}^K}{P_t^K} \right)$$

Since $\omega_{t+1}^e(j)$ is i.i.d. and $E_t\left(\omega_{t+1}^e(j)\right) = 1$, the left hand side of the above expression is the same across all entrepreneurs $j$, which implies that $r_{t+1}^e$ is the same across all entrepreneurs.

## 2.3 Capital Builders

The representative capital builder converts final goods, given by equation (2), into the physical capital purchased by entrepreneurs. At the end of period $t$, the non depreciated physical capital stock is $(1 - \delta) K_t$, and the physical capital stock at the beginning of the next period is $K_{t+1}$. The

evolution of the physical capital stock is given by:

$$K_{t+1} - (1 - \delta) K_t = \phi \left( \frac{I_t}{K_t} \right) K_t$$

where $\phi' > 0$ and $\phi'' < 0$ implying that there are diminishing marginal returns to physical capital investment. Capital builders purchase final goods for investment at a price $P_t$ and sell existing capital to entrepreneurs at a price $P_t^K$. Thus the profits of the representative capital builder are given by:

$$d_t^c = P_t^K \left( K_{t+1} - (1 - \delta) K_t \right) - P_t I_t$$

In a competitive capital building sector, profit maximization implies that the relative price of existing capital is:

$$\frac{P_t^K}{P_t} = \left[ \phi' \left( \frac{I_t}{K_t} \right) \right]^{-1}$$

Since $\phi'' < 0$, when $\frac{I_t}{K_t}$ is high, $\phi' \left( \frac{I_t}{K_t} \right)$ is low, so $\frac{P_t^K}{P_t}$ is high. This implies that during times of high physical capital investment, when the ratio of investment to the existing capital stock is high, the relative price of existing capital is high. Since investment is highly procyclical, capital adjustment costs imply that the relative price of capital is highly procyclical as well.

## 2.4  Banks

Banks, indexed $k \in [0 \; n]$ make physical capital loans to domestic entrepreneurs. They finance this loan portfolio partially with equity and partially with borrowing from domestic and foreign households.

At the beginning of period $t$, the value of the bank's assets is $B_t^e (k)$, which is the bank's stock of loans to entrepreneurs. The value of the bank's liabilities is $b_t^s (k) + b_t^{sf} (k)$, where $b_t^s (k)$ are the deposits of domestic households and $b_t^{sf} (k)$ are the deposits of foreign households.[3]

The bank also makes working capital loans to firms in order to finance the firm's wage bill. This however is not listed as a beginning of period asset for the bank. By assumption this loan is made after the beginning of the period and repaid before the end of the period. If the stock of working capital loans were to appear as a asset for the bank at the beginning of period $t$, that would imply that the loan was made in period $t - 1$, which implies that the firm made a decision about period $t$'s labor input in period $t - 1$.

Bankruptcy in the entrepreneurial sector in period $t$ means the bank's assets are worth less at the end of the period. The value of the average bank's assets at the end of the period is

---

[3]The same stock of bonds that is a liability to one party is an asset to another. Throughout this paper, when a stock of bonds is an asset, it is written with a capital $B$, when the stock of bonds is a liability it is written with a lower case $b$.

Thus market clearing in the bond market requires that the sum of physical capital loans across all banks equals the sum of borrowing by entrepreneurs, $\int_0^n B_t^e (k) \, dk = \int_0^n b_t^e (j) \, dj$.

$(1 - \zeta_t^e)(1 + r_t^e) B_t^e$, where $\zeta_t^e$ is the share of the average bank's physical capital loan portfolio that is lost to bankruptcy and liquidation costs.

$\zeta_t^e$ represents the share of the *average* bank's physical capital loan portfolio that is lost to bankruptcy and liquidation costs, however banks don't hold fully diversified loan portfolios. Some banks may be overexposed to the set of non-performing loans to the entrepreneurial sector. This overexposure may be due to a regional bias in the bank's portfolio, or it may be because a bank has a certain core competency and is therefore overexposed to a certain sector of the economy.[4]

The percent of the bank $k$'s loan portfolio that is lost to bankruptcy or liquidation costs is $\omega_t^b(k) \zeta_t^e$, where $\omega_t^b(k)$ is an i.i.d. draw from a lognormal distribution on the interval $\left[0 \ \frac{1}{\zeta_t^e}\right]$ with mean 1 and standard deviation $\sigma_t^b$.

If bank $k$ receives a large draw $\omega_t^b(k)$, it implies that the bank is overexposed to the set of non-performing loans and may itself face insolvency. The bank is insolvent if the end of period value of its assets is less than the end of period value of its liabilities:

$$\left(1 - \omega_t^b(k) \zeta_t^e\right)(1 + r_t^e) B_t^e(k) < \left(1 + r_t^b(k)\right)\left(b_t^s(k) + b_t^{sf}(k)\right)$$

The threshold value of $\omega_t^b(k)$ above which bank $k$ is forced to declare bankruptcy and below which the bank will continue operations is:

$$\bar{\omega}_t^b = \frac{(1 + r_t^e) - \left(1 + r_t^b(k)\right) \frac{b_t^s(k) + b_t^{sf}(k)}{B_t^e(k)}}{\zeta_t^e(1 + r_t^e)} \tag{13}$$

Bank $k$'s history of idiosyncratic draws, $\omega_t^b(k)$, thus its history of exposure to non-preforming sectors of the economy, will determine the levels of $B_t^e(k)$, $b_t^s(k)$, and $b_t^{sf}(k)$. However, at the beginning of the period, all banks will have the same ratio of total debt to total assets, $DA_t^b(k) = \frac{b_t^s(k) + b_t^{sf}(k)}{B_t^e(k)}$ and will have the same cost of capital, $r_t^b(k)$. This result is key for the aggregation of balance sheet variables across a continuum of individual banks, for this implies that the cutoff value $\bar{\omega}_t^b$ is common across all banks. The formal proof of this claim is presented in the appendix.

When deciding how much to lend to bank $k$ in the next period and at what rate, the bank's creditors factor in the fact that if the bank does not default, they receive a gross interest rate $1 + r_{t+1}^b(k)$. If bank $k$ defaults, creditors receive nothing.[5] Thus the expected payoff to a bank's creditors conditional on the bank's exposure to the set of non-preforming loans is:

$$\begin{array}{ll} \left(1 + r_{t+1}^b(k)\right)\left(b_{t+1}^s(k) + b_{t+1}^{sf}(k)\right) & \text{if } \omega_{t+1}^b(k) \leq \bar{\omega}_{t+1}^b \\ 0 & \text{if } \omega_{t+1}^b(k) > \bar{\omega}_{t+1}^b \end{array} \tag{14}$$

Domestic and foreign depositors will extend bank $k$ credit up to the point where the expected

---

[4]Like the banks, many of which are now bankrupt or were acquired by healthier rivals, who were overexposed to the subprime sector of the mortgage market during the recent financial crisis.

[5]The assumption that creditors receive nothing in the case of bank default is because the model is later calibrated such that the spread between the interbank rate, $r^b$, and the risk free rate, $i$, in the steady state of the model is equal to the historical average of the spread between the 3-month Libor and the 3-month T-bill. The Libor is an interbank index rate that is based on the interest rate for unsecured lending to banks.

return, after factoring in the probability of default is equal to the risk free rate:

$$(1 + i_{t+1})\left(b_{t+1}^b(k) + b_{t+1}^{bf}(k)\right) = \int_0^{\bar{\omega}_{t+1}^b} \left(1 + r_{t+1}^b(k)\right)\left(b_{t+1}^b(k) + b_{t+1}^{bf}(k)\right) dG\left(\bar{\omega}_{t+1}^b; \sigma_{t+1}^b\right)$$

This condition can be used to solve for the interest rate on interbank lending to bank $k$:

$$1 + r_{t+1}^b(k) = \frac{1 + i_{t+1}}{G\left(\bar{\omega}_{t+1}^b; \sigma_{t+1}^b\right)} \tag{15}$$

where $G\left(\bar{\omega}_{t+1}^b; \sigma_{t+1}^b\right)$ is the c.d.f. of the lognormal distribution of $\bar{\omega}_{t+1}^b$, and thus measures the proportion of banks that do not go bankrupt in period $t+1$. Since $DA_{t+1}^b(k) = \frac{b_{t+1}^s(k) + b_{t+1}^{sf}(k)}{B_{t+1}^e(k)}$ is constant across all banks, the interbank lending rate, and thus banks' cost of capital, is constant across all banks.

A first order Taylor series expansion of the expression in (15) highlights the two factors, one endogenous and one exogenous, that can cause fluctuations in the interbank lending spread, $rp_t^b = \frac{1 + r_{t+1}^b}{1 + i_{t+1}}$:

$$rp_t^b \approx rp_{ss}^b \left[1 + g_1\left(\frac{\bar{\omega}_{t+1}^b - \bar{\omega}_{ss}^b}{\bar{\omega}_{ss}^b}\right) + g_2\left(\frac{\sigma_{t+1}^b - \sigma_{ss}^b}{\sigma_{ss}^b}\right)\right] \tag{16}$$

where $g_1 = -\frac{\partial G\left(\bar{\omega}_{t+1}^b; \sigma_{t+1}^b\right)}{\partial \bar{\omega}_{t+1}^b} \frac{\bar{\omega}_{t+1}^b}{G\left(\bar{\omega}_{t+1}^b; \sigma_{t+1}^b\right)} < 0$ is the elasticity of the spread with respect to changes in the endogenous cutoff value $\bar{\omega}_{t+1}^b$, and $g_2 = -\frac{\partial G\left(\bar{\omega}_{t+1}^b; \sigma_{t+1}^b\right)}{\partial \sigma_{t+1}^b} \frac{\sigma_{t+1}^b}{G\left(\bar{\omega}_{t+1}^b; \sigma_{t+1}^b\right)} > 0$ is the elasticity of the spread with respect to changes in the exogenous variable describing uncertainty in the interbank market, $\sigma_{t+1}^b$. Thus fluctuations in the spread, $\hat{rp}_t^b = \frac{rp_t^b}{rp_{ss}^b} - 1$, can be dividend into two components, an endogenous component due to fluctuations in the endogenous cutoff value $\bar{\omega}_{t+1}^b$, and an exogenous component due to change in the exogenous uncertainty variable $\sigma_{t+1}^b$. Define $\hat{rp}_t^{b,endo} = g_1\left(\frac{\bar{\omega}_{t+1}^b - \bar{\omega}_{ss}^b}{\bar{\omega}_{ss}^b}\right)$ as the endogenous component of fluctuations in the spread and $\hat{rp}_t^{b,exo} = g_2\left(\frac{\sigma_{t+1}^b - \sigma_{ss}^b}{\sigma_{ss}^b}\right)$ as the exogenous component.

The end of period $t$ net worth of the bank that is not over-exposed to the set of non-preforming loans and is able to continue operations is:

$$\tilde{N}_t^b = \left(1 - \omega_t^b(k)\zeta_t^e\right)(1 + r_t^e)B_t^e(k) - \left(1 + r_t^b\right)\left(b_t^s(k) + b_t^{sf}(k)\right)$$

The bank will pay a dividend to shareholders and begin the next period with a net worth $N_{t+1}^b(k) = \tilde{N}_t^b(k) - d_t^b(k)$. Banks that were overexposed to the set of non-preforming loans and thus were forced into bankruptcy end the period with no net worth and drop out of the market. They are replaced with new banks that are endowed with start up capital $\bar{N}^b$. Thus the net worth of the entire banking sector at the beginning of next period is:

$$N_{t+1}^b = \int_{\bar{\omega}_t^b}^{\infty} N_{t+1}^b (i) \, dG \left( \omega_t^b; \sigma_t^b \right) + \int_0^{\bar{\omega}_t^b} N_{t+1}^b (k) \, dG \left( \omega_t^b; \sigma_t^b \right) \tag{17}$$

$$= \bar{N}^b \left( 1 - G \left( \omega_t^b; \sigma_t^b \right) \right) + \left( (1 + r_t^e) B_t^e - \left( 1 + r_t^b \right) \left( b_t^s + b_t^{sf} \right) - d_t^b \right) G \left( \omega_t^b; \sigma_t^b \right)$$

$$- (1 + r_t^e) B_t^e \zeta_t^e \int_0^{\bar{\omega}_t^b} \omega_t^b dG \left( \omega_t^b; \sigma_t^b \right)$$

## 2.5   Households

Households, indexed $l \in [0 \; n]$, supply heterogeneous labor to domestic firms and consume from their labor income, interest on savings, and profit income from domestic firms, entrepreneurs, capital builders, and banks.

The household maximizes their utility function:

$$\max \sum_{t=0}^{\infty} \beta^t \left[ \ln \left( C_t \left( l \right) \right) - \psi \left( H_t \left( l \right) \right)^{\frac{1+\sigma_H}{\sigma_H}} \right] \tag{18}$$

subject to their budget constraint:

$$P_t C_t (l) + B_{t+1}^s (l) + S_t B_{t+1}^{sf*} (l) + F (\bar{\omega}_t^e) \bar{N}^e + \left( 1 - G \left( \omega_t^b; \sigma_t^b \right) \right) \bar{N}^b \tag{19}$$

$$= W_t (l) H_t (l) + d_t^f (l) + d_t^e (l) + d_t^c (l) + d_t^b (l) + \left( 1 - \zeta_t^b \right) \left( 1 + r_t^b \right) B_t^s (l)$$

$$+ \left( 1 - \zeta_t^{b*} \right) \left( 1 + r_t^{b*} \right) S_t B_t^{sf*} (l) + \zeta_t^e + \zeta_t^b - \frac{\chi^b}{2} \left( S_t B_t^{sf*} (l) - S_t \bar{B}^{sf*} \right)^2$$

where $C_t (l)$ is consumption by household $l$ in period $t$, $H_t (l)$ is the household's labor effort in the period, $B_t^s (l)$ is the household's stock of deposits with domestic banks at the beginning of the period, $B_t^{sf*} (l)$ is the stock of deposits with foreign banks, $W_t (l)$ is the wage paid for the household's heterogenous labor supply, $\zeta_t^b$ ($\zeta_t^{b*}$) represents the small share of deposits to the home (foreign) banking sector that are lost to bankruptcy and liquidation costs, and $d_t^f (l)$, $d_t^e (l)$, $d_t^c (l)$ and $d_t^b (l)$ are the household's share of period $t$ profits from firms, entrepreneurs, capital builders and banks, respectively.[6]

The household pays a small quadratic transactions cost to holding anything other than the steady state level of deposits with foreign banks, $\frac{\chi^b}{2} \left( B_t^{sf*} (l) - \bar{B}^{sf*} \right)^2$.

Each household supplies a differentiated type of labor. The function to aggregate the labor supplied by each household into the aggregate stock of labor employed by domestic firms is:

---

[6]Market clearing in the market for deposits requires that the sum of deposits with domestic banks across all domestic households equals the sum of borrowing from domestic households across all domestic banks, $\int_0^n B_t^s (l) \, dl = \int_0^n b_t^s (k) \, dk$, and that the sum of deposits with foreign banks across all domestic households equals the sum of borrowing from domestic households across all foreign banks, $\int_0^n B_t^{sf*} (l) \, dl = \int_n^1 b_t^{sf*} (k) \, dk$.

$$H_t = \left( \int_0^n H_t\left(l\right)^{\frac{\theta-1}{\theta}} dl \right)^{\frac{\theta}{\theta-1}} \tag{20}$$

where $H_t = \int_0^n h_t\left(i\right) di$. Since the household supplies a differentiated type of labor, it faces a downward sloping labor demand function:

$$H_t\left(l\right) = \left( \frac{W_t\left(l\right)}{W_t} \right)^{-\theta} H_t$$

In any given period, household $j$ faces a probability of $1 - \xi_w$ of being able to reset their wage, otherwise it is reset automatically according to $W_t\left(l\right) = \pi_{t-1} W_{t-1}\left(l\right)$.

