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Financial Friction and International Business Cycles

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中文摘要

本文建構一個兩國並結合銀行之 DSGE 模型，旨在瞭解銀行資本與放款利差於國際景氣傳遞過程的機制。中間財廠商必須向銀行融通資金以購買資本財。本文假設廠商償還資金時存在違約衝擊，即銀行不一定能完全回收貸放總額。銀行資本水準又會影響放款利差的高低，進而改變廠商生產決策。本文以此機制連結金融與實質部門探討當違約衝擊發生時，除了對本國的影響之外，又會如何衝擊外國經濟體系。本文發現，本國違約衝擊的確會導致兩國景氣同時步入衰退，成功地捕捉兩國之產出、投資與放款呈現下降的現象。此外，本國若採行緊縮性貨幣政策，外國經濟體系也會遭受威脅。

關鍵字：DSGE、放款利差、銀行資本、國際景氣循環

Abstract

The objective of this study is to investigate the international transmission mechanism of the role of banking sector. We propose a Dynamic Stochastic and General Equilibrium model of a two-country two-bank world with nominal rigidity. Bank lends funds to entrepreneurs to purchase capital. The banking capital position has influence on loan rate spreads which can affect the real economic activities. Financial impact is originated from entrepreneur defaulting on their borrowings. The calibration results show that a country-specific financial shock causes international crisis. Furthermore, a negative monetary policy shock also drives simultaneous recession across countries.

Keywords: DSGE, loan rate spreads, banking capital, international business cycles

Contents

1 Introduction

1.1 Motivation

The 2007 subprime crisis occurred in the U.S became the global financial crisis after the bankruptcy of Lehman Brothers in the autumn of 2008. The international economy has not been on the road to recovery. The crisis provides researchers concerning financial impact on the issues of macroeconomics and international finance. However, in standard Dynamic Stochastic and General Equilibrium models (henceforth, DSGE model), both Real Business Cycles model (henceforth, RBC model) and New Keynesian model, assume that households hold capital stock and supply them to firms directly without frictions. Financial frictions and the propagation mechanism of financial-real linkage are absent from traditional DSGE models. Entrepreneurs finance their investment through borrowing funds from financial intermediation in practice. In addition, banks have to maintain the minimum capital requirement regulated by the Basel Accords. The position of banking capital influences the ability of bank's loanable funds, therefore, affects the real economic activities. Empirical studies also underline the importance of banking sector to understand business cycles. Buch and Neugebauer (2011) find that the quantity of large bank lending has significant effects on short-run fluctuations. The impact of a negative bank-specific shock is more sensitive to bank's lending level than positive shock. Kashyap and Stein (2000) measure the bank lending views of monetary transmission and how the monetary policy has asymmetric influences on bank lending.

They find that banks with lower liquidity respond more to the negative monetary policy shock by cutting loan supply.[1] As financial intermediation becomes an indispensible part of modern economy activity, its importance has been rising in the literature.

There are various studies in literatures that research the mechanism of financial frictions, moral hazard, external finance, and collateral constraint. This paper, instead, underlines banking capital mechanism and the propagation of entrepreneurs default on their borrowings. Household saves her deposits in banking sector and bank lends money to entrepreneurs to purchase capital. As entrepreneurs defaulting on their repayments, crisis sparked, banking sector faces liquidity shortage. With losing funds in financial intermediation, returns to household and loans to entrepreneurs are becoming more insufficient. As a result, the economy goes to a further recession. Financial accelerator mechanism that deepens economic fluctuation is an important part of this paper.

Furthermore, international business cycle is another concern in this study. The discussion of worldwide propagation financial shock has been a central issue these years due to the global financial crisis since 2008. However, there are few literatures considering international quantitative dynamic model embedded with banking sector. For this reason, this paper constructs a two-country New Keynesian DSGE model to evaluate financial shocks as well as international transmission across countries.

Kollmann *et al*. (2011) formulate a two-country RBC model with one global bank which collects deposits and loans to both countries to investigate the international propagation of default shock. The financial intermediation in this paper is in the spirit of Kollmann *et al*. (2011). The differences between Kollmann *et al*. (2011) and our work

[1] "Liquidity" is defined as the ratio of securities to assets in their work.

are that we assume a two-country two-bank model instead; the bank in each country collects the deposit from both countries households, but makes loans to the domestic firms only due to the difficulty in credit check. Furthermore, this paper is a New Keynesian model with nominal rigidity.

The purpose of this paper is to study the role of banking capital of a bank running the global business in the transmission of shocks. The main structure of the model is as follows. Bank collects deposits from Home and Foreign households and lends to intermediate firms (entrepreneurs). Bank faces banking capital regulation. The quantity of bank capital affects the spread between loan rate and deposit rate. Nominal rigidity is introduced in entrepreneurs. Entrepreneurs hire labor and purchase capital to produce intermediate goods and sell them to Home and Foreign final goods firms (retailers). The pricing of intermediate goods is set as producer currency pricing (PCP). Retailers behave perfect competition and final goods are non-tradable. The details will be presented in section 2.

1.2 Literature Review

There is a notable literature on modeling DSGE models with financial frictions (known as "the credit channel"), beginning with Bernanke *et al*. (1999) (henceforth, BGG model). They stress the importance of "financial accelerator" in the source of business cycle transmission mechanism, which can amplify economic fluctuation. Hereafter, financial frictions have seen increased attention being given to thesis investigating in literatures. Christensen and Dib (2008) modify BGG model and develop an estimated New Keynesian DSGE model. They show that the financial accelerator mechanism can improve the model performance and fit the data. Iacoviello (2005) completes the channel of borrowing constraint. He examines a New Keynesian DSGE model with collateral constraint; both households and entrepreneurs face restrictions in borrowing tied to their real estate holdings.[2] He simulates a scenario with housing prices shock. However, their works do not assign any role of financial intermediation, which may be the source or the propagation mechanism of the recent crisis.

Meh and Moran (2010) use a closed-economy DSGE model and indicate that the contraction monetary policy causes the declining of banking capital. As banks lose their capital, lending becoming decreasing; hence, magnify the recession. The importance of banking capital mechanism can also be found in Gerali *et al*. (2010). They augment an imperfect competition financial market à la Iacoviello (2005). They show that banking capital decrease causes tighter credit condition of banks that increases the loan rate and deepen the fluctuation. Gertler and Kiyotaki (2010) and Dib (2010) construct a fairly rich financial intermediation in a DSGE model. Dib (2010) evaluates financial shocks and liquidity injection policy (as Quantitative Easing), while Gertler and Kiyotaki (2010) involve in the unconventional credit policy. (See also Gertler and Karadi (2011).)

Since the crisis addresses the importance of global financial intermediation propagating the fluctuation across countries, the role of banking in the international business cycles literatures have been received great attention but was rarely modeled. Kollmann *et al*. (2011) incorporate a two-country RBC model with a global bank. The global bank can loan to Home and Foreign entrepreneurs. Financial shock is originated from entrepreneur defaulting on their borrowings. Default shock lowers banking capital

[2] The notation of “houses”, “real estate”, and “assets” are the same in his study.

and raises the loan rate spreads. With the mechanism of global bank and correlated shocks, both countries sink into recession simultaneously.[3] In a related work, Kamber and Thoenissen (2011) use a two-country, two-bank RBC model but consider international relative commodity prices. Specific banking sector shock spills over to another country through the current account channel. Both Kollmann *et al*. (2010) and Kamber and Thoenissen (2011) capture the behavior of loan rate spreads. The properties of their model, however, do not have obvious differences from canonical international RBC model. Productivity shock explains most of business cycles phenomenon. Instead of assuming competitive banking sector, Olivero (2010) focuses on monopolistic competition banks in the structure of two-country RBC model. Firms finance their investment by borrowing from international financial market. She draws that as a specific positive productivity shock happened, banks compete severely among each other to meet the need of firms for expanding their investment by financing from banks. Therefore, global margins decrease and benefit the other country's investors. The model behaves positive co-movement properties across countries. While these researches have highlighted the role of banking sector for international business fluctuation, their studies are constructed on RBC model, in which productivity shock is the main source of global business cycles. Financial shock plays a negligible role from their works.

The rest of this paper proceeds as follows. Section 2 presents a two-country, two-bank New Keynesian DSGE model. Section 3 pictures the mechanism of loan rate spreads associated with banking capital. Section 4 outlines the model's parameterization

[3] Kollmann *et al*. (2011) assume that there are correlations between productivity shock and default shock. The details will be described in section 4.

and the steady-state values. Section 5 describes the calibration results. Section 6 concludes.

2 The Model

Consider a discrete time two-country two-bank economy, called Home and Foreign, in which all agents are infinitely lived. In each country, there are a representative household, a financial intermediation, a retailer (final goods producer), and a continuum of monopolistic entrepreneurs (intermediate goods producers). The banking sector is based on Kollmann *et al*. (2011). Each intermediate firm produces distinct intermediate goods indexed by $i \in [0,1]$. There are also a government and a central bank. Household consumes, holds deposits, and works. Bank collects Home and Foreign households' deposits and lend to domestic entrepreneurs. Both countries are symmetric, having the same preferences and technologies; therefore, the following setup focuses on the Home country. The equation of Foreign country can be found in Appendix A. Foreign variables are denoted by an asterisk.

2.1 Household

The Home household maximizes its expected lifetime “deposits-in-the utility function” (1) by choosing real consumption, real Home and Foreign deposits holdings, and labor supply; subject to the budget constrain (2). Foreign deposit is denominated in foreign currency.

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln c_t + \chi \ln \frac{D_t^H}{P_t} + \chi \ln \frac{e_t D_t^F}{P_t} - \frac{N_t^{1+\eta}}{1+\eta} \right\}, \tag{1}$$

$$\begin{aligned} c_{H,t} + \frac{D_{t+1}^H}{P_t} + \frac{e_t D_{t+1}^F}{P} + \frac{B_{t+1}^G}{P} = \frac{W_t}{P_t} N_t + \frac{\left(1+R_{D,t}\right) D_t^H}{P_t} \\ + \frac{\left(1+R_{D,t}^*\right) e_t D_t^F}{P_t} + \frac{\left(1+R_t\right) B_t^G}{P_t} + \prod_t - T_t, \end{aligned} \tag{2}$$

where E_0 is the expectation operator, $\beta \in (0,1)$ is the discount factor. We assume that household and banker have the same discount factor.[4] Deposits provide utility to the household. c_t, D_t^H, D_t^F, and N_t are real consumption, nominal Home deposits holdings, Foreign deposits holdings, and labor supply respectively. The household enters each period with deposits and Home government bonds B_t^G. D_{t+1}^H and D_{t+1}^F are the bank deposits held by the household at the end of period t. During the period, household supplies her labor to the entrepreneur, earning her real income $(W_t/P_t)L_t$. Household is the owner of entrepreneur so that she receives dividend Π_t. Household also pays a lump-sum tax to government T_t. We denote $R_{D,t}$, $R_{D,t}^*$, R_t, and e_t as Home deposit rate, Foreign deposit rate, Home bonds rate (policy rate), and nominal exchange rate respectively. Interest rate on deposits and bonds are set at $t-1$. χ is household's deposit preference and η is the elasticity of labor supply.

The first-order conditions for Home household's maximization problem are,

[4] An alternative setup assumes that household is more patient than the bank; this can also generate a positive loan rate spreads (See e.g., Iacoviello (2011)).

$$\chi \frac{c_{H,t}}{d_t^H} + \beta \ \mathrm{E}_t \frac{c_{H,t}\left(1+R_{D,t+1}\right)}{c_{H,t+1}\pi_{t+1}} = 1, \tag{3}$$

$$\chi \frac{c_{H,t}}{d_t^F} + \beta \ \mathrm{E}_t \frac{c_{H,t}\left(1+R_{D,t+1}^*\right)e_{t+1}}{c_{H,t+1}\pi_{t+1}e_t} = 1, \tag{4}$$

$$N_t^\eta = \frac{w_t}{c_{H,t}} \tag{5}$$

$$\beta \ \mathrm{E}_t \frac{c_{H,t}\left(1+R_{t+1}\right)}{c_{H,t+1}\pi_{t+1}} = 1, \tag{6}$$

with the definition of $w_t = W_t / P_t$, $d_{t+1}^H = D_{t+1}^H / P_t$, $d_{t+1}^F = e_t D_{t+1}^F / P_t$, $\pi_{t+1} = P_{t+1} / P_t$, $e_t = P_t / P_t^*$.

Equation (3) and (4) relate the Euler equation for Home deposits and Foreign deposits. Equation (5) represents a standard intratemporal optimally condition setting the marginal rate of substitution between consumption and leisure equals to the real wage. Intertemporal allocation of consumption is in equation (6).

2.2 Retailer

The Home final goods producer operates in a perfectly competitive market. We suppose that intermediate goods are sold to retailers in both countries; however, final goods are non-tradable. The production function of retailer is in a constant-elasticity-of substitution (CES) technology,

$$Y_t = \left[(1-\omega)^{\frac{1}{v}} \left(Y_{E,t}^H\right)^{\frac{v-1}{v}} + \omega^{\frac{1}{v}} \left(Y_{E,t}^{F*}\right)^{\frac{v-1}{v}} \right]^{\frac{v}{v-1}}, \tag{7}$$

where ω measures the weight of imported goods, $0 < \omega < 1$, and v represents the elasticity of substitution between Home and Foreign intermediate goods, $v \geq 1$.[5] Retailer purchases Home intermediate goods, $Y_{E,t}^{H}$, and imports Foreign intermediate goods, $Y_{E,t}^{F*}$, and combine them to produce final outputs, Y_t. $Y_{E,t}^{H}$ and $Y_{E,t}^{F*}$ are in the composition of $Y_{E,t}^{H} = \left[\int_0^1 \left(Y_{E,t}^{H}(i)\right)^{\varepsilon-1/\varepsilon} di\right]^{\varepsilon/\varepsilon-1}$ and $Y_{E,t}^{F*} = \left[\int_0^1 \left(Y_{E,t}^{F*}(i)\right)^{\varepsilon-1/\varepsilon} di\right]^{\varepsilon/\varepsilon-1}$, with $\varepsilon > 1$ represent the elasticity of demand for each intermediate good.

Cost minimization conditions for Home retailer give,

$$Y_{E,t}^{H}(i) = \left(\frac{P_{E,t}(i)}{P_{E,t}}\right)^{-\varepsilon} Y_{E,t}^{H}, \tag{8}$$

$$Y_{E,t}^{F*}(i) = \left(\frac{P_{E,t}^{*}(i)}{P_{E,t}^{*}}\right)^{-\varepsilon} Y_{E,t}^{F*}. \tag{9}$$

Retailer's intermediate goods demand curves for $Y_{E,t}^{H}$ and $Y_{E,t}^{F*}$ are,

$$Y_{E,t}^{H} = (1-\omega)\left(\frac{P_{E,t}}{P_t}\right)^{-v} Y_t, \tag{10}$$

$$Y_{E,t}^{F*} = \omega\left(\frac{e_t P_{E,t}^{*}}{P_t}\right)^{-v} Y_t, \tag{11}$$

with $P_{E,t} = \left[\int_0^1 \left(P_{E,t}(i)\right)^{1-\varepsilon} di\right]^{1/1-\varepsilon}$ and $P_{E,t}^{*} = \left[\int_0^1 \left(P_{E,t}^{*}(i)\right)^{1-\varepsilon} di\right]^{1/1-\varepsilon}$. Therefore, the aggregate price index, CPI, in Home country yields,

$$P_t = \left[(1-\omega)P_{E,t}^{1-v} + \omega\left(e_t P_{E,t}^{*}\right)^{1-v}\right]^{\frac{1}{1-v}}. \tag{12}$$

[5] The production function reduces to a Cobb-Douglas technology as $v = 1$.

2.3 Entrepreneur

2.3.1 The Intermediate Goods Market

We assume that entrepreneurs behave monopolistic competition and introduce nominal rigidity in the intermediate goods market. Entrepreneurs finance funds from banking sector for purchasing capital. Intermediate goods producers maximize their profits subject to three restrictions. The first is production function; the second is that some firms are not allowed to adjust their price in each period; and the third is the demand curve which each intermediate firm faces. The pricing of export intermediate goods is set as producer currency pricing (PCP).

The production function of the monopolistically competitive intermediate firm i is in the Cobb-Douglas technology,

$$Y_{E,t}(i) = A_t K_t^{\alpha}(i) N_t^{1-\alpha}(i), \tag{13}$$

where $Y_{E,t}(i)$ is the output of the firm in period t, $K_t(i)$ and $N_t(i)$ denote capital stock and labor respectively, A_t is an exogenous productivity shock (see below).

The entrepreneur finances its capital acquisition from Home bank each period,

$$L_t(i) = Q_t K_{t+1}(i), \tag{14}$$

where Q_t is the capital price and $L_t(i)$ is the borrowings. We do not allow firm can finance its capital acquisition from Foreign bank due to credit check problem.

The evolution of capital accumulation equation is according to,

$$K_{t+1}(i) = (1-\delta) K_t(i) + I_t(i), \tag{15}$$

where δ is the depreciation rate.

First-order conditions suggest the following optimal labor and capital demand decisions,

$$W_t(i) = MC_t(i)(1-\alpha)\frac{Y_{E,t}(i)}{N_t(i)}, \tag{16}$$

$$1 + R_{L,t}(i) = \frac{MC_t(i)\alpha \dfrac{Y_{E,t}(i)}{K_t(i)} + (1-\delta)Q_t}{Q_{t-1}}, \tag{17}$$

therefore, we can derive the (nominal) marginal cost,

$$MC_t(i) = \frac{W_t(i)}{A_t(1-\alpha)}\left\{\frac{(1-\alpha)\left[\left(1+R_{L,t}(i)\right)Q_{t-1} - (1-\delta)Q_t\right]}{\alpha W_t(i)}\right\}^{\alpha}. \tag{18}$$

Equation (18) implies that the change of (contractual) loan rate, $R_{L,t}(i)$, can influence firm's marginal cost; marginal cost increases as loan rate rises.

Following the recent New Keynesian model literatures, we introduce nominal rigidity in the intermediate firms. We assume that the monopolistic competition entrepreneurs have the market power to choose their optimal price to maximize profits. The pricing process is followed Calvo's staggered type. All of the entrepreneurs cannot adjust their prices in every period with the probability ξ. Denote $P_{E,t}^{opt}(i)$ as the optimal decision chosen by entrepreneur in period *t*. The entrepreneur's optimal pricing strategy is to choose an optimal $P_{E,t}^{opt}(i)$ to solve,

$$\text{Max} \sum_{t=k}^{\infty} \xi^k \Lambda_{t,t+k} \left[\left(\frac{P_{E,t}(i)}{P_{E,t+k}} - MC_{t+k}(i) \right) \left(Y^H_{E,t+k}(i) + Y^F_{E,t+k}(i) \right) \right],$$

where $\Lambda_{t,t+k} = \beta^k \left(c_{H,t} / c_{H,t+k} \right)$ is a discount factor. The First-order condition is,

$$\sum_{t=k}^{\infty} \xi^k \Lambda_{t,t+k} \left\{ (1-\varepsilon) \left(P^{opt}_{E,t}(i) \right)^{-\varepsilon} P^{\varepsilon-1}_{E,t+k} Y_{E,t+k} + \varepsilon MC_{t+k}(i) \left(P^{opt}_{E,t}(i) \right)^{-\varepsilon-1} P^{\varepsilon}_{E,t+k} Y_{E,t+k} \right\} = 0.$$

We can rearrange the above equation as follow,

$$P^{opt}_{E,t}(i) = \frac{\varepsilon}{\varepsilon - 1} \frac{\sum_{t=k}^{\infty} \xi^k \Lambda_{t,t+k} MC_{t+k}(i) P^{\varepsilon}_{E,t+k} Y_{E,t+k}}{\sum_{t=k}^{\infty} \xi^k \Lambda_{t,t+k} P^{\varepsilon-1}_{E,t+k} Y_{E,t+k}}. \tag{19}$$

Consider a special case in which all entrepreneurs are able to adjust price every periods. As $\xi = 0$, equation (19) reduces to,

$$P^{opt}_{E,t}(i) = \frac{\varepsilon}{\varepsilon - 1} MC_t(i).$$

The expression $\varepsilon / (\varepsilon - 1) > 1$ is the gross markup; hence, each entrepreneur sets its optimal price equal to a markup over its (nominal) marginal cost.