If household $j$ is allowed to reset their wages in period $t$ they will set a wage to maximize the expected present value of utility from consumption minus the disutility of labor.

$$E_t \sum_{\tau=0}^{\infty} \beta^\tau \left(\xi_w\right)^\tau \left\{ \lambda_{t+\tau} \Pi_{t,t+\tau} W_t\left(l\right) H_{t+\tau}\left(l\right) - \psi \left(H_{t+\tau}\left(l\right)\right)^{\frac{1+\sigma_H}{\sigma_H}} \right\}$$

Thus after technical details which are located in the appendix, the household that can reset wages in period $t$ will choose a wage:

$$W_t\left(l\right)^{\frac{\theta}{\sigma_H}+1} = \frac{\theta}{\theta-1} \frac{1+\sigma_H}{\sigma_H} \psi \left(W_t\right)^{\frac{\theta}{\sigma_H}} \frac{E_t \sum_{\tau=0}^{\infty} \beta^\tau \left(\xi_w\right)^\tau \left( \frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t} \right)^{\frac{\theta}{\sigma_H}+\theta} \left(H_{t+\tau}\right)^{\frac{1+\sigma_H}{\sigma_H}}}{E_t \sum_{\tau=0}^{\infty} \beta^\tau \left(\xi_w\right)^\tau \lambda_{t+\tau} \Pi_{t,t+\tau} \left( \frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t} \right)^{\theta} H_{t+\tau}}$$

If wages are flexible, and thus $\xi_w = 0$, this expression reduces to:

$$W_t\left(l\right) = \frac{\theta}{\theta-1} \frac{\frac{1+\sigma_H}{\sigma_H} \psi \left(H_t\right)^{\frac{1}{\sigma_H}}}{\lambda_t}$$

Thus when wages are flexible the wage rate is equal to a mark-up, $\frac{\theta}{(\theta-1)}$, multiplied by the marginal disutility of labor, $\frac{1+\sigma_H}{\sigma_H} \psi \left(H_t\right)^{\frac{1}{\sigma_H}}$, divided by the marginal utility of consumption, $\lambda_t$.

Write the wage rate for the household that can reset wages in period $t$, $W_t\left(l\right)$, as $\tilde{W}_t\left(l\right)$ to denote it as an optimal wage. Also note that all households that can reset wages in period $t$ will reset to the same wage rate, so $\tilde{W}_t\left(l\right) = \tilde{W}_t$.

All households face a probability of $\left(1 - \xi_w\right)$ of being able to reset their wages in a given period, so by the law of large numbers $\left(1 - \xi_w\right)$ of households can reset their wages in a given period. The wages of the other $\xi_w$ will automatically reset by the previous periods inflation rate.

Substitute $\tilde{W}_t$ into the expression for the average wage rate $W_t = \left( \int_0^n W_t\left(l\right)^{1-\theta} dl \right)^{\frac{1}{1-\theta}}$, to derive an expression for the evolution of the average wage:

$$W_t = \left( \xi_w \left(\Pi_{t-1,t} W_{t-1}\right)^{1-\theta} + \left(1 - \xi_w\right) \left(\tilde{W}_t\right)^{1-\theta} \right)^{\frac{1}{1-\theta}}$$

## 2.6  Monetary Policy

The monetary policy instrument is the short term risk free rate, $i_t$, which is determined by the central bank's Taylor rule function:

$$i_{t+1} = i_{ss} + \theta_i \left( i_t - i_{ss} \right) + (1 - \theta_i) \left( \theta_p \pi_t + \theta_y \hat{y}_t + \theta_{fe} \Delta S_t + \theta_r r\hat{p}_t^b + \theta_{rf} r\hat{p}_t^{b*} \right) \qquad (21)$$

where $\pi_t = \frac{P_t}{P_{t-4}} - 1$, $\hat{y}_t = \frac{GDP_t}{G\tilde{D}P_t} - 1$, and $\Delta S_t = \frac{S_t}{S_{t-1}} - 1$. $G\tilde{D}P_t$ is the level of GDP at time $t$ in an economy with the same structure as the one just described and subject to the same shocks, only there are no price or wage frictions, $\xi_p = \xi_w = 0$, and there are no financial frictions, $\sigma^e = \sigma^b = 0$.

When $\theta_r = \theta_{rf} = 0$, the central bank does not place any weight on conditions in the interbank markets and the Taylor rule is simply the conventional Taylor rule with smoothing.

Recall from equation (16) that fluctuations in the interbank lending spread $r\hat{p}_t^b$ have an endogenous and exogenous component, $r\hat{p}_t^b = r\hat{p}_t^{b,endo} + r\hat{p}_t^{b,exo}$. In another version of the Taylor rule, we assume that the central bank can distinguish between these two components and potentially respond differently to fluctuations in the spread depending on whether it is due to endogenous or exogenous factors. In this case the Taylor rule would take the form:

$$i_{t+1} = i_{ss} + \theta_i \left( i_t - i_{ss} \right) + (1 - \theta_i) \left( \theta_p \pi_t + \theta_y \hat{y}_t + \theta_{fe} \Delta S_t + \theta_r^{endo} r\hat{p}_t^{b,endo} + \theta_r^{exo} r\hat{p}_t^{b,exo} + \theta_{rf}^{endo} r\hat{p}_t^{b,endo*} + \theta_{rf}^{exo} r\hat{p}_t^{b,exo*} \right)$$
$$(22)$$

# 3  Parameter Values

The model in the previous section is solved with a first-order approximation and the results are found from simulations of the calibrated model. This section will begin by presenting the basic parameter values used in this calibration. Then we will describe the various types of exogenous shocks that will drive the simulations of the model and the calibration of these different shock processes.

The full list of the model's parameters and their values is found in table 1.

The first eight parameters: the discount factor, the capital depreciation rate, capital's share of income, the elasticity of substitution between home and foreign goods, the bond adjustment cost parameter, the labor supply elasticity, the elasticity of substitution between goods from different firms, and the elasticity of substitution between labor from different households are all set to values that are commonly found in the literature.

The capital adjustment cost parameter, $\kappa$, describes the curvature of the capital adjustment function $\phi \left( \frac{I_t}{K_t} \right)$. It is the elasticity of the relative price of capital with respect to changes in the investment-capital ratio. This parameter preforms the important functions of lowering the relative volatility of investment and ensuring the procyclicality of the price of capital. Empirical estimates of this parameter vary, but the value of 0.250 is in the middle of the range of empirical estimates and ensures that the relative volatility of investment in the model is near what we see in the data.

The next two parameters in the table are the Calvo price and wage stickiness parameters. The wage stickiness parameter is chosen such that on average a household adjusts their wages once a year. The price stickiness parameter implies that prices are a little more flexible than wages and is taken from the DSGE estimation literature (see e.g. Christiano et al., 2005).

The next four parameters are all determined so that the steady state of the model is able to match certain features of the data. The $\gamma$ and $\gamma^f$ parameters from the function that aggregates home and foreign goods in (2) are set such that the home country has a steady state import share of 25%.[7] The next two parameters, $\phi$ and $\psi$ are the fixed cost in the production of intermediate goods and the weight on the disutility from labor in the household's utility function, respectively. These are set to ensure that in the steady state, intermediate goods firms earn zero economic profit and the household's labor supply is unity.

Finally the last three parameters in the table relate to the risk of bankruptcy and liquidation costs in either the banking or entrepreneurial sectors. The steady state value of $\sigma_t^b$ measures the steady state level of uncertainty in the financial sector. This parameter is determined to ensure that in the steady state of the model, when banks have a debt-asset ratio of about 0.9, there is a 13 basis point spread between interbank rates and the risk free rate, the average quarterly spread between the 3-month Libor and the 3-month T-bill from 1984 to 2007.

The cost of liquidation and the idiosyncratic bankruptcy risk in the entrepreneurial sector, $\mu^e$ and $\sigma_e$ are jointly determined. These parameters ensure that in the steady state of the model, when firms in the entrepreneurial sector have a debt-asset ratio of 0.5, an entrepreneur faces a 2% probability of bankruptcy and the steady state spread between the interest rate on physical capital loans and the bank's cost of capital is approximately 70 basis points.[8]

## 3.1 Exogenous Shock Processes

In this model there are two types of shocks. The first shock is simply a country specific shock to total factor productivity (TFP) in (1). The second shock is a shock arising out of the financial sector. In terms of the model this is a shock to the uncertainty about the health of a bank's assets, $\sigma_t^b$, more generally it can be thought of as a shock to the intermediation process that pushes back the supply curve in the credit market.

Since TFP shocks are not the primary focus of the study, we set the exogenous process that governs TFP shocks to a simple process that is familiar in the real business cycle literature. Shocks to home and foreign TFP, $\hat{A}_t$ and $\hat{A}_t^*$ each follow an AR(1) process with an autoregressive coefficient of 0.9. Since the model is solved using a first order approximation, we simply normalize the variance

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[7]From the demand functions for domestically supplied intermediate inputs and imports, equations (3) and (4),

the steady state import share is: $m = \dfrac{\displaystyle\int_n^1 P_t^m(i)y_t^m(i)}{\displaystyle\int_0^n P_t^d(i)y_t^d(i) + \int_n^1 P_t^m(i)y_t^m(i)} = \dfrac{\gamma^f(1-n)^{\frac{1-\rho}{1-\sigma}}}{\gamma(n)^{\frac{1-\rho}{1-\sigma}} + \gamma^f(1-n)^{\frac{1-\rho}{1-\sigma}}}$

[8]The calibration that entrepreneurs have a steady state debt-asset ratio of about 0.5 and banks have a steady state debt-asset ratio of about 0.9 is based on the historical average debt-asset ratios for U.S. non-financial and financial firms as reported in the Federal Reserve's Flow of Funds Accounts.

of the shocks to TFP to one.

Alternatively we can consider shocks to the financial sector uncertainty variable, $\sigma_{t+1}^b$. Equation (16) describes how fluctuations in the interbank lending spread can be broken down into two components, one due to fluctuations in the endogenous cutoff value $\bar{\omega}_{t+1}^b$, and one due to exogenous fluctuations in financial sector risk, $\sigma_{t+1}^b$.

$$r\hat{p}_t^b \approx g_1 \left( \frac{\bar{\omega}_{t+1}^b - \bar{\omega}_{ss}^b}{\bar{\omega}_{ss}^b} \right) + g_2 \left( \frac{\sigma_{t+1}^b - \sigma_{ss}^b}{\sigma_{ss}^b} \right)$$

Due to the financial frictions in the model, movements in $\bar{\omega}_{t+1}^b$ will cause movements in $r\hat{p}_t^b$ even when the TFP shock is the only shock in the model. If we calculate the spread between the 3-month Libor and the 3-month T-bill (the TED spread) from U.S. data from the first quarter of 1984 to the third quarter of 2011, the TED spread has a first order autocorrelation coefficient of 0.762, and the ratio of the standard deviation of the TED spread to the standard deviation of HP filtered GDP over the same period is 0.106.

In the model with only TFP shocks, the first order autocorrelation of $r\hat{p}_t^b$ is 0.966 and the volatility of $r\hat{p}_t^b$ relative to the volatility of $GDP$ is 0.012. If we assume that $\sigma_{t+1}^b$ follows an AR(1) process with autoregressive coefficient of 0.8 then as the variance of the financial shock increases, the autoregressive coefficient of $r\hat{p}_t^b$ approaches 0.762. In the next section we will present the results from finding the optimal Taylor rule coefficients in the model under different assumptions about the volatility of the exogenous process for the financial shocks $\sigma_{t+1}^b$. Under each of these different assumptions about the strength of the financial shocks, we will report the volatility of $r\hat{p}_t^b$ relative to the volatility of $GDP$. In the different cases we consider, this relative volatility varies from about 1% under no financial shocks to as high as 20%.

## 4    Results

To find the optimal coefficients in the central bank's Taylor rule and access how these optimal parameters change as the degree of financial sector risk in the economy changes, we first have to define the loss function that the central bank will attempt to minimize. In order to ensure that the changes in optimal policy are due to changes in the structure of the economy and the transmission mechanism and not due to changes in the central bank's preferences, this loss function should remain the same regardless of the degree of financial sector risk in the economy.

When finding the optimal coefficients in the Taylor rule, the central bank will attempt to minimize:

$$\mathcal{L} = var\left(\pi_t\right) + 0.5 * var\left(\hat{y}_t\right) + 0.1 * var\left(i_t - i_{t-1}\right)$$

where $\pi_t$ is the inflation rate, $\hat{y}_t$ is the output gap, and $i_t - i_{t-1}$ is the quarter-over-quarter difference in the nominal risk free interest rate.

## 4.1 Taylor rule parameters in the benchmark version of the model

To evaluate how monetary policy should respond to financial sector risk, we first identify the optimal weights on inflation, the output gap, the lagged interest rate, and possibly the nominal exchange rate in the Taylor rule function in the model where business cycles are driven by both productivity and financial shocks.

We find these parameters through a grid search. We vary $\theta_p$, $\theta_y$, $\theta_i$, and possibly $\theta_{fe}$ until we find the combination of the terms in the central bank's Taylor rule function that minimizes the central bank's loss function. As described in equation (16), fluctuations in the interbank lending rate are driven in part by fluctuations in $\bar{\omega}_t^b$, the cutoff value for insolvency in the banking sector, which is determined by endogenous variables like debt-asset ratios and loan loss ratios. In addition, fluctuations in the interbank spread are also driven by exogenous fluctuations in $\sigma_t^b$, the stochastic variable that measures the degree of ex-ante uncertainty about the health of a particular bank's assets.

Define $\Sigma$ as the standard deviation of the exogenous fluctuations in the interbank lending spread. The standard deviation of exogenous TFP fluctuations is normalized to one, so $\Sigma$ measures the ratio of the standard deviations of the two shocks in the model, the exogenous shocks to the interbank spread and the exogenous shocks to TFP.

$$\Sigma^2 = \frac{var\left[g_2\left(\frac{\sigma_{t+1}^b - \sigma_{ss}^b}{\sigma_{ss}^b}\right)\right]}{var\left[A_t\right]}$$

The optimal weights on inflation, the output gap, the lagged interest rate, and possibly the exchange rate under different values of $\Sigma$ are presented in table 2. The first four columns in the table present the optimal values of the four Taylor rule parameters. The fifth column reports the ratio of the standard deviation of fluctuations in the interbank lending spread to the standard deviation of fluctuations to $GDP$. As reported in an earlier section, this ratio is approximately 0.1 in U.S. data. Finally the sixth column reports the distance between the value of the loss function when the Taylor rule parameters are optimally chosen and the value of the loss function under the cooperative Ramsey optimal policy.

The coefficient on the nominal exchange rate in the Taylor rule is fixed at zero in the top panel of table 2. In the bottom panel the central bank also chooses the optimal coefficient on the exchange rate. In the first row in each panel, when $\Sigma = 0$, there are no exogenous final shocks in the model and fluctuations are driven entirely by exogenous TFP shocks. In this case, fluctuations in the interbank lending spread are about 1.2% as volatile as fluctuations to $GDP$, and the combination of optimal Taylor rule parameters yield a value of the loss function about 12.6% higher than the value under the Ramsey optimal policy.

When the central bank can also choose an optimal coefficient on the nominal exchange rate, the central bank will place slightly less weight on the inflation rate and the output gap and instead put some weight on the exchange rate. The value of the optimal exchange rate coefficient is about 0.15,

implying that the central bank will increase the risk free rate by about 15 basis points in response to a 1 percentage point exchange rate depreciation. If the central bank is able to put some weight on the nominal exchange rate, the outcome is slightly better and now the value of the loss function under the optimal Taylor rule parameters is about 12.3% above Ramsey optimal policy.

As $\Sigma$ increases the exogenous financial shocks become increasingly important in driving the model. The fifth column in table 2 shows that when the model is driven solely by TFP shocks, fluctuations in the interbank lending spread are about 1.2% as volatile as fluctuations to $GDP$, but when $\Sigma = 0.175$, fluctuations in the interbank lending spread are about 20% as volatile as fluctuations to $GDP$. As financial shocks becomes a more important driver of the business cycle, the central bank will want to increase the weight on the inflation rate, the output gap, and the lagged nominal interest rate. While the central bank does adjust the optimal parameters somewhat when financial shocks drive business cycle fluctuations, the central bank can't do very much, and the value of the loss function under the optimal choice of Taylor rule coefficients just gets further from the Ramsey optimal policy. When $\Sigma = 0$, and thus there are no exogenous final shocks in the model, the value of the loss function is about 12.6% higher than the value under the Ramsey optimal policy. When $\Sigma = 0.175$, the value of the central bank's loss function under the optimal choice of Taylor rule parameters is about 16.5% higher than its value under Ramsey optimal policy.

### 4.1.1 The optimal weight on the home and foreign interbank lending spread

The previous section discusses how a central bank would shift the weights on inflation, the output gap, the lagged interest rate, and possibly the exchange rate when there is variability in the interbank lending spread. This section will consider if there is any additional benefit to putting a measure of financial risk, like interbank lending spreads, directly in the Taylor rule.

Recall from equation (21), $\theta_r$ and $\theta_{rf}$ are the weights on the home and foreign interbank lending spreads, respectively, in the central bank's Taylor rule. If $\theta_r = 0$, then the central bank does not react to changes in home interbank lending spreads, but if $\theta_r < 0$, the central bank responds to an increase in interbank lending spreads by lowering the nominal risk free rate.

We use the same procedure that was used to calculate the results in table 2, only now instead of finding the optimal coefficients $\theta_p$, $\theta_y$, $\theta_i$, and possibly $\theta_{fe}$, we vary $\theta_p$, $\theta_y$, $\theta_i$, $\theta_r$, $\theta_{rf}$ and possibly $\theta_{fe}$. These optimal coefficients are presented in table 3.

The first and most important finding in the table is that the optimal coefficient on the interbank spread is zero when $\Sigma$ is zero. In other words, when the conventional Taylor rule parameters are chosen optimally, there is no need to also include interbank spreads in the central bank's policy function provided that any fluctuations in the spread are endogenous reactions to real shocks in the model. If fluctuations in the spread are the endogenous reaction to fluctuations in real and nominal variables in the model, then interbank spreads provide no new information that is not already provided by measures of the output gap and inflation. If the central bank chooses the optimal weights on the output gap and inflation, then there is no need to also pay attention to changes in spreads. If the central bank were to assign a non-zero coefficient on the interbank spread, $\theta_r < 0$

or $\theta_{rf} < 0$, the weighting of the available information is no longer optimal.

This result changes when the model is also driven by exogenous financial sector shocks. When there are exogenous financial sector shocks, there is information in the interbank spread that may not be contained in readings of current inflation and the current output gap. Thus the central bank may find it worthwhile to also pay attention to interbank spreads, $\theta_r < 0$ and $\theta_{rf} < 0$, given that they potentially contain new information that is not already factored into the optimal weighting of the output gap and inflation.

The table shows that as the standard deviation of the exogenous financial sector shocks increases, the amount of new information contained in the interbank spread increases and thus the coefficient on the interbank spread increases (in absolute value). This highlights the fact that when setting a non-zero coefficient to the interbank spread, the central bank faces a trade-off. When there are exogenous financial sector shocks in the model, fluctuations in the spread are driven by both endogenous and exogenous factors. Since the endogenous fluctuations contain no new information that is not already contained in the optimally chosen weighting of inflation and the output gap, assigning any weight to these endogenous components is suboptimal. However the exogenous component does contain new information, and thus ignoring this component is suboptimal. When increasing the weight on the interbank spread, the central bank is balancing the marginal benefit of increasing the coefficient on the exogenous component against the marginal cost of increasing the weight on the endogenous component. Thus when $\Sigma = 0.05$, the exogenous financial sector shocks are weak enough that the cost still outweighs the benefit and thus the optimal coefficient is zero, $\theta_r = 0$ or $\theta_{rf} = 0$. When $\Sigma = 0.10$ the exogenous financial sector shock is stronger and now the marginal benefit of including spreads in the Taylor rule equals the marginal cost at a non-zero coefficient. When $\Sigma = 0.175$ the exogenous financial shock is stronger still and thus the marginal benefit of targeting the exogenous component of the spread is equal to the marginal cost of targeting the endogenous component at an even higher coefficient (in absolute value).

Notice that the central bank will put less weight on the foreign interbank lending spread than the domestic spread. The results from the $\Sigma = 0.175$ row in the top panel of the table show that when the central bank cannot put weight on the nominal exchange rate, it will cut the risk free rate by 61 basis points in response to a 1 percentage point increase in the domestic interbank spread, and it will cut the risk free rate by 17 basis points in response to a 1 percentage point increase in the foreign interbank spread. However, if the central bank is also able to assign a non-zero coefficient to the nominal exchange rate, then it will only cut the risk free rate by 6 basis points in response to the increase in the foreign interbank spread, and will instead cut the risk free rate by 18 basis points in response to a 1 percentage point nominal exchange rate appreciation.

Recall from table 2 that when $\Sigma$ increases, the conventional Taylor rule quickly becomes a poor approximation for the true optimal policy. When $\Sigma = 0$, the value of the loss function under the Taylor rule is about 12.6% higher than the value under the Ramsey solution but when $\Sigma = 0.175$, the conventional Taylor rule now misses the true optimum by 16.5%. This trend is largely halted when the Taylor rule is also a function of the interbank lending spread. Table 3 shows that when

$\Sigma = 0$, the Taylor rule with interbank lending spreads as a potential argument misses the true optimum by 12.6%, and when $\Sigma = 0.175$ the modified Taylor rule only misses the true optimum by about 14%. Thus when credit shocks are a potential source of economic fluctuations, including interbank spreads in the Taylor rule leads to a significant improvement over conventional monetary policy that is simply a function of inflation and the output gap.

### 4.1.2 The optimal weights when endogenous fluctuations are separated from exogenous fluctuations

Given that when setting the optimal coefficients on the home and foreign interbank lending spreads the central bank must balance the benefit of targeting the exogenous component of the spread against the cost of targeting the endogenous component of the spread, the natural question arises, what are the optimal coefficients on the home and foreign interbank lending spreads when the central bank can distinguish between endogenous and exogenous fluctuations?

The optimal coefficients on interbank lending spreads assuming that the central bank can distinguish between endogenous and exogenous components of the spread are presented in table 4. The results in the table confirm the earlier intuition. The optimal policy is to assign a coefficient of zero to endogenous fluctuations in the spread and assign a negative coefficient to exogenous fluctuations. Thus the optimal policy is to ignore endogenous fluctuations since they contain no new information that is not already contained in the optimal weighting of the output gap and the inflation rate, but at the same time accommodate exogenous fluctuations in the spread, and thus lower the nominal risk free rate in response to an exogenous increase in the interbank spread.

In the case where the central bank cannot react to fluctuations in the nominal exchange rate, the central bank cuts the risk free rate by about $80 - 90$ basis points in response to a 100 basis point increase in the exogenous portion of the domestic spread and by about $30 - 40$ basis points in response to a similar increase in the foreign spread. Unlike the results in table 3 where the central bank cannot distinguish between the endogenous and exogenous fluctuations in the spread, and thus the central bank had to balance the cost of putting weight on the endogenous portion against the benefit of putting weight on the exogenous position, the optimal weights in table 4 are largely invariant to the relative strength of the exogenous financial sector shocks.

The last column of table 4 shows again that when the Taylor rule is also a function of interbank lending spreads, the severity of the exogenous financial shocks do not have much of an effect on the distance between the value of the loss function under the Taylor rule and the value under Ramsey optimal policy. A comparison of the last column in table 3 with that in table 4 shows that there is a slight welfare improvement when the central bank is able to distinguish between the endogenous and exogenous portions of the spread. In the closed economy, when $\Sigma = 0.175$, the modified Taylor rule where the central bank cannot identify the the source of the fluctuations in the spread yields a loss function about 14.2% above the optimum, when the central bank can distinguish between different types of fluctuations, the value of the loss function is only 14% above the optimum.

## 4.2 Optimal policy under increased trade and financial integration

The results so far are calculated for the benchmark parameterization of the model, in the steady state imports make up 25% of the consumption basket, and entrepreneurs borrow only from banks in their own country. In this subsection we will examine how the prescription for optimal policy can change when the degree of trade or financial integration increases.

**Optimal policy under increased levels of trade integration**  The optimal Taylor rule parameters when in the steady state, imports make up 50% of the consumption basket are presented in tables 5-7. The optimal parameters when the central bank does not directly target the interbank lending spread are presented in table 5. The results are similar to the results from the benchmark parameterization in table 2. As financial shocks become increasingly important for driving business cycle fluctuations, the central bank will increase the coefficients on the inflation rate, the output gap, and the lagged interest rate. However, the last column of the table shows that really the central bank can't do much in the face of financial shocks without directly targeting the interbank rate. When $\Sigma = 0$, and thus fluctuations in the interbank spread are only about 1% as volatile as GDP, the loss function under the optimally chosen Taylor rule is about 12% higher than its value under Ramsey optimal policy, but when $\Sigma = 0.175$ and fluctuations in the interbank spread are more than 20% as volatile as GDP, the loss function under the optimally chosen Taylor rule is 16% higher than its value under Ramsey policy.

The major difference between the benchmark case when the import share is 25% and the case where the import share is 50%, is that the the optimal coefficients $\theta_p$, $\theta_y$, and $\theta_i$, are smaller when trade integration is higher. The central bank places less weight on the domestic inflation rate, output gap, and lagged interest rate when the import share is equal to 50%. Also, under increased trade integration, the central bank places significantly more weight on the nominal exchange rate. Under the benchmark parameterization, when the import share is equal to 25%, the central bank will raise the risk free rate by about 16 basis points in response to a 1% nominal currency depreciation. When the trade share is equal to 50% now the central bank will increase the risk free rate by 60 basis points in response to a 1% nominal currency depreciation.

The optimal parameters from the case where the central bank can target the home and foreign interbank spreads, but cannot distinguish between the endogenous and exogenous components of the spread, are found in table 6.Recall that under the benchmark parameterization in table 3, that the central bank faces a trade-off between wanting to target the exogenous part of the spread, but wanting to ignore the endogenous portion. This same tendency is seen in the table 6. When $\Sigma = 0$, and thus there are only TFP shocks in the model, the central bank will ignore the interbank spread. As $\Sigma$ increases, the central bank will gradually place more weight on the home and foreign interbank spread.

However, in the benchmark parameterization, the central bank will always places significantly more weight on the home interbank spread, around 4-5 times more. Under increased trade integration, the central bank puts roughly the same weight on the home and foreign interbank spreads

when the central bank cannot directly target the nominal exchange rate. When the central bank can target the exchange rate, it puts weight on the exchange rate and lessens the weight it places on the foreign interbank spread.

Table 7 presents the optimal Taylor rule parameters under high trade integration in the case where the central bank can distinguish between endogenous and exogenous fluctuations in the interbank lending spread. The results are similar to those in under the benchmark parameterization, except under the benchmark parametrization the central bank would place about twice as much weight on exogenous fluctuations in the domestic interbank spread as they would on the exogenous component of the foreign spread. Under higher levels of trade integration, the weights the central bank places on the exogenous components of the domestic and foreign spreads are about equal.

**Optimal policy under increased levels of financial integration** In the benchmark parameterization, domestic banks lent exclusively to domestic entrepreneurs and foreign banks lent exclusively to foreign entrepreneurs. The optimal Taylor rule parameters from the alternative parameterization where banks make 50% of their loans to entrepreneurs in the other country are presented in tables 8-10. Tables 8-10 present the results where this foreign borrowing is denominated in the entrepreneur's currency. The results where the foreign borrowing is denominated in the bank's currency are forthcoming.

The results from table 8, where half of an entrepreneur's borrowing is from foreign banks in the entrepreneur's currency, show the familiar result from the earlier model where the central bank can only choose the optimal conventional Taylor rule parameters. Other than slightly increase the weight on the lagged interest rate, the inflation rate, and the output gap, there isn't much the central bank can do in the face of financial shocks. Despite reoptimizing for each new level of financial shocks, the distance between the value of the loss function under the Taylor rule and the value under Ramsey optimal policy gets worse as the variance of the financial shocks increases.

If the central bank can target the home and foreign interbank lending spread, its ability to reoptimize in the face of increasing risk from the financial sector is greatly improved, as seen in table 9. Unlike the benchmark case where there was no foreign borrowing, when there is a high degree of foreign borrowing, even in the domestic currency, the central bank will place about equal weight both the home and foreign interbank spread. This was true in the case with high trade integration as well in table 6, except in the case with high trade integration when the central bank could also target the nominal exchange rate, the optimal weight on the foreign interbank spread fell considerably. When there is a high degree of borrowing from foreign banks, the central bank will not change the weight it places on the foreign interbank spread even when it can also target the nominal exchange rate. When it can also target the exchange rate, the optimal policy is to actually reduce the weight it places on the home interbank spread. This same pattern holds in table 10 when the central bank can distinguish between endogenous and exogenous changes in the interbank lending spread. As in the benchmark case, the central bank will choose to ignore the endogenous movements in the spread, yet react to the exogenous movements in the spread. However, unlike

the benchmark case, when there is a high degree of foreign borrowing, the central bank will put about equal weight on the exogenous components of both the home and foreign interbank lending spreads.

## 4.3 Impulse responses under Ramsey optimal policy and Taylor rules with and without spreads

In the previous section we show how including spreads in the Taylor rule can numerically bring us closer to true optimal policy. In this section we will instead consider impulse responses to see the path of the output gap, inflation and other macro variables following a shock and show how including spreads in the Taylor rule can make the path of these variables following a shock closer to the true optimal path.