The Calvo's type adjustment process implies the following price evolution,

$$P_{E,t} = \left[\xi \left(P_{E,t-1} \right)^{1-\varepsilon} + (1-\xi) \left(P^{opt}_{E,t} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{20}$$

2.3.2 Aggregation

Without loss of generality, we restrict attention to a scenario in which all entrepreneurs behave symmetrically. Entrepreneurs have the same marginal cost due to operating in perfect competition factor markets. As the same demand elasticity, they choose the same price and face the same demand. Entrepreneurs hire the same amount of labor and purchase the same quantity of capital, therefore, to produce an equal amount of ouput. Since all intermediate goods firms operate identically, the aggregate intermediate goods price level equals to the price level of the entrepreneur. Hence, we can substitute an entrepreneur on behalf of the intermediate goods market. Notation (i) can be eliminated from the above.

Starting with the composition of intermediate goods, $Y_{E,t}^{H}=\left[\int_0^1\left(Y_{E,t}^{H}(i)\right)^{\varepsilon-1/\varepsilon}\right]^{\varepsilon/\varepsilon-1}$ and $Y_{E,t}^{F}=\left[\int_0^1\left(Y_{E,t}^{F}(i)\right)^{\varepsilon-1/\varepsilon}\right]^{\varepsilon/\varepsilon-1}$. Since they are the same across all i, we have, $Y_{E,t}^{H}=Y_{E,t}^{H}(i)\left[\int_0^1 di\right]^{\varepsilon/\varepsilon-1}=Y_{E,t}^{H}(i)$ and $Y_{E,t}^{F}=Y_{E,t}^{F}(i)\left[\int_0^1 di\right]^{\varepsilon/\varepsilon-1}=Y_{E,t}^{F}(i)$ respectively. Therefore, the output of intermediate good is $Y_{E,t}=Y_{E,t}(i)\left[\int_0^1 di\right]^{\varepsilon/\varepsilon-1}=Y_{E,t}(i)$. We can apply an integral on equation (13) and obtain $Y_{E,t}=A_t\int_0^1 K_t^{\alpha}(i)N_t^{1-\alpha}(i)=A_tK_t^{\alpha}N_t^{1-\alpha}$. Since all the intermediate firms are behaving the same, the aggregate intermediate goods price level equals to the price level of each intermediate firm, $P_{E,t}=P_{E,t}(i)$.

According to the same logic, the finance of capital accqusition and the capital accumulation equation are becoming $L_t=Q_tK_{t+1}$ and $K_{t+1}=\left(1-\delta\right)K_t+I_t$ respectively. The first-order conditions can be written as $W_t=\left(1-\alpha\right)MC_t\,Y_{E,t}/N_t$ and $\left(1+R_{L.t}\right)Q_{t-1}=\alpha MC_t\,Y_{E,t}/K_t+\left(1+\delta\right)Q_t$. Therefore, the nominal marginal cost is $MC_t=\left(1/A_t\right)\left(W_t\right)^{1-\alpha}\left[\left(1+R_{L,t}\right)Q_{t-1}-\left(1-\delta\right)Q_t\right]^{\alpha}\alpha^{-\alpha}\left(1-\alpha\right)^{-(1-\alpha)}$. The optimal staggered pricing will be,

$$P_{E,t}^{opt}=\frac{\varepsilon}{\varepsilon-1}\frac{\sum_{t=k}^{\infty}\xi^k\Lambda_{t,t+k}MC_{t+k}P_{E,t+k}^{\varepsilon}Y_{E,t+k}}{\sum_{t=k}^{\infty}\xi^k\Lambda_{t,t+k}P_{E,t+k}^{\varepsilon-1}Y_{E,t+k}}.$$

To compute the above equation in Dynare, we have to rewrite the expression as follows,

$$P_{E,t}^{opt}=\frac{\varepsilon}{\varepsilon-1}\frac{Z_t^1}{Z_t^2},$$

with $Z_t^1=MC_tP_{E,t}^{\varepsilon}Y_{E,t}+\xi\ \Lambda_{t,t+1}\mathrm{E}_tZ_{t+1}^1$ and $Z_t^2=P_{E,t}^{\varepsilon-1}Y_{E,t}+\xi\ \Lambda_{t,t+1}\mathrm{E}_tZ_{t+1}^2$.

2.4 Financial Intermediation

The banking sector is followed Kollmann *et al*. (2011). There is a representative bank in each country. In the beginning of period t, bank receives the repayments from entrepreneur, $(1-\delta_{E,t})(1+R_{L,t})L_t$, where $\delta_{E,t}$ is the default shock (see below). Financial intermediation obtains deposits, D_{t+1}^H and D_{t+1}^{F*}, from Home and Foreign households and lends L_{t+1} to Home entrepreneur at the end of period t. Let $D_{t+1}^W=D_{t+1}^H+D_{t+1}^{F*}$ be the aggregate deposits in the bank. We induce the bank's capital $L_{t+1}-D_{t+1}^W$ has to satisfy a proportion γ of the assets L_{t+1}.[6] It is costly for bank to hold less capital than the ratio γ. Denote the bank's excess capital as

[6] We do not interpret γ is the minimum capital requirement as the Basel Accord suggested. γ is not the constraint when banking sector running services. The bank capital position in our model behaves rise and fall through business cycles. We allow that the level of bank capital can be lower than the ratio γ. However, capital has to hold at γ in the steady-state; in other words, there is no excess bank capital in the steady-state.

$x_t = \left(L_{t+1} - D_{t+1}^W\right) - \gamma L_{t+1} = \left(1-\gamma\right) L_{t+1} - D_{t+1}^W$ at the end of period t.

Bank bears a cost $\phi(x_t)$ as a function of x_t. The properties of $\phi(x_t)$: $\phi(x_t)$ is a strictly convex function; $\phi(0)=0$, $\phi'(x_t)<0$, and $\phi''(x_t)>0$. $\phi'(x_t)<0$ implies that decreasing banking capital raises the cost; but the cost equals to zero as bank meets the bank capital ratio γ. The financial intermediation also carries an operating cost, $\Gamma\left(D_{t+1}^W, L_{t+1}\right) = \Gamma_D D_{t+1}^W + \Gamma_L L_{t+1}$ with $\Gamma_D,\ \Gamma_L > 0$. We suppose that the marginal operating costs are constant over time.

We assume that the discount factor of bank is the same as household. The Home bank maximizes its expected lifetime utility (21) by choosing real consumption subject to the budget constrain (22),

$$E_0 \sum_{t=0}^{\infty} \beta^t \ln c_{B,t}, \tag{21}$$

$$c_{B,t} + \frac{L_{t+1}}{P_t} + \frac{\left(1+R_{D,t}\right) D_t^W}{P_t} + \frac{\Gamma\left(D_{t+1}^W, L_{t+1}\right)}{P_t} + \phi(x_t) = \frac{D_{t+1}^W}{P_t} + \frac{\left(1-\delta_{E,t}\right)\left(1+R_{L,t}\right) L_t}{P_t}. \tag{22}$$

The first-order conditions yield,

$$\beta\ \mathrm{E}_t \frac{c_{B,t}\left(1+R_{D,t+1}\right)}{c_{B,t+1}\pi_{t+1}} = 1 - \Gamma_D + \phi'(x_t), \tag{23}$$

$$\beta\ \mathrm{E}_t \frac{c_{B,t}\left(1+R_{D,t+1}\right)}{c_{B,t+1}\pi_{t+1}} = 1 - \Gamma_D + \phi'(x_t), \tag{24}$$

$$\beta\ \mathrm{E}_t \frac{c_{B,t}\left(1-\delta_{E,t+1}\right)\left(1+R_{L,t+1}\right)}{c_{B,t+1}\pi_{t+1}} = 1 + \Gamma_L + \phi'(x_t)\left(1-\gamma\right). \tag{25}$$

Equation (23) and (24) behave the Euler equation for Home and Foreign deposits. The marginal benefit for accepting more deposits to increase the consumption of bank is on the left hand side of equation (23). Meanwhile, however, bank bears a marginal operating cost Γ_D and her excess banking capital decreases are on the right hand side of equation (23). The intuition of equation (25) is equivalent to equation (23); at the optimal of lending decision, the expected marginal benefit equals to the marginal cost.

2.5 Government

Government balances the budget with a lump-sum tax and bonds,

$$G_t + \frac{(1+R_t)B_t}{P_t} = T_t + \frac{B_{t+1}}{P_t}.$$

We do not impose government purchases in each period, which implies $G_t = 0$. Hence, we do not discuss government expenditure here.

2.6 Central Bank

We suppose that the monetary policy according to a Taylor rule. The central bank adjusts the policy rate, R_t, endogenously in response to the deviation of inflation and output from their steady-state,

$$R_t = (1-\rho_R)\left[R + \rho_\pi(\pi_t - \pi) + \rho_Y(\log Y_t - \log Y)\right] + \rho_R R_{t-1} + \varepsilon_{R,t}, \qquad (26)$$

where R, π, and Y are the steady-state values of policy rate, inflation, and output respectively. $\varepsilon_{R,t}$ is a monetary policy shock which is normally distributed.

2.7 Shocks Process

There are productivity shock and default shock except for monetary policy shock. Both of them follow AR(1) processes,

$$\ln A_t = (1-\rho_A)\ln A + \rho_A \ln A_{t-1} + \varepsilon_{A,t}, \tag{27}$$

$$\delta_{E,t} = (1-\rho_\delta)\delta_E + \rho_\delta \delta_{E,t-1} + \varepsilon_{\delta,t}, \tag{28}$$

where A and δ_E are the steady-state values. ρ_A and ρ_δ are the autocorrelation parameters all assumed to be between 0 and 1, while $\varepsilon_{A,t}$ and $\varepsilon_{\delta,t}$ are white noise.