Figure 1 presents the responses of the output gap, inflation, investment, the real risk free rate, the entrepreneurial risk spread $(r_t^e - r_t^b)$, and the interbank lending spread $(r_t^b - i_t)$ following an exogenous shock to home financial sector uncertainty, $\sigma_t^b$. The responses are plotted under three assumptions for monetary policy. The solid line represents Ramsey optimal monetary policy, the dashed line is the path when policy is determined by a Taylor rule function of the output gap, inflation, and the lagged interest rate, and the line with stars is the path when monetary policy is determined by a Taylor rule function of the output gap, inflation, the lagged interest rate, and the home and foreign interbank lending spreads.[9]

The entire process is driven by an exogenous 30 basis point increase in the interbank lending spread, as shown in the lower right-hand diagram. When monetary policy is determined by a conventional Taylor rule without interbank lending spreads, this exogenous increase in the spread leads to a 4% fall in investment and a 20 basis point increase in the gap between potential and actual output. If however monetary policy is the true optimal, there is a sudden cut in the real risk free rate. This ensures that there is only a 2.5% fall in investment and a slight improvement in the output gap.

When spreads are included in the Taylor rule, the path of the risk free rate following the shock is closer to the path determined by Ramsey optimal policy. As a result the path of investment and the output gap when policy is determined by the Taylor rule with spreads is very similar to the optimal policy under Ramsey policy.

It should be noted however that the policy of including spreads in the Taylor rule, while closer to true optimal policy than when spreads are ignored, is not costless. The exogenous financial sector uncertainty shock is a shock to the efficiency of financial intermediation. Specifically it represents a shift in the supply curve in the interbank lending market. The central bank can cut the risk free rate to accommodate the shock, but it cannot reverse the shock. The cost of accommodation is higher inflation, as shown in the top right-hand diagram in the figure. Specifically, when monetary

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[9]In the case of the optimally chosen conventional Taylor rule without spreads, we use the coefficients from the $\Sigma = 0.15$ line of table 2. The parameters for the optimally chosen modified Taylor rule are taken from the $\Sigma = 0.15$ line of table 3.

policy is determined by a Taylor rule with spreads, accommodating the exogenous 30 basis point increase in the interbank lending spread results in a 10 basis point increase in inflation.

Figure 2 presents the responses of the same variables, but this time following a foreign financial shock. Again, the dashed line in the figure represents the optimal Taylor rule function of the output gap, inflation, and the lagged interest rate, and the line with stars plots the optimal responses when the Taylor rule is also a function of both home and foreign interbank lending spreads. The solid line in the figure plots the responses where monetary policy in both countries is determined in a cooperative Ramsey equilibrium.

When monetary policy is determined by the optimal Taylor rule without interbank lending spreads, the output gap initially turns negative following the foreign financial shock. However, under the Ramsey optimal policy, monetary accommodation means that the output gap is initially positive following the foreign shock. This is also true when monetary policy is determined by the optimal Taylor rule with interbank lending spreads. The negative coefficient on the foreign interbank lending spread in the Taylor rule makes monetary policy more accommodative and the home output gap is actually positive following the foreign financial shock.

Figures 3 and 4 present the responses of the same variables to the same home and foreign financial shocks, but here the steady state import share is 0.5, and thus the two symmetric countries have fully integrated trade markets. Figure 5 and 6 present these same impulse responses but where half of a bank's loan portfolio is in loan to foreign entrepreneurs. All four of these figures show the same story. Following the shock, the output gap turns negative in the version of the model where monetary policy is determined by the optimal Taylor rule ignoring interbank lending spreads. When monetary policy is determined by Ramsey optimal policy, monetary policy is very accommodative and the response of the output gap is positive following both the home and foreign financial shocks. However the positive response of the output gap comes at the expense of higher inflation.

The impulse responses from the version of the model where spreads are included in the Taylor rule is much closer to the responses from Ramsey policy, implying that including spreads in the Taylor rule brings us much closer to the true optimal policy following a financial shock.

## 5  Conclusion

This paper presents a framework to think about how monetary policy should react to periods of stress in the financial markets in an open economy environment. Specifically, should the central bank incorporate domestic or foreign interbank lending spreads into their Taylor type policy rule?

The answer is a resounding maybe! More specifically, it should depend on whether or not the spread contains any new information that isn't already contained in measures of the output gap and inflation. If the fluctuations in the interbank rates are the endogenous responses to other variations and if the coefficients on the conventional target variables in the Taylor rule policy function are chosen optimally, then the central bank has already chosen the optimal weighting to assign to information contained in the output gap and information contained in the inflation

rate. Thus assigning any weight to a new term like the interbank lending spreads that contains no new information is suboptimal. However, when fluctuations in the interbank rate are driven by exogenous financial sector shocks, the central bank may want to reduce the risk free rate in response to an exogenous increase in the interbank lending spread.

A second interesting question to come out of this analysis is, how are these weights affected by the fact that the central bank may also respond directly to the nominal exchange rate? We have shown how the option of the central bank to also respond directly to the nominal exchange rate may significantly affect the optimal responses to the financial market conditions. The fact that the central bank can also target the nominal exchange rate makes its optimal response to the domestic interbank leading spread stronger but that to the foreign interbank leading spread weaker. The central bank faces a trade-off between exchange rate stability and reacting to domestic financial shocks. Following a domestic financial shock, the policy prescription for exchange rate stability is the opposite of what the central bank would like to do to ensure stability in the domestic interbank market, so when the central bank puts weight on the exchange rate, it will want to compensate by putting more weight on the domestic interbank lending spread. Following a foreign financial shock, the central bank faces no such trade-off, and the policy prescription to ensure exchange rate stability is the same as the prescription to ensure financial stability. Thus when the central bank places weight on the nominal exchange rate, it is already partially doing the job of putting weight on the foreign interbank lending spread, so it does not need to put as much weight on foreign financial conditions.

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# A    Technical Appendix

This appendix will present some of the more technical derivations in the paper related to the nominal rigidities and financial frictions present in the model. The first part of the appendix, section A.1 presents the derivations involved with the Calvo style wage and price equations. The second part of this appendix, section A.2 presents the proofs necessary for aggregation in the presence of financial frictions.

## A.1    Nominal Rigidities

### A.1.1    Sticky Wages

In any given period, household $j$ faces a probability of $1 - \xi_w$ of being able to reset their wage, otherwise it is reset automatically according to $W_t(l) = \pi_{t-1}W_{t-1}(l)$, where $\pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$.

If household $j$ is allowed to reset their wages in period $t$ they will set a wage to maximize the expected present value of utility from consumption minus the disutility of labor.

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left\{ \lambda_{t+\tau} \Pi_{t,t+\tau} W_t(l) H_{t+\tau}(l) - \psi (H_{t+\tau}(l))^{\frac{1+\sigma_H}{\sigma_H}} \right\} \tag{23}$$

where $\lambda_{t+\tau}$ is the marginal utility of consumption in period $t + \tau$.[10]

$$\Pi_{t,t+\tau} = \begin{cases} 1 & \text{if } \tau = 0 \\ \pi_{t+\tau-1}\Pi_{t,t+\tau-1} & \text{if } \tau > 0 \end{cases}$$

The imperfect combination of labor from different households is described in (20). Use this function to derive the demand function for labor from a specific household:

$$H_t(l) = \left(\frac{W_t(l)}{W_t}\right)^{-\theta} H_t \tag{24}$$

where $W_t = \left(\int_0^n W_t(l)^{1-\theta} dl\right)^{\frac{1}{1-\theta}}$ is the average wage across households, and $H_t$ is aggregate labor supplied by all households.

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[10]We assume complete contingent claims markets among households within a country. This implies that the marginal utility of consumption is the same across all households within a country, regardless of their income. Therefore the total utility from the consumption of labor income in any period is simply the country specific marginal utility of comsumption, $\lambda_t$, multiplied by the household's labor income, $W_t(l) N_t(l)$.

Substitute the labor demand function into the maximization problem to express the maximization problem as a function of one choice variable, the wage rate, $W_t(l)$:

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left\{ \lambda_{t+\tau} \Pi_{t,t+\tau} W_t(l) \left( \frac{\Pi_{t,t+\tau} W_t(l)}{W_{t+\tau}} \right)^{-\theta} H_{t+\tau} - \psi \left( \left( \frac{\Pi_{t,t+\tau} W_t(l)}{W_{t+\tau}} \right)^{-\theta} H_{t+\tau} \right)^{\frac{1+\sigma_H}{\sigma_H}} \right\}$$

After some rearranging, the first order condition of this problem is:

$$W_t(l)^{\frac{\theta}{\sigma_N}+1} = \frac{\theta}{\theta-1} \frac{1+\sigma_H}{\sigma_H} \psi (W_t)^{\frac{\theta}{\sigma_H}} \frac{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left( \frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t} \right)^{\frac{\theta}{\sigma_H}+\theta} (H_{t+\tau})^{\frac{1+\sigma_H}{\sigma_H}}}{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \lambda_{t+\tau} \Pi_{t,t+\tau} \left( \frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t} \right)^{\theta} H_{t+\tau}}$$

If wages are flexible, and thus $\xi_w = 0$, this expression reduces to:

$$W_t(l) = \frac{\theta}{\theta-1} \frac{\frac{1+\sigma_H}{\sigma_H} \psi (H_t)^{\frac{1}{\sigma_H}}}{\lambda_t}$$

Thus when wages are flexible the wage rate is equal to a mark-up, $\frac{\theta}{(\theta-1)}$, multiplied by the marginal disutility of labor, $\frac{1+\sigma_H}{\sigma_H} \psi (H_t)^{\frac{1}{\sigma_H}}$, divided by the marginal utility of consumption, $\lambda_t$.

Write the wage rate for the household that can reset wages in period $t$, $W_t(l)$, as $\tilde{W}_t(l)$ to denote it as an optimal wage. Also note that all households that can reset wages in period $t$ will reset to the same wage rate, so $\tilde{W}_t(l) = \tilde{W}_t$.

All households face a probability of $(1 - \xi_w)$ of being able to reset their wages in a given period, so by the law of large numbers $(1 - \xi_w)$ of households can reset their wages in a given period. The wages of the other $\xi_w$ will automatically reset by the previous periods inflation rate.

So substitute $\tilde{W}_t$ into the expression for the average wage rate $W_t = \left( \int_0^n W_t(l)^{1-\theta} dl \right)^{\frac{1}{1-\theta}}$, to derive an expression for the evolution of the average wage:

$$W_t = \left( \xi_w (\Pi_{t-1,t} W_{t-1})^{1-\theta} + (1 - \xi_w) \left( \tilde{W}_t \right)^{1-\theta} \right)^{\frac{1}{1-\theta}}$$

### A.1.2   Sticky Output Prices

**Domestic Prices**   In the model, intermediate goods prices are sticky. Intermediate goods firms can set separate domestic and export prices.

In period $t$, the firm will be able to change it's price in the domestic market with probability $1 - \xi_p$. If the firm cannot change prices then they are reset automatically according to $P_t^d(i) = \pi_{t-1} P_{t-1}^d(i)$.

The firm that can reset prices in period $t$ will choose $P_t^d(i)$ to maximize discounted future profits:

$$\max_{P_t^d(i)} E_t \sum_{\tau=0}^{\infty} \beta^\tau \left(\xi_p\right)^\tau \lambda_{t+\tau} \left\{ \Pi_{t,t+\tau} P_t^d(i) y_{t+\tau}^d(i) - MC_{t+\tau} y_{t+\tau}^d(i) \right\}$$

where $MC_{t+\tau}$ is marginal cost of production in period $t + \tau$.

The firm's domestic demand is given in (3). Substitute this demand function into the maximization problem to express this problem as a function of one choice variable, $P_t(i)$:

$$\max_{P_t^d(i)} E_t \sum_{\tau=0}^{\infty} \beta^\tau \left(\xi_p\right)^\tau \lambda_{t+\tau} \left\{ \begin{array}{l} \Pi_{t,t+\tau} P_t^d(i) \gamma(n)^{\frac{1-\rho}{1-\sigma}-1} \left(\frac{\Pi_{t,t+\tau} P_t^d(i)}{P_{t+\tau}^d}\right)^{-\sigma} \left(\frac{P_{t+\tau}^d}{P_{t+\tau}}\right)^{-\rho} y_{t+\tau} \\ - MC_{t+\tau} \gamma(n)^{\frac{1-\rho}{1-\sigma}-1} \left(\frac{\Pi_{t,t+\tau} P_t^d(i)}{P_{t+\tau}^d}\right)^{-\sigma} \left(\frac{P_{t+\tau}^d}{P_{t+\tau}}\right)^{-\rho} y_{t+\tau} \end{array} \right\}$$

After some rearranging, the first order condition with respect to $P_t^d(i)$ is:

$$P_t^d(i) = \frac{\sigma}{\sigma - 1} \frac{E_t \sum_{\tau=0}^{\infty} \beta^\tau \left(\xi_p\right)^\tau \lambda_{t+\tau} MC_{t+\tau} \left(\frac{\Pi_{t,t+\tau}}{P_{t+\tau}^d}\right)^{-\sigma} \left(\frac{P_{t+\tau}^d}{P_{t+\tau}}\right)^{-\rho} y_{t+\tau}}{E_t \sum_{\tau=0}^{\infty} \beta^\tau \left(\xi_p\right)^\tau \lambda_{t+\tau} \Pi_{t,t+\tau} \left(\frac{\Pi_{t,t+\tau}}{P_{t+\tau}^d}\right)^{-\sigma} \left(\frac{P_{t+\tau}^d}{P_{t+\tau}}\right)^{-\rho} y_{t+\tau}}$$

If prices are flexible, and thus $\xi_p = 0$, then this expression reduces to:

$$P_t^d(i) = \frac{\sigma}{\sigma - 1} MC_t$$

which says that the firm will set a price equal to a constant mark-up over marginal cost.

Write the domestic price set by the firm that can reset prices in period $t$ as $\tilde{P}_t^d(i)$ to denote that it is an optimal price. Firms that can reset prices in period $t$ will all reset to the same level, so $\tilde{P}_t^d(i) = \tilde{P}_t^d$. Substitute this optimal price into the price index $P_t^d = \left(\frac{1}{n} \int_0^n \left(P_t^d(i)\right)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$ and use the fact that in any period $1 - \xi_p$ percent of firms will reoptimize prices, and the prices of $\xi_p$ percent of firms will be automatically reset using the previous periods inflation rate, to derive an expression for the domestic price index, $P_t^d$:

$$P_t^d = \left( \xi_p \left( \Pi_{t-1,t} P_{t-1}^d \right)^{1-\sigma} + (1 - \xi_p) \left( \tilde{P}_t^d \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

**Export Prices**  Domestic firm $i$, where $i \in [0, n]$, will set a price $P_t^{m*}(i)$ for its intermediate input in the foreign market.

The demand for the intermediate good from domestic firm $i$ in the rest of the world is given by:

$$y_t^{m*}(i) = (n)^{\frac{1-\rho}{1-\sigma}-1} \left( \frac{P_t^{m*}(i)}{P_t^{m*}} \right)^{-\sigma} \left( \frac{P_t^{m*}}{P_t^*} \right)^{-\rho} y_t^*$$

In period $t$, the firm will be able to change it's export price with probability $1 - \xi_p$. If the firm cannot change its price in the foreign market then it is reset automatically according to $P_t^{m*}(i) = \pi_{t-1}^* P_{t-1}^{m*}(i)$, where $\pi_{t-1}^* = \frac{P_{t-1}^*}{P_{t-2}^*}$.

If domestic firm $i$ was last able to change their export price in period $t$, the demand for the intermediate good from firm $i$ in the rest of the world in period $t + \tau$ is:

$$y_{t+\tau}^{m*}(i) = \gamma^{f*}(n)^{\frac{1-\rho}{1-\sigma}-1} \left( \frac{\Pi_{t,t+\tau}^* P_t^{m*}(i)}{P_{t+\tau}^{m*}} \right)^{-\sigma} \left( \frac{P_{t+\tau}^{m*}}{P_{t+\tau}^*} \right)^{-\rho} y_{t+\tau}^*$$

The firm that can reset prices in period $t$ will choose $P_t^{m*}(i)$ to maximize discounted future profits:

$$\max_{P_t^{m*}(i)} E_t \sum_{\tau=0}^{\infty} \beta^\tau (\xi_p)^\tau \lambda_{t+\tau} \left\{ \Pi_{t,t+\tau}^* \frac{P_t^{m*}(i)}{S_{t+\tau}} y_{t+\tau}^{m*}(i) - MC_{t+\tau} y_{t+\tau}^{m*}(i) \right\}$$

where $S_t$ is the nominal exchange rate denoted in units of the foreign currency per units of the home currency.

After some rearranging, the first order condition with respect to $P_t^{m*}(i)$ is:

$$P_t^{m*}(i) = \frac{\sigma}{\sigma - 1} \frac{E_t \sum_{\tau=0}^{\infty} \beta^\tau (\xi_p)^\tau \lambda_{t+\tau} MC_{t+\tau} \left( \frac{\Pi_{t,t+\tau}^*}{P_{t+\tau}^{m*}} \right)^{-\sigma} \left( \frac{P_{t+\tau}^{m*}}{P_{t+\tau}^*} \right)^{-\rho} y_{t+\tau}^*}{E_t \sum_{\tau=0}^{\infty} \beta^\tau (\xi_p)^\tau \lambda_{t+\tau} \frac{\Pi_{t,t+\tau}^*}{S_{t+\tau}} \left( \frac{\Pi_{t,t+\tau}^*}{P_{t+\tau}^{m*}} \right)^{-\sigma} \left( \frac{P_{t+\tau}^{m*}}{P_{t+\tau}^*} \right)^{-\rho} y_{t+\tau}^*}$$

If prices are flexible, and thus $\xi_p = 0$, then this expression reduces to:

$$P_t^{m*}(i) = \frac{\sigma}{\sigma - 1} S_t MC_t$$

Denote $\tilde{P}_t^{m*}(i)$ as the optimal price for the foreign market set by a firm that was able to change their prices in period $t$. Firms that can reset prices in period $t$ will all reset to the same level, so $\tilde{P}_t^{m*}(i) = \tilde{P}_t^{m*}$. Substitute this optimal price into the price index $P_t^{m*} = \left(\frac{1}{n}\int_0^n \left(P_t^{m*}(i)\right)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$ and use the fact that in any period $1 - \xi_p$ percent of firms will reoptimize prices, and the prices of $\xi_p$ percent of firms will be automatically reset using the previous periods inflation rate, to derive an expression for the import price index, $P_t^{m*}$:

$$P_t^{m*} = \left(\xi_p\left(\Pi_{t-1,t}^* P_{t-1}^{m*}\right)^{1-\sigma} + \left(1 - \xi_p\right)\left(\tilde{P}_t^{m*}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

## A.2 Financial Frictions

The derivation of the various interest rates in the model, $r_t^e$, $r_t^b$, $r_t^{wc}$ is presented in the text. However in the text, aggregation was only possible because at the beginning of the period, entrepreneur $j$'s debt-asset ratio, $DA_t^e(j) = \frac{b_t^e(j)}{K_t(j)}$, was equal across all entrepreneurs, and bank $k$'s debt-asset ratio, $DA_t^b(k) = \frac{b_t^s(k) + b_t^{sf}(k)}{B_t^e(k)}$, was equal across all banks. This section of the appendix will present the formal proof to both of these claims.

### A.2.1 Entrepreneurial sector

Prove: $DA_{t+1}^e(i) = DA_{t+1}^e(j)$ :

Entrepreneur $i$ will purchase capital up to the point where:

$$1 + r_{t+1}^e(i) = E_t\left(\frac{R_{t+1} + \omega_{t+1}^e(i) P_{t+1}^K (1 - \delta) K_{t+1}}{P_t^K}\right)$$

Since $E_t\left(\omega_{t+1}^e(i)\right) = 1$ and $cov\left(\omega_{t+1}^e(i), P_{t+1}^K(1-\delta)K_{t+1}\right) = 0$, $E_t\left(\frac{R_{t+1} + \omega_{t+1}^e(i) P_{t+1}^K (1-\delta) K_{t+1}}{P_t^K}\right) = E_t\left(\frac{R_{t+1} + P_{t+1}^K (1-\delta) K_{t+1}}{P_t^K}\right)$

Since $E_t\left(\frac{R_{t+1} + P_{t+1}^K (1-\delta) K_{t+1}}{P_t^K}\right)$ does not depend on any characteristics that are specific to entrepreneur $i$, in equilibrium $r_{t+1}^e(i) = r_{t+1}^e(j)$ for any two entrepreneurs $i$ and $j$.

Proof by contradiction:

Suppose $DA_{t+1}^e(i) < DA_{t+1}^e(j)$

From the bank's loan supply schedule:

$$1 + r_{t+1}^e (j) = \frac{\left(1 + r_{t+1}^b\right)}{1 - F\left(\bar{\omega}_{t+1}^e (j)\right)} - \frac{(1 - \mu^e)\left[R_{t+1}F\left(\bar{\omega}_{t+1}^e (j)\right) + (1 - \delta) P_t^K \int_0^{\bar{\omega}_{t+1}^e (j)} \omega_{t+1}^e dF\left(\omega_{t+1}^e\right)\right]}{\left(1 - F\left(\bar{\omega}_{t+1}^e (j)\right)\right) \frac{b_{t+1}^e (j)}{K_{t+1}(j)}}$$

where

$$\bar{\omega}_{t+1}^e (j) = \frac{\left(1 + r_{t+1}^e\right) \frac{b_{t+1}^e (j)}{K_{t+1}(j)} - R_{t+1}}{P_{t+1}^K (1 - \delta)}$$

If $DA_{t+1}^e (i) < DA_{t+1}^e (j)$, then $\frac{b_t^e (i)}{K_t(i)} < \frac{b_t^e (j)}{K_t(j)}$, so $\bar{\omega}_t^e (i) < \bar{\omega}_t^e (j)$ and $r_t^e (i) < r_t^e (j)$.

This contradicts with the earlier equilibrium condition that $r_{t+1}^e (i) = r_{t+1}^e (j)$, thus $DA_{t+1}^e (i) \not< DA_{t+1}^e (j)$ and since the choice of $i$ and $j$ where arbitrary the only possible equilibrium is one where $DA_{t+1}^e (i) = DA_{t+1}^e (j)$.

### A.2.2 Banking sector

Prove $DA_{t+1}^b (i) = DA_{t+1}^b (j)$ :

Bank $i$ will make loans up to the point where:

$$1 + r_{t+1}^b (i) = E_t\left(\left(1 - \omega_{t+1}^b (i) \zeta_{t+1}^e\right)\left(1 + r_{t+1}^e\right)\right)$$

Since $\omega_{t+1}^b (i)$ is i.i.d. and $E_t\left(\omega_{t+1}^b (i)\right) = 1$, $E_t\left(\left(1 - \omega_{t+1}^b (i) \zeta_{t+1}^e\right)\left(1 + r_{t+1}^e\right)\right) = E_t\left(\left(1 - \zeta_{t+1}^e\right)\left(1 + r_{t+1}^e\right)\right)$
Thus $r_{t+1}^b (i) = r_{t+1}^b (j)$ for any two banks $i$ and $j$.

Proof by contradiction:

Suppose $DA_{t+1}^b (i) < DA_{t+1}^b (j)$

From the equilibrium condition that determines how much credit is extended to a bank:

$$1 + r_{t+1}^b (i) = \frac{1 + i_{t+1}}{G\left(\omega_{t+1}^b; \sigma_{t+1}^b\right)}$$

where

$$\bar{\omega}^b_{t+1}(i) = \frac{\left(1 + r^e_{t+1}\right) - \left(1 + r^b_{t+1}(i)\right)\frac{b^s_{t+1}(i) + b^{sf}_{t+1}(i)}{B^e_{t+1}(i)}}{\zeta^e_{t+1}\left(1 + r^e_{t+1}\right)}$$

If $DA^b_{t+1}(i) < DA^b_{t+1}(j)$ then $\frac{b^s_{t+1}(i) + b^{sf}_{t+1}(i)}{B^e_{t+1}(i)} < \frac{b^s_{t+1}(j) + b^{sf}_{t+1}(j)}{B^e_{t+1}(j)}$, so $\bar{\omega}^b_{t+1}(i) > \bar{\omega}^b_{t+1}(j)$, so $r^b_{t+1}(i) < r^b_{t+1}(j)$.

This contradicts with the earlier equilibrium condition that $r^b_{t+1}(i) = r^b_{t+1}(j)$, thus $DA^b_{t+1}(i) \not< DA^b_{t+1}(j)$ and since the choice of $i$ and $j$ where arbitrary the only possible equilibrium is one where $DA^b_{t+1}(i) = DA^b_{t+1}(j)$.

## Table 1: Benchmark Parameter Values

| Symbol | Value | Description |
|--------|-------|-------------|
| $\beta$ | 0.99 | discount factor |
| $\delta$ | 0.025 | depreciation rate |
| $\alpha$ | 0.36 | capital's share of income |
| $\rho$ | 1.5 | substitution elasticity between home and foreign goods |
| $\chi^b$ | 0.01 | cost of adjusting foreign bond holdings |
| $\sigma_n$ | 1 | labor supply elasticity |
| $\sigma$ | 10 | substitution elasticity across goods from domestic firms |
| $\theta$ | 21 | substitution elasticity across differentiated labor inputs |
| $\kappa$ | 0.125 | capital adjustment cost parameter |
| $\xi_p$ | 0.62 | probability that a firm cannot change prices in the current period |
| $\xi_w$ | 0.75 | probability that a worker cannot change wages in the current period |
| $\gamma$ | 0.78 | weight on domestic goods |
| $\gamma^f$ | 0.26 | weight on imported goods |
| $\phi$ | 0.271 | fixed cost in production |
| $\psi$ | 0.021 | coefficient on labor effort in the utility function |
| $\sigma^b$ | 1.133 | standard deviation of idiosyncratic bank shocks |
| $\mu^e$ | 0.134 | cost of liquidation in the entrepreneurial sector |
| $\sigma^e$ | 0.370 | standard deviation of idiosyncratic entrepreneur shocks |

Table 2: The optimal Taylor rule parameters under increasing levels of financial sector shocks.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\sqrt{\frac{var(rp_t^b)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|
| $\theta_{fe} = 0$ : | | | | | | |
| $\Sigma = 0$ | 1.709 | 0.417 | 0.746 | – | 0.0124 | 12.61% |
| $\Sigma = 0.025$ | 1.713 | 0.417 | 0.746 | – | 0.0345 | 12.71% |
| $\Sigma = 0.050$ | 1.726 | 0.429 | 0.748 | – | 0.0655 | 12.98% |
| $\Sigma = 0.075$ | 1.733 | 0.434 | 0.749 | – | 0.0966 | 13.44% |
| $\Sigma = 0.100$ | 1.762 | 0.452 | 0.752 | – | 0.1271 | 14.05% |
| $\Sigma = 0.125$ | 1.788 | 0.469 | 0.755 | – | 0.1569 | 14.81% |
| $\Sigma = 0.150$ | 1.822 | 0.494 | 0.759 | – | 0.1859 | 15.67% |
| $\Sigma = 0.175$ | 1.951 | 0.544 | 0.774 | – | 0.2099 | 16.54% |
| | | | | | | |
| $\theta_{fe} \neq 0$ : | | | | | | |
| $\Sigma = 0$ | 1.641 | 0.375 | 0.741 | 0.154 | 0.0126 | 12.26% |
| $\Sigma = 0.025$ | 1.650 | 0.385 | 0.743 | 0.156 | 0.0347 | 12.36% |
| $\Sigma = 0.050$ | 1.667 | 0.396 | 0.745 | 0.153 | 0.0656 | 12.65% |
| $\Sigma = 0.075$ | 1.681 | 0.406 | 0.746 | 0.146 | 0.0967 | 13.13% |
| $\Sigma = 0.100$ | 1.719 | 0.434 | 0.751 | 0.145 | 0.1274 | 13.75% |
| $\Sigma = 0.125$ | 1.751 | 0.457 | 0.755 | 0.139 | 0.1573 | 14.51% |
| $\Sigma = 0.150$ | 1.785 | 0.480 | 0.754 | 0.134 | 0.1864 | 15.47% |
| $\Sigma = 0.175$ | 1.838 | 0.513 | 0.760 | 0.129 | 0.2138 | 16.43% |

Table 3: The optimal coefficients on home and foreign interbank lending spreads.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\theta_r$ | $\theta_{rf}$ | $\sqrt{\frac{var(rp_t^b)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|---|---|
| $\theta_{fe} = 0:$ | | | | | | | | |
| $\Sigma = 0$ | 1.709 | 0.417 | 0.746 | – | 0.000 | 0.000 | 0.012 | 12.61% |
| $\Sigma = 0.025$ | 1.713 | 0.417 | 0.746 | – | 0.000 | 0.000 | 0.035 | 12.71% |
| $\Sigma = 0.050$ | 1.726 | 0.429 | 0.748 | – | 0.000 | 0.000 | 0.066 | 12.98% |
| $\Sigma = 0.075$ | 1.737 | 0.430 | 0.749 | – | −0.343 | 0.000 | 0.094 | 13.29% |
| $\Sigma = 0.100$ | 1.754 | 0.439 | 0.756 | – | −0.484 | −0.049 | 0.123 | 13.49% |
| $\Sigma = 0.125$ | 1.768 | 0.440 | 0.759 | – | −0.548 | −0.112 | 0.151 | 13.71% |
| $\Sigma = 0.150$ | 1.777 | 0.441 | 0.762 | – | −0.584 | −0.147 | 0.178 | 13.93% |
| $\Sigma = 0.175$ | 1.797 | 0.444 | 0.768 | – | −0.612 | −0.172 | 0.204 | 14.15% |
| | | | | | | | | |
| $\theta_{fe} \neq 0:$ | | | | | | | | |
| $\Sigma = 0$ | 1.641 | 0.375 | 0.741 | 0.154 | 0.000 | 0.000 | 0.013 | 12.26% |
| $\Sigma = 0.025$ | 1.650 | 0.385 | 0.743 | 0.156 | 0.000 | 0.000 | 0.035 | 12.36% |
| $\Sigma = 0.050$ | 1.667 | 0.396 | 0.745 | 0.153 | 0.000 | 0.000 | 0.066 | 12.65% |
| $\Sigma = 0.075$ | 1.665 | 0.394 | 0.746 | 0.154 | −0.370 | 0.000 | 0.094 | 12.94% |
| $\Sigma = 0.100$ | 1.673 | 0.394 | 0.749 | 0.159 | −0.526 | 0.000 | 0.123 | 13.13% |
| $\Sigma = 0.125$ | 1.677 | 0.391 | 0.752 | 0.165 | −0.597 | −0.028 | 0.151 | 13.31% |
| $\Sigma = 0.150$ | 1.693 | 0.398 | 0.756 | 0.176 | −0.643 | −0.049 | 0.178 | 13.48% |
| $\Sigma = 0.175$ | 1.704 | 0.400 | 0.760 | 0.183 | −0.671 | −0.067 | 0.204 | 13.66% |