2.8 Market-Clearing Conditions

We assume that the bank purchases final goods to operate deposits and lending services and the excess banking capital cost also carries in final goods. Therefore, these costs have to be computed to clear the final goods market in addition to the consumption from household and bank and the investment,

$$Y_t = c_{H,t} + c_{B,t} + I_t + \frac{\Gamma\left(D_t^W, L_t\right)}{P_t} + \phi(x_t), \tag{29}$$

$$Y_t^* = c_{H,t}^* + c_{B,t}^* + I_t^* + \frac{\Gamma\left(D_t^{W*}, L_t^*\right)}{P_t^*} + \phi(x_t^*). \tag{30}$$

Equation (30) is the market-clearing condition for Foreign final goods. As for intermediate goods,

$$Y_{E,t} = Y_{E,t}^{H} + Y_{E,t}^{F}, \tag{31}$$

$$Y_{E,t}^{*} = Y_{E,t}^{H*} + Y_{E,t}^{F*}, \tag{32}$$

3 Bank Capital and Spreads

Here we picture the mechanism how banking capital influences loan rate spreads. It is the core of the model. Furthermore, we obtain some of the bank variables by using first-order approximation.

First of all, dividing equation (24) and (25) together,

$$\frac{\mathrm{E}_t\left(1-\delta_{E,t+1}\right)\left(1+R_{L,t+1}\right)}{1+R_{D,t+1}} = \frac{1+\Gamma_L+\phi'(x_t)\left(1-\gamma\right)}{1-\Gamma_D+\phi'(x_t)},$$

and using first-order approximation, the above equation becomes,

$$R_{L,t+1}^{e} - R_{D,t+1} \cong \Gamma_D + \Gamma_L - \gamma\phi'(0) - \gamma\phi''(0)x_t, \tag{33}$$

where $R_{L,t+1}^{e} = \mathrm{E}_t\left(1-\delta_{E,t+1}\right)R_{L,t+1}$ is the effective loan rate and a linear approximation of $\phi'(x_t)$ at $x_t = 0$ is assumed, $\phi'(x_t) \cong \phi'(0) + \phi''(0)x_t$. Equation (33) suggests that a decrease in banking capital raises the effective loan rate spreads. This implies the dynamic of effective loan rate is not only be decided by equation (25) but the position of banking capital does. Furthermore, the financial friction behaves more stern as $\phi''(0)$ becoming larger. The value of $\phi''(0)$ is estimated by Kollmann *et al*. (2011).

The entrepreneur makes optimal decision based on the contractual loan rate (see equation (17)), therefore, shock on default rate alters the optimal decision making for entrepreneur. Consumption, investment, deposits, loans, and output are influenced in turn.

We use first-order approximation to provide more details for the loan rate spreads mechanism associated with a default shock. Up to first-order approximation, the banker's optimal (real) consumption equals a proportion $1-\beta$ of her beginning wealth,

$$c_{B,t} = \frac{(1-\beta)\left[\left(1-\delta_{E,t}\right)\left(1+R_{L,t}\right)L_t - \left(1+R_{D,t}\right)D_t^W\right]}{P_t}. \tag{34}$$

Bank's consumption equals to the repayments from entrepreneur but subtracts the returns of worldwide obligation debt, deposits, at each period, and times a fraction of $1-\beta$.

Define (nominal) bank wealth at the end of period *t* is,

$$S_{t+1} = L_{t+1} - D_{t+1}^W + \Gamma\left(D_{t+1}^W, L_{t+1}\right) + \phi(x_t) \tag{35}$$

Equation (34) and the budget constraint, equation (22) suggest that the optimal bank wealth is the fraction β of bank's beginning wealth,

$$S_{t+1} = \beta\left[\left(1-\delta_{E,t}\right)\left(1+R_{L,t}\right)L_t - \left(1+R_{D,t}\right)D_t^W\right]. \tag{36}$$

The form of bank wealth is similar to equation (34). Note that only default shock influences the bank credit health; however, productivity shock plays no direct role in the financial intermediation system. Kollmann *et al*. (2011) argue there is an attenuate effect by equation (33) as a positive productivity shock occurred. Positive productivity shock raises household's wage rate; hence, deposits holdings increase. Increasing aggregate deposits lower the (excess) banking capital and the loan rate spreads rise. Therefore, the banking capital mechanism mitigates the positive effects on investment and aggregate production. Note that Kollmann *et al*. (2011) is a two-country, one global bank model.

Up to first-order approximation of equation (35),

$$S_{t+1} = L_{t+1}\left[1+\Gamma_L + (1-\gamma)\phi'(0)\right] - D_{t+1}^W\left(1-\Gamma_D + \phi'(0)\right), \tag{37}$$

and using $\beta(1+R_D) = 1-\Gamma_D + \phi'(0)$ and $\beta\left(1+R_L^e\right) = 1+\Gamma_L + \phi'(0)(1-\gamma) = 1$, which are the steady-state of equation (23) and (25), we can simplified equation (37),

$$S_{t+1} = L_{t+1} - \beta(1+R_D)\, D_{t+1}^W. \tag{38}$$

Substituting equation (38) into the definition of the excess banking capital that is mentioned in section 2, we can obtain,

$$x_t = \frac{(1-\gamma)S_{t+1} + \left[\beta(1-\gamma)(1+R_D) - 1\right]D_{t+1}^W}{P_t}. \tag{39}$$

Therefore, we connect the relationship between bank wealth and banking capital. Equation (39) implies that the decreasing of bank wealth and aggregate deposits lower the banking capital; according to equation (33), which raises loan rate spreads in turn.

4 Calibrated Parameters

4.1 Steady-State

The steady-state values are the same in two countries due to a symmetric model.

Kollmann *et al*. (2011) obtain their steady-state by using a specific method. First of all, they assign the steady-state values of deposit rate, effective loan rate, and contractual loan rate based on empirical data instead of solving them endogenously. Given these assumptions, second, compute the other variables values. The method of obtaining the steady-state of our model is equivalent the same as Kollmann *et al*. (2011). However, comparing to them, we obtain the deposit rate endogenously. Detail is shown in Appendix B. We set the steady-state deposit rate, R_D, at 1.47% per annum. The steady-state effective loan rate, R_L^e, and the default rate, δ_E, are set at 2.5% and 0.95% per annum respectively, following Kollmann *et al*. (2011); hence, the steady-state contractual loan rate (which includes default rate), R_L, is 3.48% per annum. There is no inflation in the steady-state so that all of the prices equals to 1 in the steady-state. Capital price also equals to 1. The model has to behave deterministic, therefore, productivity shock in the steady-state is set at $A = 1$.

4.2 Parameter Values

The discount factor, β, is calibrated at 0.9938 as Kollmann *et al*. (2011), so that the steady-state policy rate is 2.5% per annum. The capital share of intermediate good output, α, and the depreciation rate, δ, are set at 0.36 and 0.025 respectively. The inverse of elasticity of labor supply, η, is set at 1, following Bergin *et al*. (2007). We calibrate the country's elasticity of substitution between Home and Foreign intermediate goods, in final goods production, $v = 5$ according to Bergin *et al*. (2007). The ratio of the value of imported good, ω, is set at 0.2. We assume the markup of price over marginal cost in the production of intermediate goods, $\varepsilon/(\varepsilon-1)$, equals to 1.2 which suggests $\varepsilon=6$. We calibrate the average duration between price changes at $\xi=0.75$ as commonly assumed in the New Keynesian model literatures. Household's deposit preference parameter, χ, is set to 0.014, following Kollmann *et al*. (2011).

The banking capital requirement, γ, is set at 7%. We suppose that the excess baking capital, x, has to be hold at zero in the steady-state. As equation (23) and (25) show, $\beta\, c_B(1+R_D)=1-\Gamma_D+\phi'(0)$ and $\beta\, c_B(1-\delta_E)(1+R_L)=1+\Gamma_L+\phi'(0)(1-\gamma)$, give the same steady-state with any values of Γ_D, Γ_L, and $\phi'(0)$. According to the properties, $\Gamma_D>0$, $\Gamma_L>0$, and $\phi'(0)<0$ associate with the steady-state statement of equation (23) and (25) mentioned above, we can obtain the relationship among these parameters. We assume $\phi'(0)=-0.002$. We set $\phi''(0)=0.125/Y$ in the steady-state.[7]

The random processes of productivity shock and default shock are based on Kollmann *et al*. (2011). The autocorrelation of productivity shock in both countries, ρ_A equals to 0.95. We calibrate the standard deviation as $\mathrm{E}\left(\varepsilon_{A,t}\right)^2=\mathrm{E}\left(\varepsilon^*_{A,t}\right)^2=(0.0053)^2$. The correlation between Home and Foreign productivity shocks is 0.82. The autocorrelation of default shock in both countries, ρ_δ, equals to 0.97, while the standard deviation is $\mathrm{E}\left(\varepsilon_{\delta,t}\right)^2=\mathrm{E}\left(\varepsilon^*_{\delta,t}\right)^2=(0.000282)^2$. The correlation between Home and Foreign default shock is set at $Corr\left(\varepsilon_{\delta,t},\varepsilon^*_{\delta,t}\right)=0.76$. Kollmann *et al*. (2011) also suppose that there are correlations between both countries' productivity shock and

[7] Kollmann *et al*. (2011) set $\phi''(0)=0.25/Y$ in their work. Not that they are one global bank model; however, there are two banks in each country in our study. Therefore, we bisect the value.

default shock, $Corr\left(\varepsilon_{\delta,t},\varepsilon_{A,t}\right)=Corr\left(\varepsilon_{\delta,t},\varepsilon_{A,t}^{*}\right)=Corr\left(\varepsilon_{\delta,t}^{*},\varepsilon_{A,t}\right)=\mathrm{E}\left(\varepsilon_{\delta,t}^{*},\varepsilon_{A,t}^{*}\right)=-0.63$.

The monetary policy follows Clarida *et al*. (2000), therefore, $\rho_R=0.8$, $\rho_\pi=1.5$, and $\rho_Y=0.1$; the standard deviation is set to 0.0016.

We outline the parameter values in table 1; table 2 summarizes some of the steady-state values (see page 29 and page 30 respectively).

5 Dynamics

To evaluate the contribution of the banking sector in our model, we simulate the impulse responses to the Home productivity shock, the Home default shock, and the Home monetary shock. Figures 1 to 12 report the results. Each variable's response is expressed in percentage deviations from its steady-state, interest rate in percentage points.