Table 4: The optimal coefficients on the endogenous and exogenous parts of the home and foreign interbank lending spreads.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\theta_r^{endo}$ | $\theta_{rf}^{endo}$ | $\theta_r^{exo}$ | $\theta_{rf}^{exo}$ | $\sqrt{\frac{var\left(rp_t^b\right)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|---|---|---|---|
| $\theta_{fe} = 0$ : | | | | | | | | | | |
| $\Sigma = 0$ | 1.709 | 0.417 | 0.746 | — | 0.000 | 0.000 | $na$ | $na$ | 1.24% | 12.61% |
| $\Sigma = 0.025$ | 1.788 | 0.467 | 0.760 | — | 0.000 | 0.000 | $-0.696$ | $-0.246$ | 3.33% | 12.56% |
| $\Sigma = 0.050$ | 1.736 | 0.432 | 0.750 | — | 0.000 | 0.000 | $-0.816$ | $-0.340$ | 6.23% | 12.70% |
| $\Sigma = 0.075$ | 1.737 | 0.430 | 0.749 | — | 0.000 | 0.000 | $-0.813$ | $-0.351$ | 9.20% | 12.86% |
| $\Sigma = 0.100$ | 1.746 | 0.432 | 0.752 | — | 0.000 | 0.000 | $-0.811$ | $-0.359$ | 12.11% | 13.03% |
| $\Sigma = 0.125$ | 1.785 | 0.455 | 0.758 | — | 0.000 | 0.000 | $-0.826$ | $-0.388$ | 14.99% | 13.25% |
| $\Sigma = 0.150$ | 1.816 | 0.469 | 0.761 | — | 0.000 | 0.000 | $-0.858$ | $-0.406$ | 17.76% | 13.57% |
| $\Sigma = 0.175$ | 1.888 | 0.506 | 0.767 | — | 0.000 | 0.000 | $-0.944$ | $-0.434$ | 20.39% | 14.03% |
| | | | | | | | | | | |
| $\theta_{fe} \neq 0$ : | | | | | | | | | | |
| $\Sigma = 0$ | 1.641 | 0.375 | 0.741 | 0.154 | 0.000 | 0.000 | $na$ | $na$ | 1.26% | 12.26% |
| $\Sigma = 0.025$ | 1.641 | 0.375 | 0.741 | 0.154 | 0.000 | 0.000 | $-0.726$ | $-0.124$ | 3.32% | 12.28% |
| $\Sigma = 0.050$ | 1.659 | 0.384 | 0.745 | 0.157 | 0.000 | 0.000 | $-0.828$ | $-0.216$ | 6.21% | 12.34% |
| $\Sigma = 0.075$ | 1.665 | 0.390 | 0.746 | 0.161 | 0.000 | 0.000 | $-0.850$ | $-0.201$ | 9.17% | 12.44% |
| $\Sigma = 0.100$ | 1.679 | 0.393 | 0.748 | 0.163 | 0.000 | 0.000 | $-0.837$ | $-0.226$ | 12.08% | 12.58% |
| $\Sigma = 0.125$ | 1.689 | 0.398 | 0.749 | 0.171 | 0.000 | 0.000 | $-0.865$ | $-0.211$ | 14.94% | 12.75% |
| $\Sigma = 0.150$ | 1.706 | 0.403 | 0.752 | 0.177 | 0.000 | 0.000 | $-0.883$ | $-0.214$ | 17.68% | 12.97% |
| $\Sigma = 0.175$ | 1.749 | 0.428 | 0.757 | 0.189 | 0.000 | 0.000 | $-0.922$ | $-0.231$ | 20.38% | 13.25% |

Table 5: The optimal Taylor rule parameters under increasing levels of financial sector shocks. Results from the version of the model where the steady state import share=0.5.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\sqrt{\dfrac{var\left(rp_t^b\right)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|
| $\theta_{fe} = 0:$ | | | | | | |
| $\Sigma = 0$ | 1.579 | 0.332 | 0.741 | – | 0.0132 | 12.18% |
| $\Sigma = 0.025$ | 1.579 | 0.332 | 0.741 | – | 0.0364 | 12.27% |
| $\Sigma = 0.050$ | 1.589 | 0.337 | 0.742 | – | 0.0689 | 12.54% |
| $\Sigma = 0.075$ | 1.606 | 0.352 | 0.744 | – | 0.102 | 12.97% |
| $\Sigma = 0.100$ | 1.629 | 0.368 | 0.747 | – | 0.1345 | 13.55% |
| $\Sigma = 0.125$ | 1.645 | 0.379 | 0.749 | – | 0.1662 | 14.27% |
| $\Sigma = 0.150$ | 1.687 | 0.407 | 0.754 | – | 0.1972 | 15.08% |
| $\Sigma = 0.175$ | 1.719 | 0.430 | 0.758 | – | 0.2274 | 16.00% |
| | | | | | | |
| $\theta_{fe} \neq 0:$ | | | | | | |
| $\Sigma = 0$ | 1.548 | 0.309 | 0.741 | 0.599 | 0.0135 | 11.86% |
| $\Sigma = 0.025$ | 1.552 | 0.309 | 0.741 | 0.591 | 0.0364 | 11.96% |
| $\Sigma = 0.050$ | 1.558 | 0.318 | 0.742 | 0.585 | 0.0691 | 12.23% |
| $\Sigma = 0.075$ | 1.580 | 0.333 | 0.745 | 0.561 | 0.102 | 12.66% |
| $\Sigma = 0.100$ | 1.607 | 0.353 | 0.748 | 0.536 | 0.1347 | 13.24% |
| $\Sigma = 0.125$ | 1.640 | 0.377 | 0.753 | 0.510 | 0.1667 | 13.92% |
| $\Sigma = 0.150$ | 1.678 | 0.405 | 0.758 | 0.496 | 0.198 | 14.71% |
| $\Sigma = 0.175$ | 1.717 | 0.430 | 0.763 | 0.485 | 0.2279 | 15.58% |

Table 6: The optimal coefficients on home and foreign interbank lending spreads. Results from the version of the model where the steady state import share=0.5.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\theta_r$ | $\theta_{rf}$ | $\sqrt{\frac{var(rp_t^b)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|---|---|
| $\theta_{fe} = 0$ : | | | | | | | | |
| $\Sigma = 0$ | 1.579 | 0.332 | 0.741 | – | 0.000 | 0.000 | 0.013 | 12.18% |
| $\Sigma = 0.025$ | 1.579 | 0.332 | 0.741 | – | 0.000 | 0.000 | 0.036 | 12.27% |
| $\Sigma = 0.050$ | 1.589 | 0.337 | 0.742 | – | 0.000 | 0.000 | 0.069 | 12.54% |
| $\Sigma = 0.075$ | 1.594 | 0.340 | 0.744 | – | −0.160 | −0.121 | 0.100 | 12.87% |
| $\Sigma = 0.100$ | 1.616 | 0.352 | 0.750 | – | −0.260 | −0.232 | 0.131 | 13.05% |
| $\Sigma = 0.125$ | 1.621 | 0.351 | 0.752 | – | −0.315 | −0.286 | 0.162 | 13.23% |
| $\Sigma = 0.150$ | 1.638 | 0.358 | 0.757 | – | −0.346 | −0.321 | 0.191 | 13.38% |
| $\Sigma = 0.175$ | 1.653 | 0.364 | 0.761 | – | −0.364 | −0.343 | 0.221 | 13.55% |
| | | | | | | | | |
| $\theta_{fe} \neq 0$ : | | | | | | | | |
| $\Sigma = 0$ | 1.548 | 0.309 | 0.741 | 0.599 | 0.000 | 0.000 | 0.014 | 11.86% |
| $\Sigma = 0.025$ | 1.552 | 0.309 | 0.741 | 0.591 | 0.000 | 0.000 | 0.036 | 11.96% |
| $\Sigma = 0.050$ | 1.558 | 0.318 | 0.742 | 0.585 | 0.000 | 0.000 | 0.069 | 12.23% |
| $\Sigma = 0.075$ | 1.563 | 0.320 | 0.744 | 0.578 | −0.258 | −0.031 | 0.100 | 12.54% |
| $\Sigma = 0.100$ | 1.567 | 0.323 | 0.746 | 0.563 | −0.339 | −0.146 | 0.131 | 12.74% |
| $\Sigma = 0.125$ | 1.578 | 0.327 | 0.749 | 0.562 | −0.383 | −0.215 | 0.162 | 12.89% |
| $\Sigma = 0.150$ | 1.598 | 0.336 | 0.756 | 0.603 | −0.434 | −0.213 | 0.191 | 13.00% |
| $\Sigma = 0.175$ | 1.609 | 0.337 | 0.757 | 0.576 | −0.457 | −0.231 | 0.220 | 13.15% |

Table 7: The optimal coefficients on the endogenous and exogenous parts of the home and foreign interbank lending spreads. Results from the version of the model where the steady state import share=0.5.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\theta_r^{endo}$ | $\theta_{rf}^{endo}$ | $\theta_r^{exo}$ | $\theta_{rf}^{exo}$ | $\sqrt{\frac{var(rp_t^b)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|---|---|---|---|
| $\theta_{fe}=0$ : | | | | | | | | | | |
| $\Sigma=0$ | 1.579 | 0.332 | 0.741 | $-$ | 0.000 | 0.000 | $na$ | $na$ | 1.32% | 12.18% |
| $\Sigma=0.025$ | 1.594 | 0.340 | 0.744 | $-$ | 0.000 | 0.000 | $-0.418$ | $-0.395$ | 3.54% | 12.18% |
| $\Sigma=0.050$ | 1.895 | 0.543 | 0.801 | $-$ | 0.000 | 0.000 | $-0.251$ | $-1.030$ | 6.82% | 11.92% |
| $\Sigma=0.075$ | 1.648 | 0.373 | 0.756 | $-$ | 0.000 | 0.000 | $-0.516$ | $-0.471$ | 9.83% | 12.25% |
| $\Sigma=0.100$ | 1.614 | 0.351 | 0.749 | $-$ | 0.000 | 0.000 | $-0.502$ | $-0.454$ | 12.99% | 12.43% |
| $\Sigma=0.125$ | 1.642 | 0.366 | 0.754 | $-$ | 0.000 | 0.000 | $-0.520$ | $-0.468$ | 16.08% | 12.57% |
| $\Sigma=0.150$ | 1.660 | 0.373 | 0.756 | $-$ | 0.000 | 0.000 | $-0.516$ | $-0.492$ | 19.11% | 12.78% |
| $\Sigma=0.175$ | 1.688 | 0.388 | 0.760 | $-$ | 0.000 | 0.000 | $-0.533$ | $-0.504$ | 22.06% | 13.01% |
| | | | | | | | | | | |
| $\theta_{fe}\neq0$ : | | | | | | | | | | |
| $\Sigma=0$ | 1.548 | 0.309 | 0.741 | 0.599 | 0.000 | 0.000 | $na$ | $na$ | 1.35% | 11.86% |
| $\Sigma=0.025$ | 1.548 | 0.305 | 0.741 | 0.599 | 0.000 | 0.000 | $-0.460$ | $-0.321$ | 3.54% | 11.88% |
| $\Sigma=0.050$ | 1.546 | 0.304 | 0.740 | 0.596 | 0.000 | 0.000 | $-0.573$ | $-0.315$ | 6.63% | 11.92% |
| $\Sigma=0.075$ | 1.560 | 0.311 | 0.743 | 0.595 | 0.000 | 0.000 | $-0.588$ | $-0.315$ | 9.78% | 11.99% |
| $\Sigma=0.100$ | 1.579 | 0.321 | 0.748 | 0.786 | 0.000 | 0.000 | $-0.762$ | $-0.151$ | 12.84% | 12.11% |
| $\Sigma=0.125$ | 1.579 | 0.321 | 0.748 | 0.556 | 0.000 | 0.000 | $-0.516$ | $-0.401$ | 16.05% | 12.21% |
| $\Sigma=0.150$ | 1.607 | 0.336 | 0.753 | 0.595 | 0.000 | 0.000 | $-0.595$ | $-0.344$ | 19.02% | 12.34% |
| $\Sigma=0.175$ | 1.614 | 0.337 | 0.754 | 0.618 | 0.000 | 0.000 | $-0.610$ | $-0.342$ | 21.95% | 12.52% |

Table 8: The optimal Taylor rule parameters under increasing levels of financial sector shocks. Results from the version of the model where half of entrepreneur's loans are from foreign banks in his own currency.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\sqrt{\frac{var\left(rp_t^b\right)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|
| $\theta_{fe} = 0:$ | | | | | | |
| $\Sigma = 0$ | 1.659 | 0.377 | 0.745 | – | 0.0128 | 11.04% |
| $\Sigma = 0.025$ | 1.665 | 0.382 | 0.746 | – | 0.033 | 11.13% |
| $\Sigma = 0.050$ | 1.676 | 0.387 | 0.747 | – | 0.0618 | 11.38% |
| $\Sigma = 0.075$ | 1.693 | 0.398 | 0.749 | – | 0.0912 | 11.79% |
| $\Sigma = 0.100$ | 1.715 | 0.414 | 0.751 | – | 0.1205 | 12.35% |
| $\Sigma = 0.125$ | 1.733 | 0.425 | 0.753 | – | 0.1492 | 13.06% |
| $\Sigma = 0.150$ | 1.780 | 0.456 | 0.759 | – | 0.1773 | 13.83% |
| $\Sigma = 0.175$ | 1.814 | 0.481 | 0.763 | – | 0.2049 | 14.74% |
| | | | | | | |
| $\theta_{fe} \neq 0:$ | | | | | | |
| $\Sigma = 0$ | 1.594 | 0.341 | 0.739 | 0.149 | 0.0132 | 10.58% |
| $\Sigma = 0.025$ | 1.600 | 0.346 | 0.740 | 0.154 | 0.033 | 10.67% |
| $\Sigma = 0.050$ | 1.610 | 0.351 | 0.741 | 0.151 | 0.0616 | 10.93% |
| $\Sigma = 0.075$ | 1.625 | 0.367 | 0.744 | 0.156 | 0.0912 | 11.35% |
| $\Sigma = 0.100$ | 1.648 | 0.383 | 0.747 | 0.162 | 0.1203 | 11.91% |
| $\Sigma = 0.125$ | 1.683 | 0.406 | 0.751 | 0.165 | 0.1489 | 12.60% |
| $\Sigma = 0.150$ | 1.713 | 0.426 | 0.756 | 0.168 | 0.1768 | 13.40% |
| $\Sigma = 0.175$ | 1.761 | 0.458 | 0.762 | 0.172 | 0.2041 | 14.29% |

Table 9: The optimal coefficients on home and foreign interbank lending spreads. Results from the version of the model where half of entrepreneur's loans are from foreign banks in his own currency.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\theta_r$ | $\theta_{rf}$ | $\sqrt{\frac{var(rp_t^b)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|---|---|
| $\theta_{fe}=0:$ | | | | | | | | |
| $\Sigma=0$ | 1.659 | 0.377 | 0.745 | – | 0.000 | 0.000 | 0.013 | 11.04% |
| $\Sigma=0.025$ | 1.665 | 0.382 | 0.746 | – | 0.000 | 0.000 | 0.033 | 11.13% |
| $\Sigma=0.050$ | 1.676 | 0.387 | 0.747 | – | 0.000 | 0.000 | 0.062 | 11.38% |
| $\Sigma=0.075$ | 1.693 | 0.398 | 0.749 | – | −0.143 | −0.139 | 0.090 | 11.72% |
| $\Sigma=0.100$ | 1.695 | 0.394 | 0.751 | – | −0.261 | −0.253 | 0.118 | 11.99% |
| $\Sigma=0.125$ | 1.717 | 0.406 | 0.756 | – | −0.320 | −0.320 | 0.145 | 12.22% |
| $\Sigma=0.150$ | 1.748 | 0.420 | 0.762 | – | −0.361 | −0.357 | 0.172 | 12.46% |
| $\Sigma=0.175$ | 1.769 | 0.427 | 0.766 | – | −0.385 | −0.385 | 0.199 | 12.73% |
| | | | | | | | | |
| $\theta_{fe}\neq 0:$ | | | | | | | | |
| $\Sigma=0$ | 1.594 | 0.341 | 0.739 | 0.149 | 0.000 | 0.000 | 0.013 | 10.58% |
| $\Sigma=0.025$ | 1.600 | 0.346 | 0.740 | 0.154 | 0.000 | 0.000 | 0.033 | 10.67% |
| $\Sigma=0.050$ | 1.610 | 0.351 | 0.741 | 0.151 | 0.000 | 0.000 | 0.062 | 10.93% |
| $\Sigma=0.075$ | 1.621 | 0.359 | 0.744 | 0.156 | −0.133 | −0.145 | 0.090 | 11.27% |
| $\Sigma=0.100$ | 1.624 | 0.361 | 0.745 | 0.157 | −0.235 | −0.259 | 0.118 | 11.53% |
| $\Sigma=0.125$ | 1.635 | 0.361 | 0.748 | 0.159 | −0.286 | −0.321 | 0.145 | 11.77% |
| $\Sigma=0.150$ | 1.656 | 0.373 | 0.753 | 0.162 | −0.316 | −0.360 | 0.172 | 12.01% |
| $\Sigma=0.175$ | 1.675 | 0.379 | 0.757 | 0.165 | −0.337 | −0.387 | 0.198 | 12.28% |

Table 10: The optimal coefficients on the endogenous and exogenous parts of the home and foreign interbank lending spreads. Results from the version of the model where half of entrepreneur's loans are from foreign banks in his own currency.

| | $\theta_p$ | $\theta_y$ | $\theta_i$ | $\theta_{fe}$ | $\theta_r^{endo}$ | $\theta_{rf}^{endo}$ | $\theta_r^{exo}$ | $\theta_{rf}^{exo}$ | $\sqrt{\frac{var(rp_t^b)}{var(GDP_t)}}$ | Rel. Loss |
|---|---|---|---|---|---|---|---|---|---|---|
| $\theta_{fe} = 0$ : | | | | | | | | | | |
| $\Sigma = 0$ | 1.659 | 0.377 | 0.745 | — | 0.000 | 0.000 | $na$ | $na$ | 1.28% | 11.04% |
| $\Sigma = 0.025$ | 1.709 | 0.410 | 0.756 | — | 0.000 | 0.000 | −0.447 | −0.443 | 3.21% | 11.02% |
| $\Sigma = 0.050$ | 1.733 | 0.425 | 0.760 | — | 0.000 | 0.000 | −0.550 | −0.563 | 5.96% | 11.10% |
| $\Sigma = 0.075$ | 1.707 | 0.407 | 0.754 | — | 0.000 | 0.000 | −0.545 | −0.545 | 8.80% | 11.27% |
| $\Sigma = 0.100$ | 1.699 | 0.398 | 0.751 | — | 0.000 | 0.000 | −0.538 | −0.550 | 11.62% | 11.48% |
| $\Sigma = 0.125$ | 1.734 | 0.418 | 0.756 | — | 0.000 | 0.000 | −0.553 | −0.574 | 14.42% | 11.72% |
| $\Sigma = 0.150$ | 1.764 | 0.427 | 0.759 | — | 0.000 | 0.000 | −0.589 | −0.581 | 17.08% | 12.04% |
| $\Sigma = 0.175$ | 1.802 | 0.452 | 0.763 | — | 0.000 | 0.000 | −0.616 | −0.608 | 19.79% | 12.43% |
| | | | | | | | | | | |
| $\theta_{fe} \neq 0$ : | | | | | | | | | | |
| $\Sigma = 0$ | 1.594 | 0.341 | 0.739 | 0.149 | 0.000 | 0.000 | $na$ | $na$ | 1.32% | 10.58% |
| $\Sigma = 0.025$ | 1.600 | 0.346 | 0.740 | 0.154 | 0.000 | 0.000 | −0.381 | −0.427 | 3.21% | 10.60% |
| $\Sigma = 0.050$ | 1.612 | 0.353 | 0.742 | 0.151 | 0.000 | 0.000 | −0.457 | −0.519 | 5.95% | 10.68% |
| $\Sigma = 0.075$ | 1.625 | 0.359 | 0.744 | 0.152 | 0.000 | 0.000 | −0.469 | −0.523 | 8.78% | 10.81% |
| $\Sigma = 0.100$ | 1.621 | 0.356 | 0.744 | 0.156 | 0.000 | 0.000 | −0.473 | −0.512 | 11.58% | 10.98% |
| $\Sigma = 0.125$ | 1.625 | 0.356 | 0.744 | 0.156 | 0.000 | 0.000 | −0.461 | −0.531 | 14.36% | 11.20% |
| $\Sigma = 0.150$ | 1.663 | 0.378 | 0.751 | 0.161 | 0.000 | 0.000 | −0.482 | −0.546 | 17.09% | 11.47% |
| $\Sigma = 0.175$ | 1.694 | 0.392 | 0.755 | 0.163 | 0.000 | 0.000 | −0.490 | −0.576 | 19.73% | 11.80% |
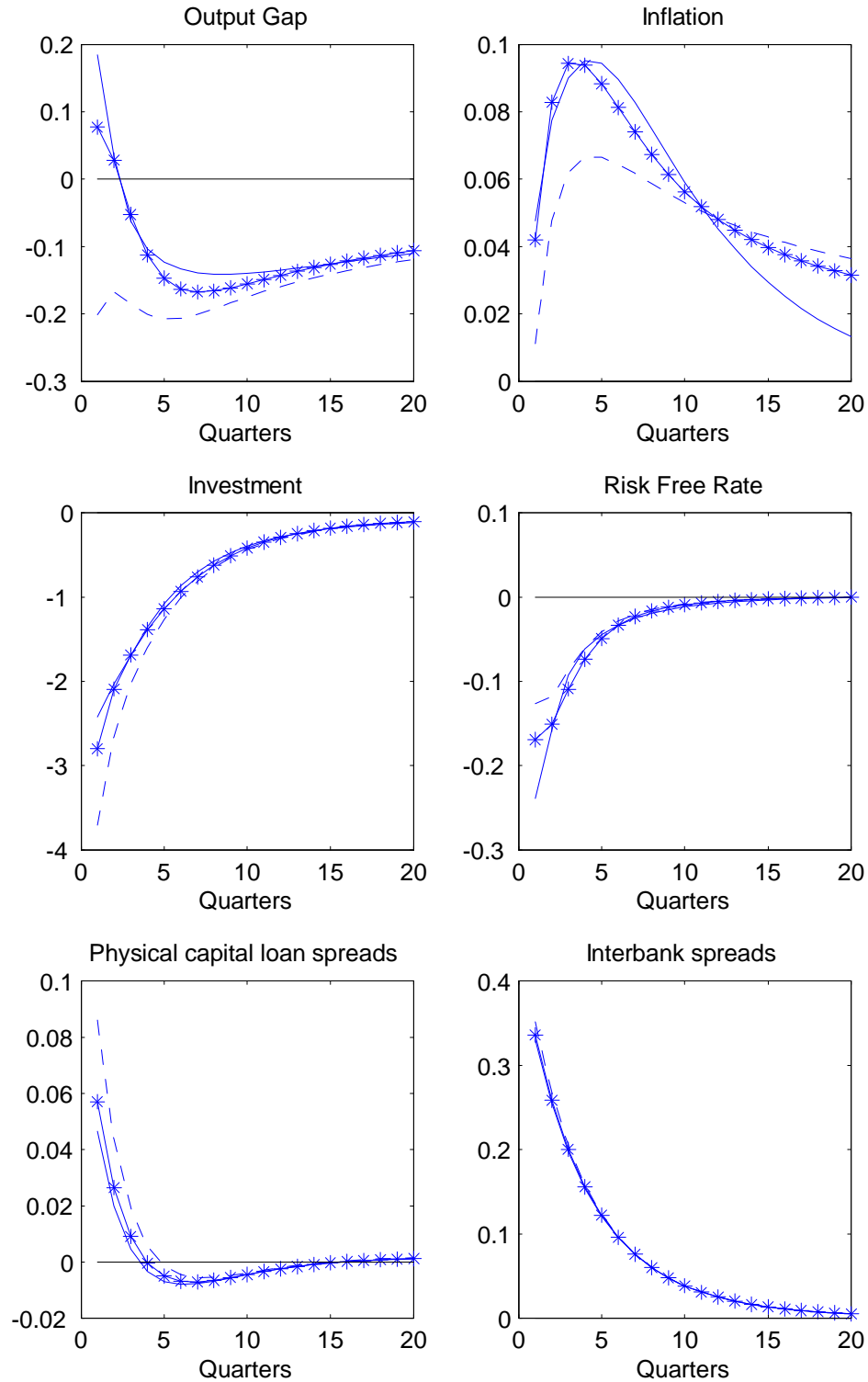
Figure 1: Responses of the output gap, inflation, investment, the real risk free rate, and lending spreads to a home financial shock. The dashed line is from the optimal Taylor rule without spreads, the line with stars is from the optimal Taylor rule including interbank spreads, and the solid line is the cooperative Ramsey policy.
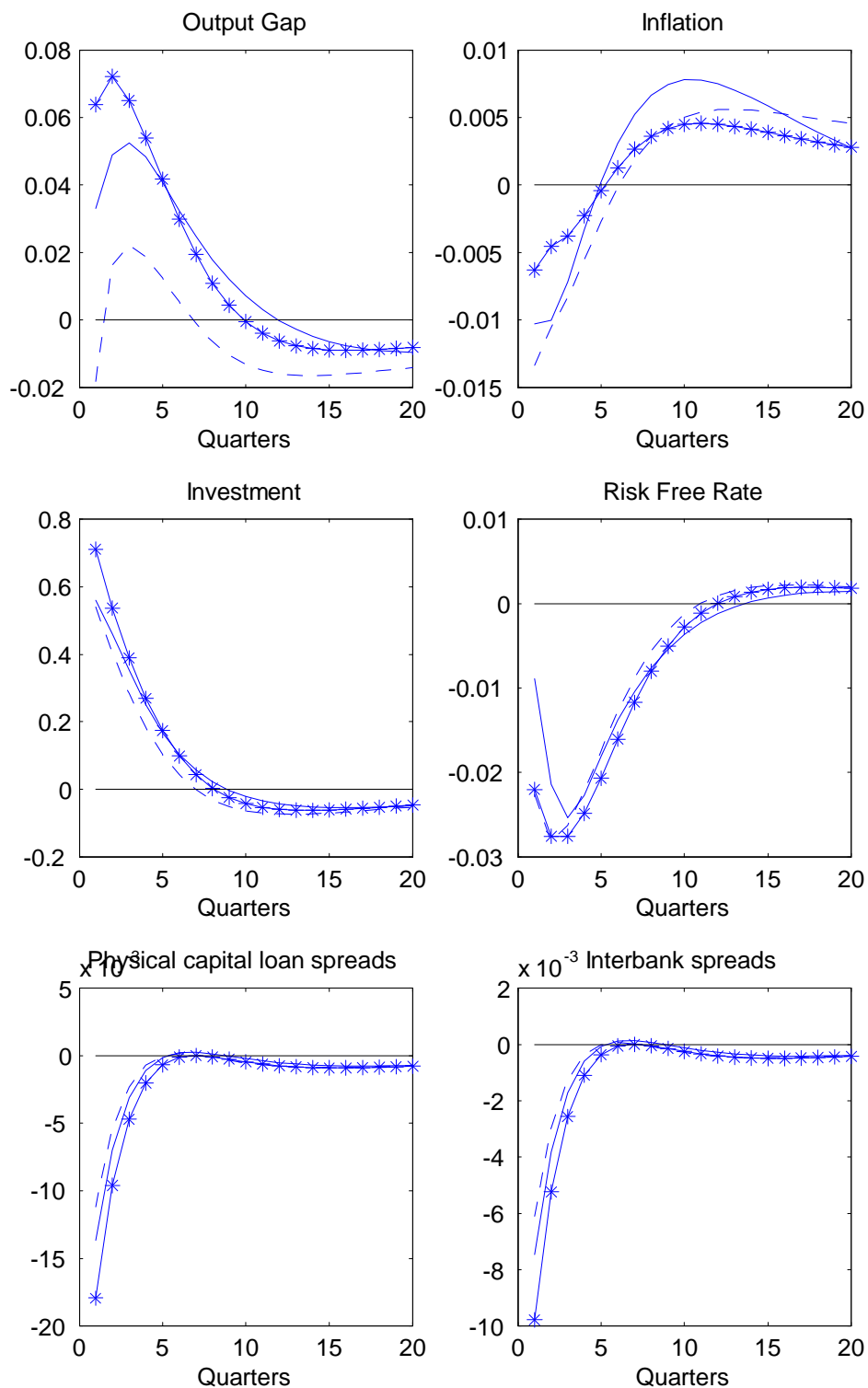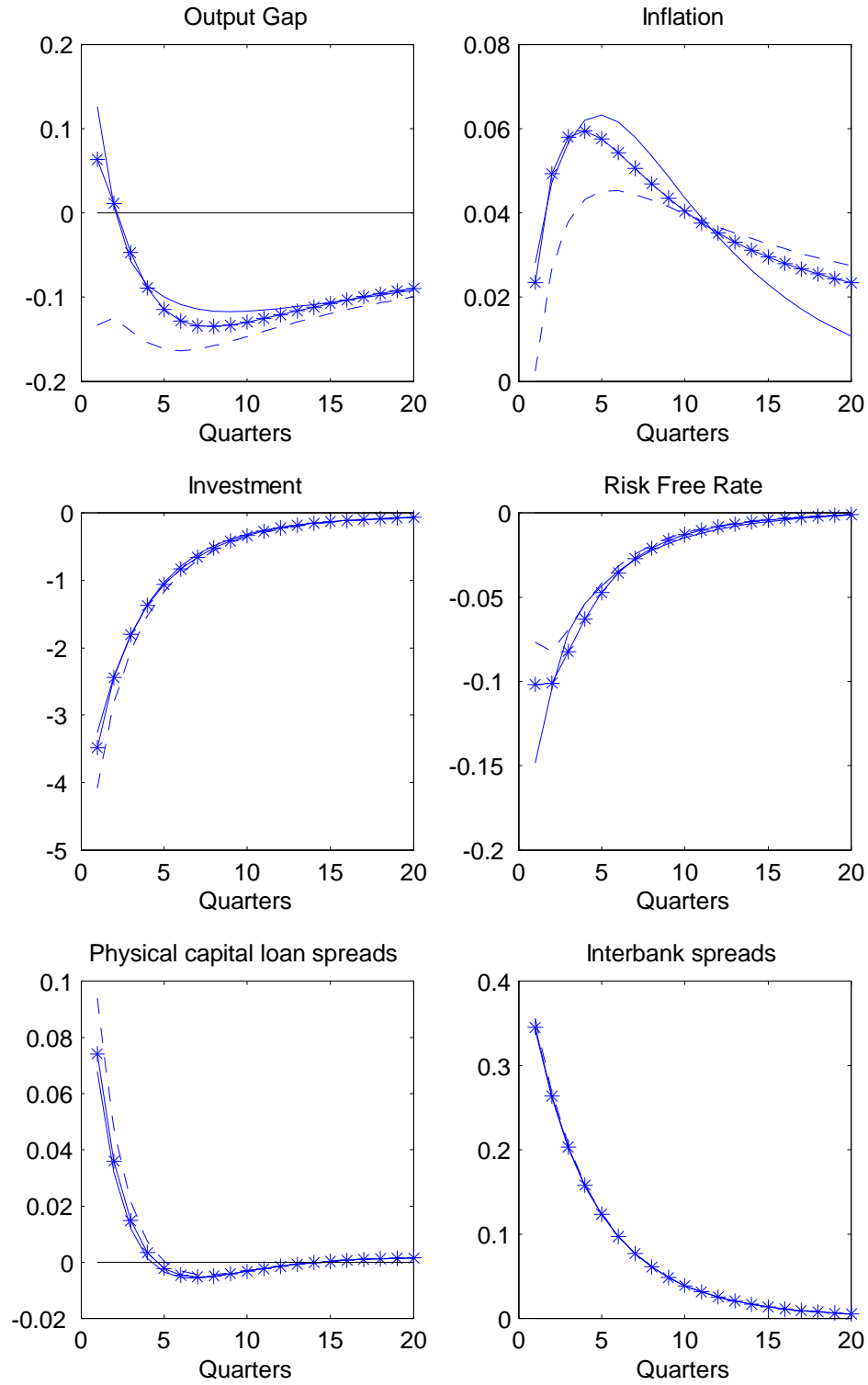
Figure 2: Responses of the output gap, inflation, investment, the real risk free rate, and lending spreads to a foreign financial shock. The dashed line is from the optimal Taylor rule without spreads, the line with stars is from the optimal Taylor rule including interbank spreads, and the solid line is the cooperative Ramsey policy.
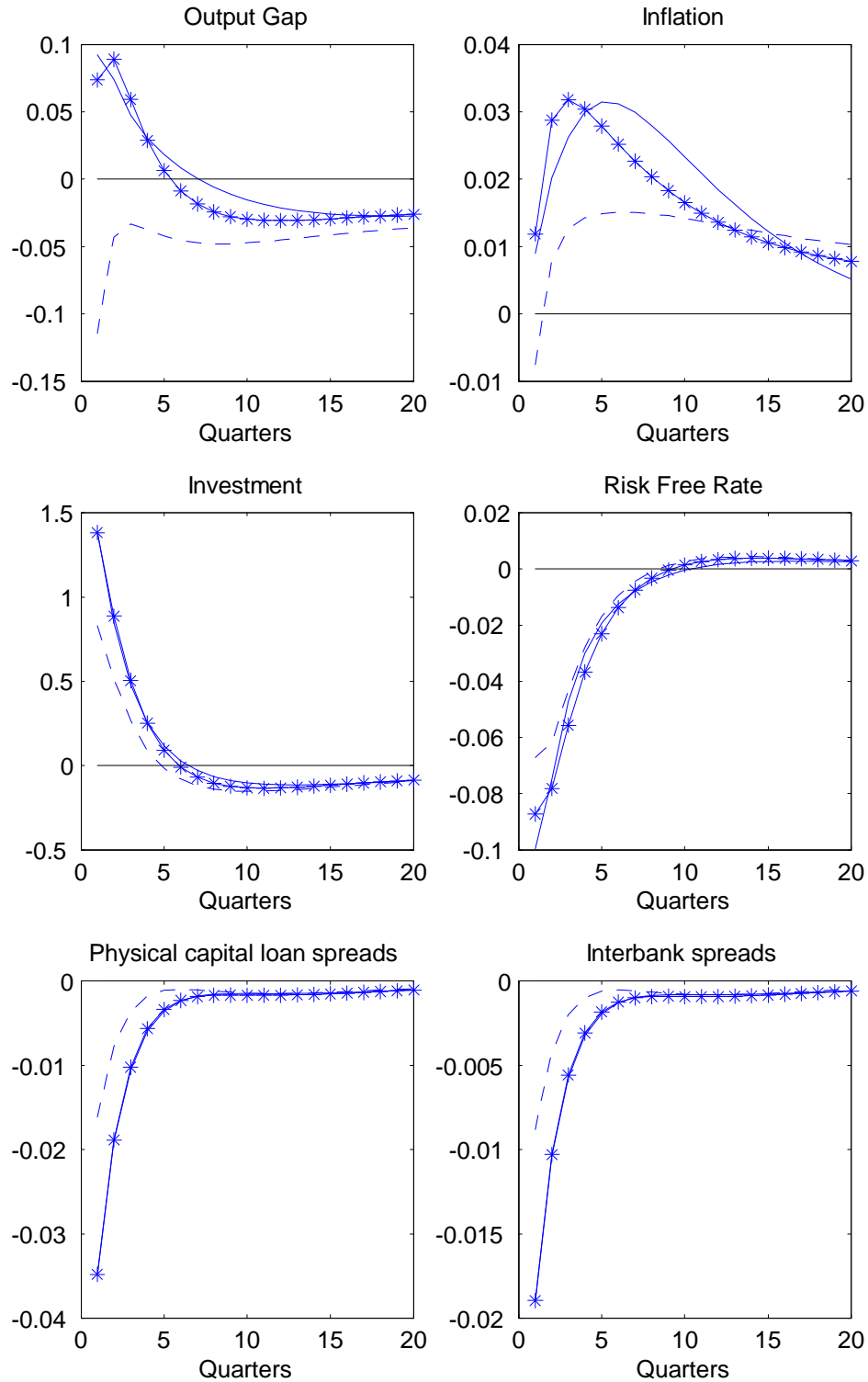
Figure 3: Responses of the output gap, inflation, investment, the real risk free rate, and lending spreads to a home financial shock in the version of the model with high trade integration. The dashed line is from the optimal Taylor rule without spreads, the line with stars is from the optimal Taylor rule including interbank spreads, and the solid line is the cooperative Ramsey policy.