5.1 Productivity Shock

Figures 1 to 4 represent responses to a 1% positive Home productivity shock (see page 31 to page 34 respectively). The positive shock results in more efficient in producing, hence, intermediate goods firm is more willing to purchase capital and more willing to borrow funds from bank, loans are increasing which trigger investment rising in turn as well as output. There is a moderate deflation accompanied with the shock. The positive productivity shock causes appreciation in Home country. Home intermediate goods are relatively expensive for Foreign retailer and Foreign intermediate goods are becoming inexpensive for Home retailer, therefore, Home export falls which implies that the output of Foreign retailer decreases. Furthermore, Home household saves less in the Foreign bank, the Foreign bank loanable funds becomes insufficient, therefore, loans decays as well as investment. Hence, the decreasing of import and the loans result in a recession in Foreign country. Note that the spread decreases in Home country while rises in Foreign country. This may another reason can explain that why in this experiment, positive Home productivity shock does not predict a simultaneous boom across countries.

5.2 Default Shock

Figures 5 to 8 report dynamics to a one-time unexpected increase in Home default shock, Home intermediate firm default on their borrowings (see page 35 to page 38 respectively). We use this experiment on behalf of a financial shock scenario in our model. The default shock sparks the international recession; output, investment, employment, export, and loans decrease in both countries. As Home intermediate goods firm defaulting, crisis happened, Home bank faces liquidity shortage. With losing funds in banking sector, returns to household and loans to intermediate goods firm are becoming more insufficient. The shock causes Home capital price decreasing which influences the ability of borrowings of the Home intermediate goods firm, furthermore, accompanied with losing loanable funds in financial intermediation, there is a sizeable fall in Home investment and the aggregate production decreases in turn. The recession dominates the effect of the depreciating Home currency, Home export falls. Since the import and the bank deposits decay in Foreign country, the result is similar as the above case, Foreign country suffers form a recession; output, investment, loans and export decrease. There is also unemployment in Foreign country. Therefore, Home default shock drives an international crisis in our model.

5.3 Monetary Policy Shock

Figures 9 to 12 plot the impulse responses to a negative 1% Home monetary policy (see page 39 to page 42 respectively). The contraction monetary policy also triggers a recession across countries. Output, investment, loans, and employment fall in both countries. Note that the negative monetary policy shock causes a sizeable decay in Home investment. Home real wage behaves persistently decreases. For Foreign country, the dynamic paths and international transmission mechanism are equivalent the same as the default shock experiment.

6 Concluding Remarks

The global financial crisis has highlighted the financial factor and the role of financial intermediation in the propagation of international business cycles. The importance of embedding banking sector with DSGE model has been growing in literatures. To investigate the international transmission mechanism of financial shock, this paper proposes a two-country two-bank New Keynesian model. The crisis is triggered by entrepreneur defaulting on their borrowings.

The calibration results suggest that the model predicts an international crisis with a Home default shock as well as a negative Home monetary policy shock. The country-specific default shock to Home intermediate goods firm not only causes a recession in Home country but transmits the financial shock to Foreign country. As the repayments is less than contractual agreed to financial intermediation, the liquidity in the economy is becoming more inadequate. Intermediate goods firm finances funds from banking sector for purchasing capital; therefore, with the shortage of liquidity, the financial mechanism magnifies the fluctuations. The Home country-specific shocks transmit to Foreign country through bank deposits and the international trade channel. With Home household saves less in Foreign bank and the fall of Home intermediate goods export, Foreign loanable funds decreases as well as Foreign final goods output.

To concentrate on formulating a two-country two-bank New Keynesian model, we leave a number of issues for further works. Sensitivity analysis is absent from our study as well as the optimal monetary policy. The international loan channel is also be simplified in our model. It would be interesting to investigate these issues to understand more details of international business cycles with financial intermediation.

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Table 1: Parameters

Parameter	Description	Value
	Calibrated parameters	
α	Capital ratio	0.36
β	Discount factor	0.9938
δ	Depreciation rate	0.025
χ	Deposit preference	0.014
η	Labor supply aversion	1
ν	Elasticity of substitution between Home and Foreign intermediate goods	5
ω	Imported goods share	0.2
ε	Price elasticity of demand	6
ξ	Nominal rigidity	0.75
γ	Required banking capital ratio	0.07
	Autocorrelation of shocks	
ρ_A	Productivity	0.95
ρ_δ	Default	0.97
ρ_R	Policy rate	0.8
ρ_π	Inflation	1.5
ρ_Y	Output	0.1
	Standard deviation of shocks	
ε_A	Productivity	0.0053
ε_δ	Default	0.000282
ε_R	Policy rate	0.0016

Table 2: Steady-state

Variable	Description	Value
C_H	Household consumption	2.1664
C_B	Bank consumption	0.0116
C	Aggregate consumption	2.1779
I	Investment	0.6407
Y	Output	2.8796
K	Capital input	25.6286
w	Real wage	1.8240
N	employment	0.8420
L	Loan	25.6286
D^W	Aggregate deposit in bank	23.8346
R_D	Deposit rate (p.a.)	1.47%
R_L	Contractual loan rate (p.a.)	3.48%
R_L^e	Effective loan rate (p.a.)	2.5%
R	Policy rate (p.a.)	2.5%

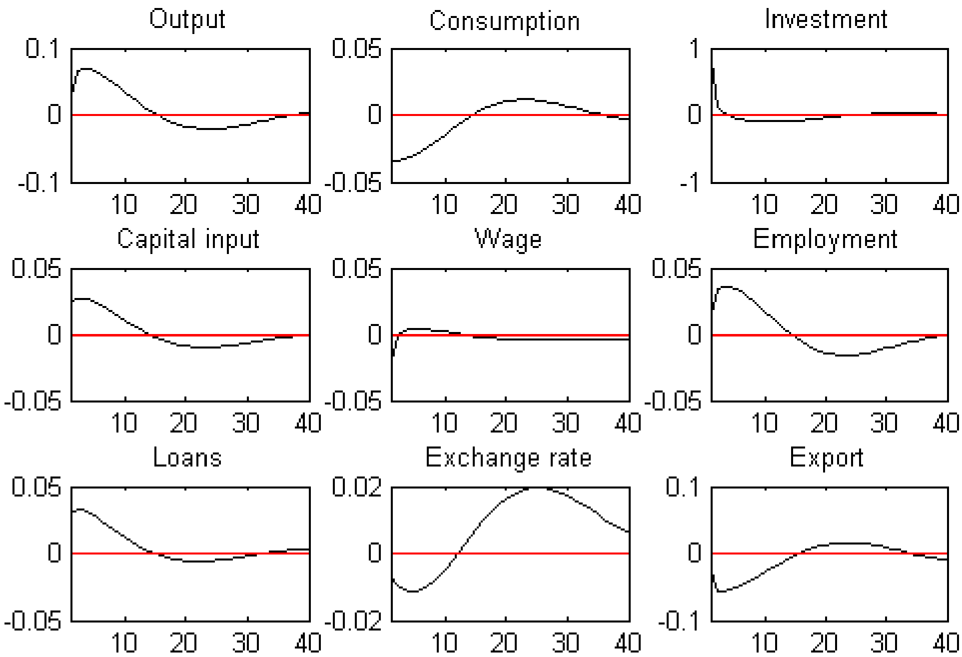

Figure 1: Productivity shock

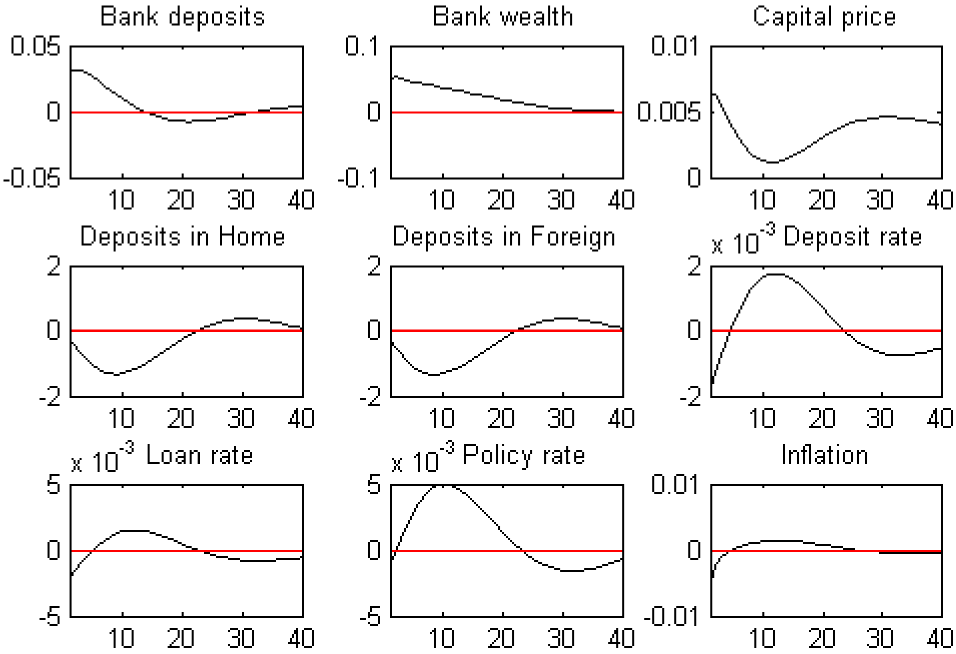

Figure 2: Productivity shock (cont.)