Figure 4: Responses of the output gap, inflation, investment, the real risk free rate, and lending spreads to a foreign financial shock in the version of the model with high trade integration. The dashed line is from the optimal Taylor rule without spreads, the line with stars is from the optimal Taylor rule including interbank spreads, and the solid line is the cooperative Ramsey policy.
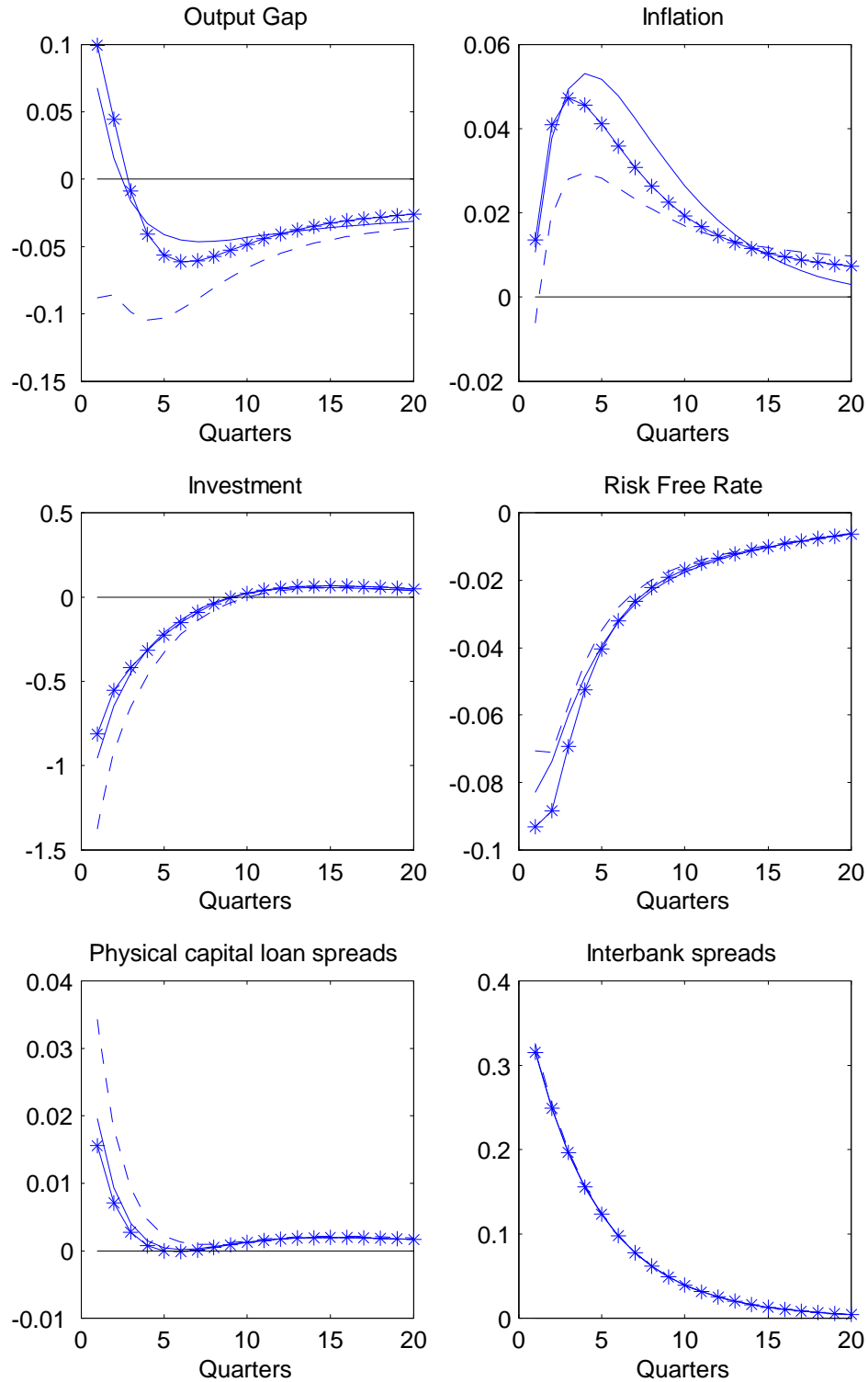
Figure 5: Responses of the output gap, inflation, investment, the real risk free rate, and lending spreads to a home financial shock in the version of the model with borrowing from foreign banks. The dashed line is from the optimal Taylor rule without spreads, the line with stars is from the optimal Taylor rule including interbank spreads, and the solid line is the cooperative Ramsey policy.
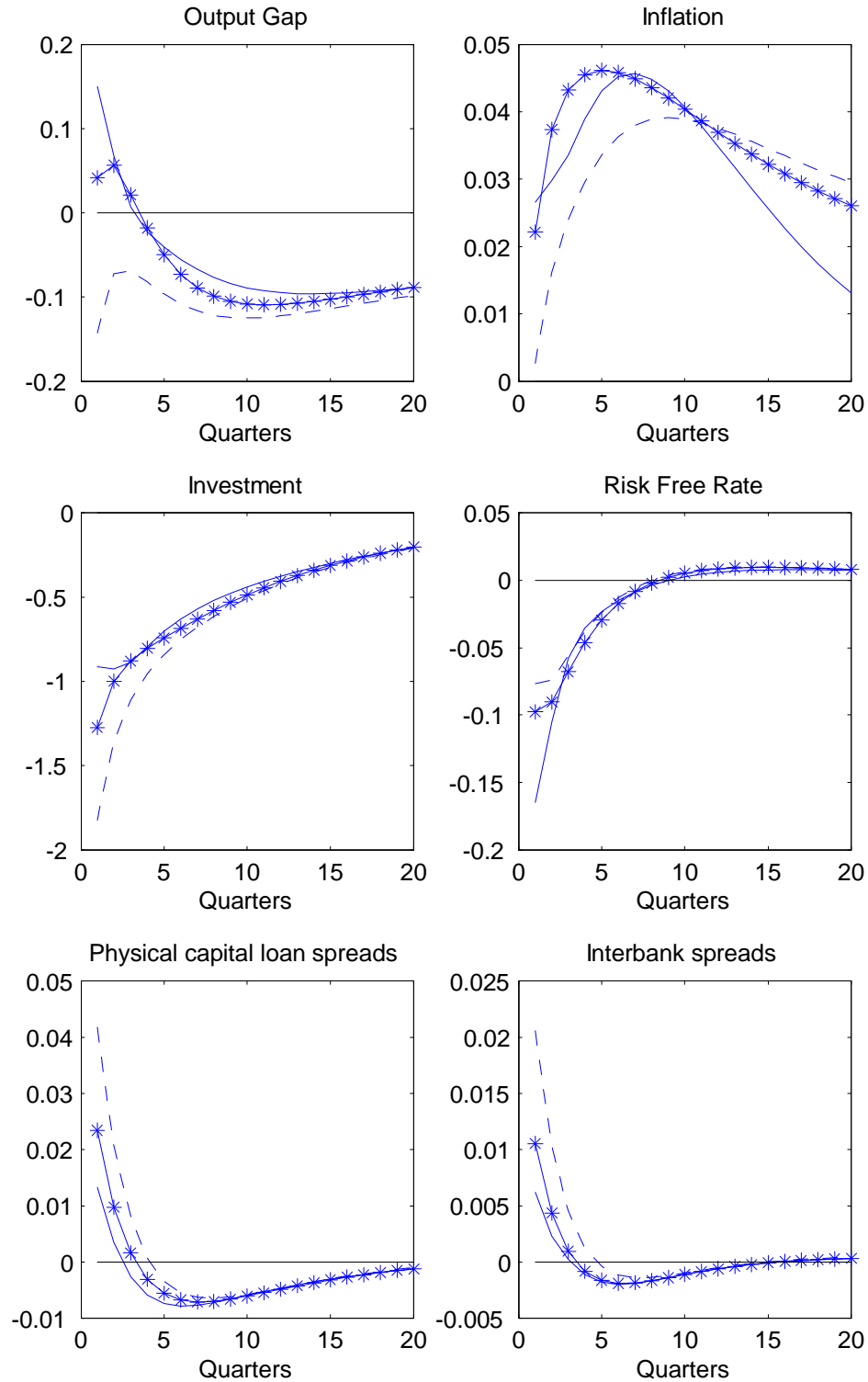
Figure 6: Responses of the output gap, inflation, investment, the real risk free rate, and lending spreads to a foreign financial shock in the version of the model with borrowing from foreign banks. The dashed line is from the optimal Taylor rule without spreads, the line with stars is from the optimal Taylor rule including interbank spreads, and the solid line is the cooperative Ramsey policy.