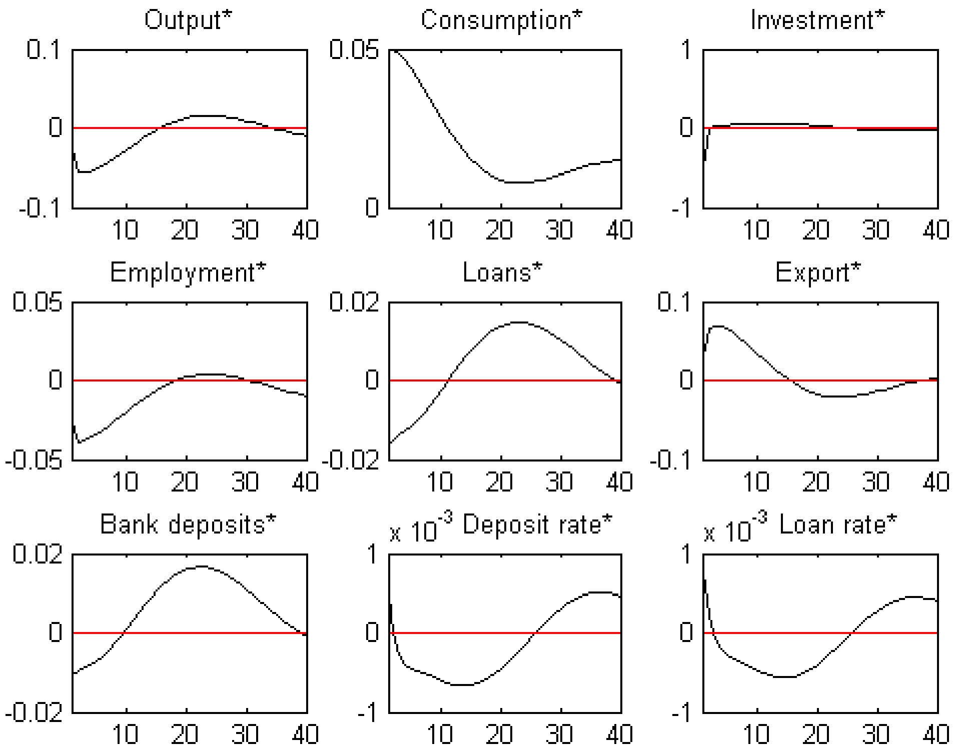

Figure 3: Productivity shock (cont.)

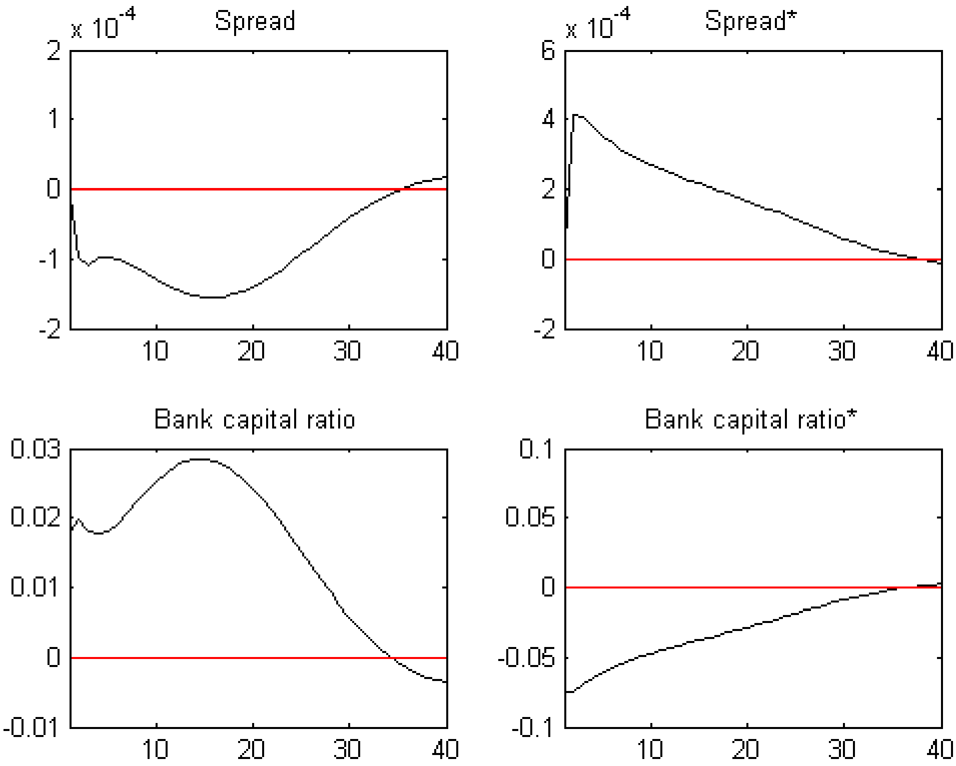

Figure 4: Productivity shock (cont.)

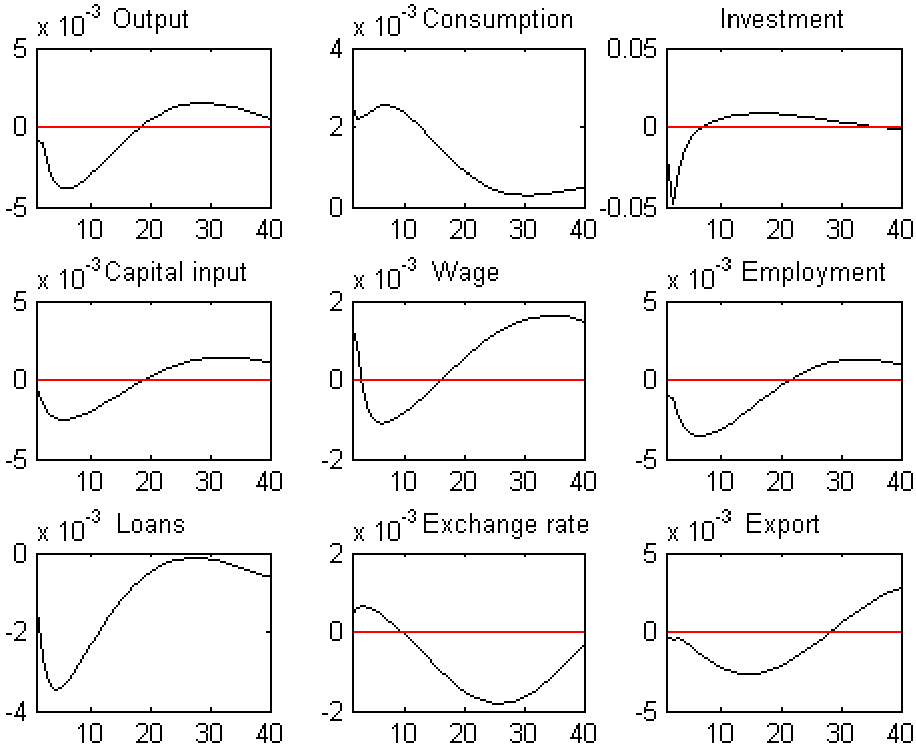

Figure 5: Default shock

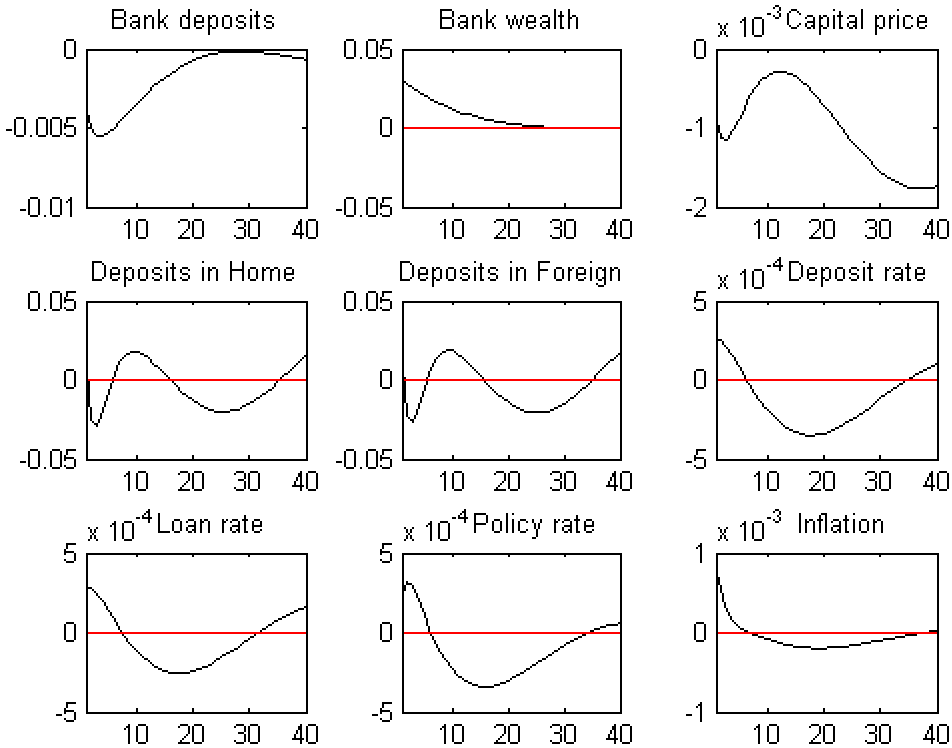

Figure 6: Default shock (cont.)

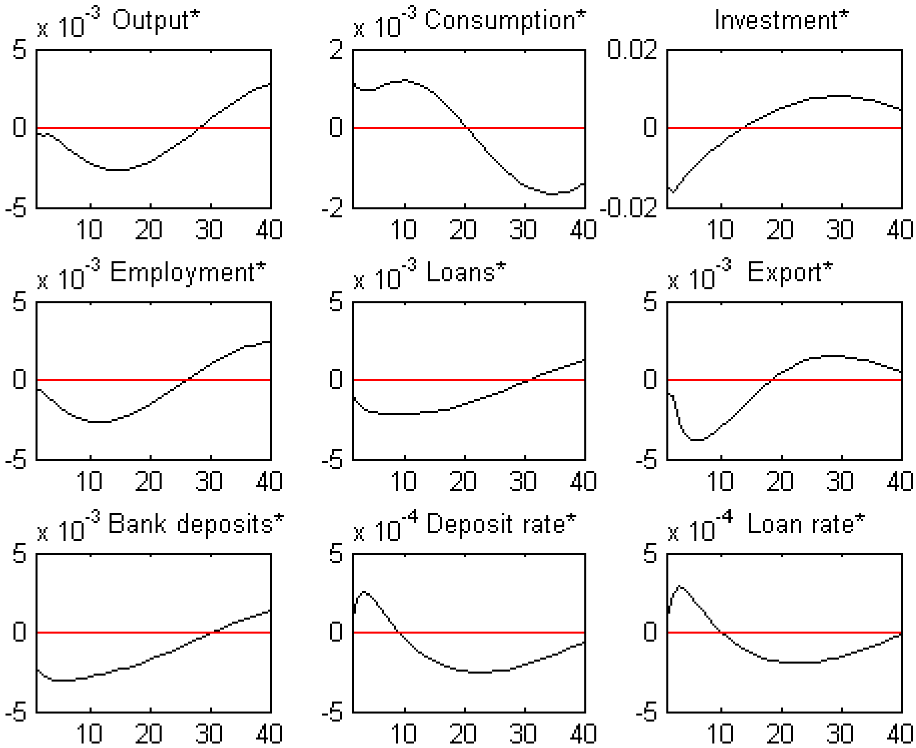

Figure 7: Default shock (cont.)

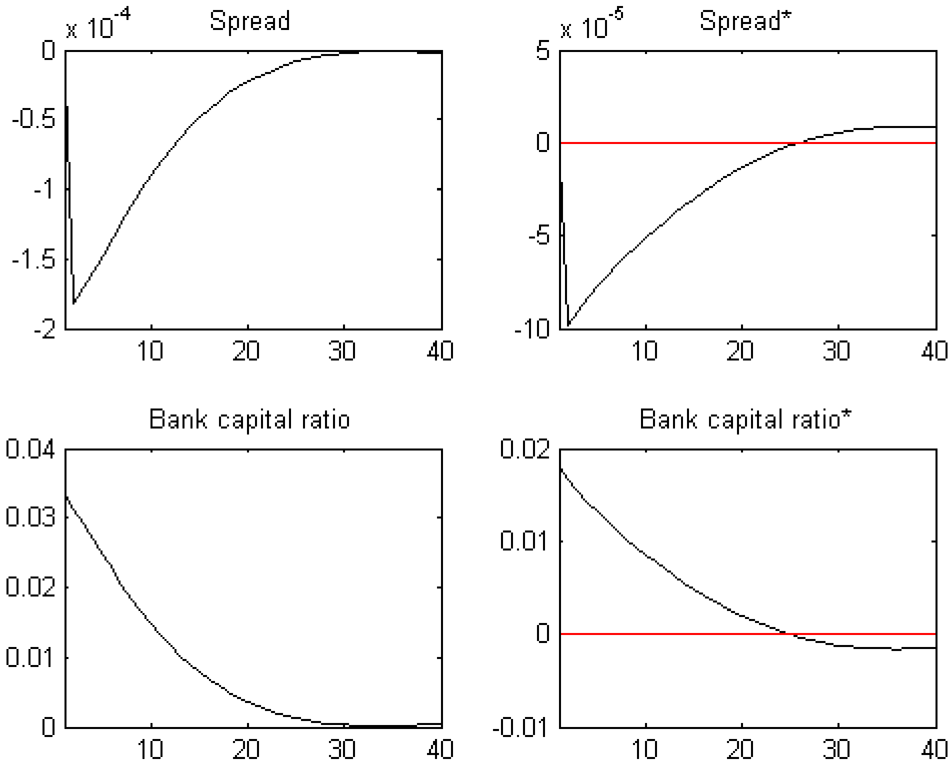

Figure 8: Default shock (cont.)

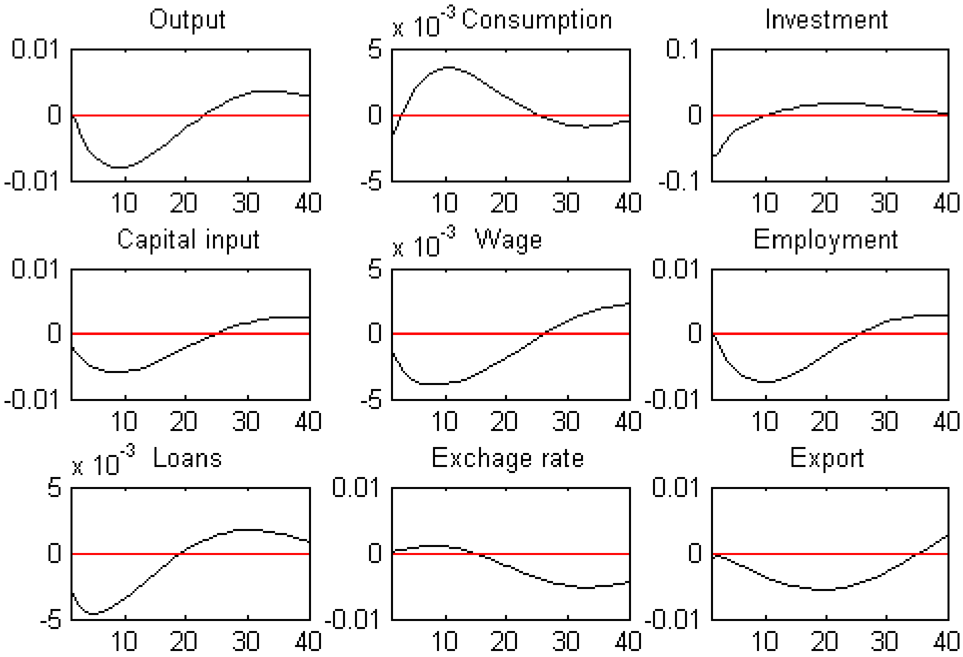

Figure 9: Monetary policy shock

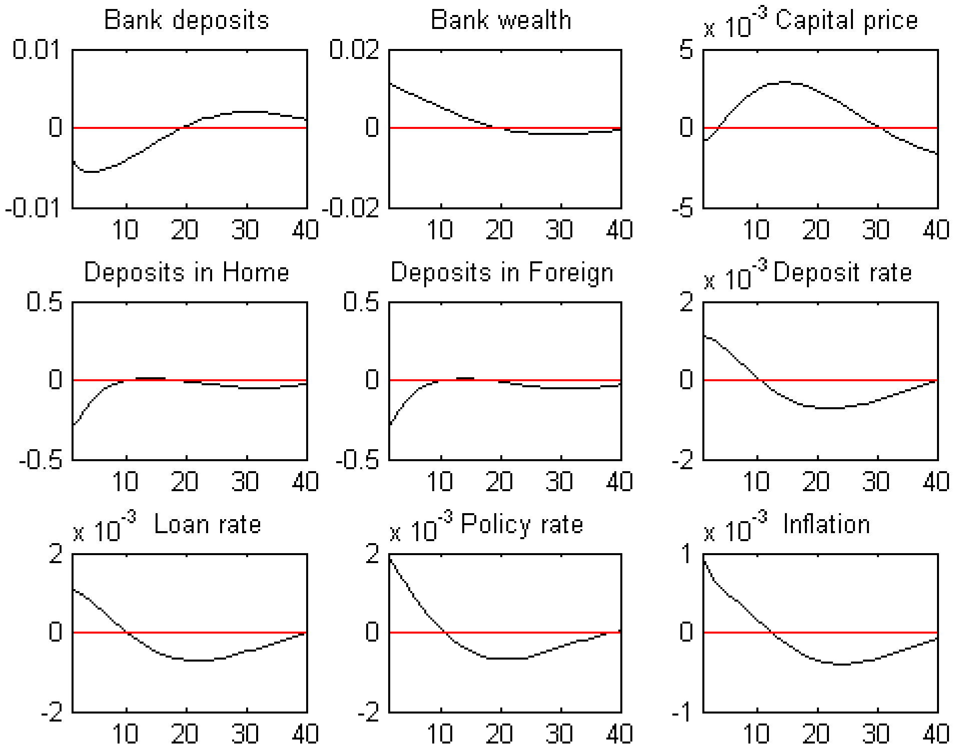

Figure 10: Monetary policy shock (cont.)

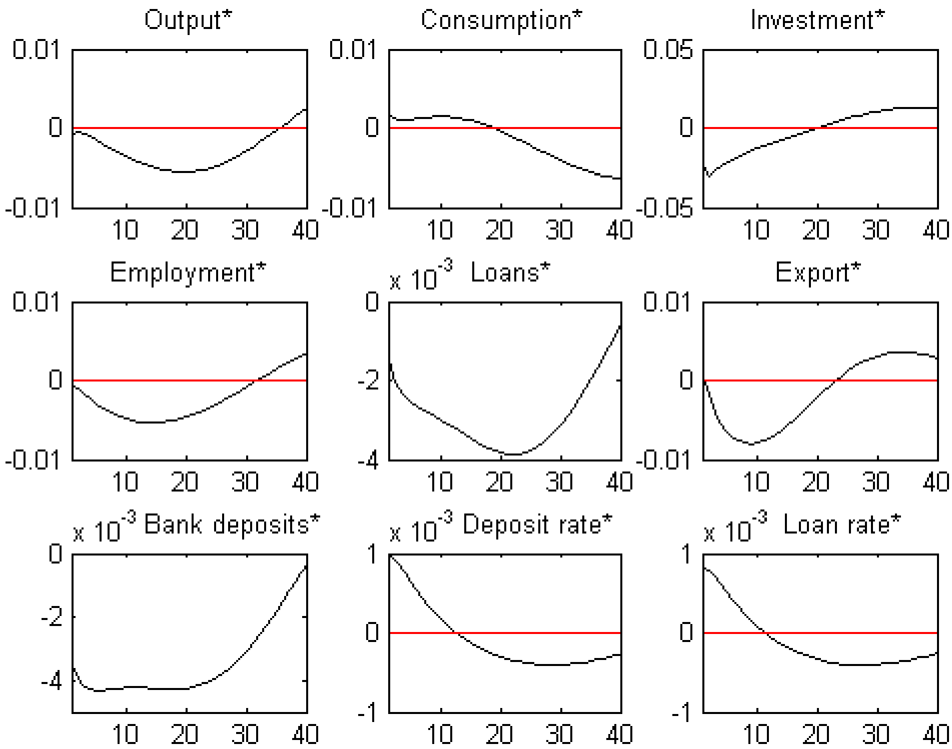

Figure 11: Monetary policy shock (cont.)

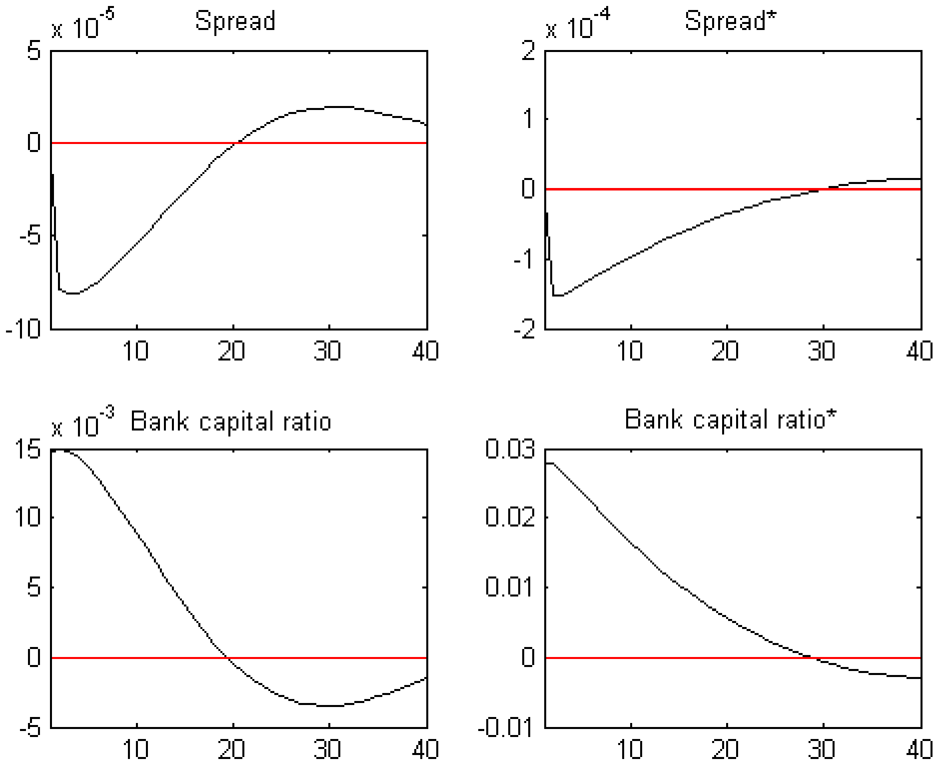

Figure 12: Monetary policy shock (cont.)

Appendix

Appendix A: Foreign country equations

A.1 Household

The First-order conditions of the Foreign worker's optimization are,

$$\chi \frac{c_{H,t}^{*}}{d_t^{H*}} + \beta \,\mathrm{E}_t \frac{c_{H,t}^{*}\left(1+R_{D,t+1}^{*}\right)}{c_{H,t+1}^{*}\pi_{t+1}^{*}} = 1,$$

$$\chi \frac{c_{H,t}^{*}}{d_t^{F*}} + \beta \,\mathrm{E}_t \frac{c_{H,t}^{*}\left(1+R_{D,t+1}\right)e_t}{c_{H,t+1}^{*}\pi_{t+1}^{*}e_{t+1}} = 1,$$

$$\left(N_t^{*}\right)^{\eta-1} = \frac{w_t^{*}}{c_{H,t}^{*}}$$

$$\beta \,\mathrm{E}_t \frac{c_{H,t}^{*}\left(1+R_{t+1}^{*}\right)}{c_{H,t+1}^{*}\pi_{t+1}^{*}} = 1,$$

with the definition of $w_t^{*} = W_t^{*}/P_t^{*}$, $d_{t+1}^{H*} = D_{t+1}^{H*}/P_t^{*}$, $d_{t+1}^{F*} = D_{t+1}^{F*}/e_t P_t^{*}$, $\pi_{t+1}^{*} = P_{t+1}^{*}/P_t^{*}$.

A.2 Final goods producer

The production function is,

$$Y_t^{*} = \left[(1-\omega)^{\frac{1}{\nu}}\left(Y_{E,t}^{H*}\right)^{\frac{\nu-1}{\nu}} + \omega^{\frac{1}{\nu}}\left(Y_{E,t}^{F}\right)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}.$$

The First-order conditions of the Foreign retailer are,

$$Y_{E,t}^{H*} = (1-\omega)\left(\frac{P_{E,t}^{*}}{P_t^{*}}\right)^{-\nu} Y_t^{*},$$

$$Y_{E,t}^{F} = \omega\left(\frac{P_{E,t}}{e_t P_t^{*}}\right)^{-\nu} Y_t^{*},$$

The aggregate price index yields,

$$P_t^{*} = \left[(1-\omega)\left(P_{E,t}^{*}\right)^{1-\nu} + \omega\left(\frac{P_{E,t}}{e_t}\right)^{1-\nu}\right]^{\frac{1}{1-\nu}},$$

A.3 Intermediate goods producer

The technology is,

$$Y_{E,t}^{*} = A_t^{*}\left(K_t^{*}\right)^{\alpha}\left(N_t^{*}\right)^{1-\alpha}.$$

The finance of capital acquisition,

$$L_t^{*} = Q_t^{*} K_{t+1}^{*}.$$

The evolution of capital accumulation equation is according to,

$$K_{t+1}^{*} = (1-\delta) K_t^{*} + I_t^{*}.$$

The optimal labor and capital demand decisions,

$$W_t^{*} = MC_t^{*}(1-\alpha)\frac{Y_{E,t}^{*}}{N_t^{*}},$$

$$\left(1+R^*_{L,t}\right)Q^*_{t-1} = MC^*_t \alpha \frac{Y^*_{E,t}}{K^*_t} + \left(1-\delta\right)Q^*_t.$$

Therefore, the (nominal) marginal cost,

$$MC^*_t = \frac{1}{A^*_t}\left(W^*_t\right)^{1-\alpha}\left[\left(1+R^*_{L,t}\right)Q^*_{t-1} - (1-\delta)Q^*_t\right]^{\alpha}\alpha^{-\alpha}\left(1-\alpha\right)^{-(1-\alpha)}.$$

The optimal pricing strategy,

$$\left(P^*_{E,t}\right)^{opt} = \frac{\varepsilon}{\varepsilon-1}\frac{\sum_{t=k}^{\infty}\xi^k\Lambda^*_{t,t+k}MC^*_{t+k}\left(P^*_{E,t+k}\right)^{\varepsilon}Y^*_{E,t+k}}{\sum_{t=k}^{\infty}\xi^k\Lambda^*_{t,t+k}\left(P^*_{E,t+k}\right)^{1-\varepsilon}Y^*_{E,t+k}}.$$

The evolution of intermediate goods price,

$$P^*_{E,t} = \left[\xi\left(P^*_{E,t-1}\right)^{1-\varepsilon} + \left(1-\xi\right)\left(P^{opt*}_{E,t}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}.$$

A.4 Banker

The definition of excess banking capital,

$$x^*_t = \left(1-\gamma\right)L^*_{t+1} - D^{W*}_{t+1}.$$

The first-order conditions,

$$\beta\ \mathrm{E}_t\frac{c^*_{B,t}\left(1+R^*_{D,t+1}\right)}{c^*_{B,t+1}\pi^*_{t+1}} = 1-\Gamma_D + \phi'(x^*_t).$$

The dynamic of loan rate spreads,

$$R^{e*}_{L,t+1} - R^*_{D,t+1} \cong \Gamma_D + \Gamma_L - \gamma\phi'(0) - \gamma\phi''(0)x^*_t.$$

The banker's optimal (real) consumption,

$$c_{B,t}^{*}=\frac{(1-\beta)\left[\left(1-\delta_{E,t}^{*}\right)\left(1+R_{L,t}^{*}\right)L_{t}^{*}-\left(1+R_{D,t}^{*}\right)D_{t}^{W*}\right]}{P_{t}^{*}}.$$

The bank wealth,

$$S_{t+1}^{*}=L_{t+1}^{*}-\beta\left(1+R_{D}^{*}\right)D_{t+1}^{W*}.$$

Therefore, the relationship between bank wealth and banking capital,

$$x_{t}^{*}=\frac{(1-\gamma)S_{t+1}^{*}+\left[\beta(1-\gamma)\left(1+R_{D}^{*}\right)-1\right]D_{t+1}^{W*}}{P_{t}^{*}}.$$

A.5 Shock processes

Monetary policy shock,

$$R_{t}^{*}=(1-\rho_{R})\left[R^{*}+\rho_{\pi}\left(\pi_{t}^{*}-\pi^{*}\right)+\rho_{Y}\left(\log Y_{t}^{*}-\log Y^{*}\right)\right]+\rho_{R}R_{t-1}^{*}+\varepsilon_{R,t}.$$

Productivity shock,

$$\ln A_{t}^{*}=(1-\rho_{A})\ln A^{*}+\rho_{A}\ln A_{t-1}^{*}+\varepsilon_{A,t}.$$

Default shock,

$$\delta_{E,t}^{*}=(1-\rho_{\delta})\delta_{E}^{*}+\rho_{\delta}\delta_{E,t-1}^{*}+\varepsilon_{\delta,t}.$$

Appendix B: Endogenous deposit rate

As the steady-state assumption that we describe in section 4, from equation (3) and (4), we can obtain $d^H = d^F$. The steady-state deposit holding is,

$$d^H = \frac{\chi}{1-\beta\left(1+R_D\right)} c_H . \tag{A.1}$$

The steady-state of equation (5) is,

$$c_H = \frac{w}{N^\eta}.$$

Hence, equation (A.1) can be written as,

$$d^H = \frac{\chi}{1-\beta\left(1+R_D\right)} \frac{w}{N^\eta}. \tag{A.2}$$

The steady-state of equation (19) is $MC = \varepsilon - 1/\varepsilon$. Therefore, we can obtain the steady-state wage, $w = \left\{ MC\left(R_L+\delta\right)^{-\alpha}\left[\alpha^\alpha\left(1-\alpha\right)^{1-\alpha}\right]\right\}^{1/1-\alpha}$. The steady-state of equation (16) and (17) are $N = \left[\left(1-\alpha\right)MC\ Y\right]/w$ and $K = \left(\alpha MC\ Y\right)/\left(R_L+\delta\right)$. Thus we can also obtain the steady-state investment $I = \left(\delta\alpha MC\ Y\right)/\left(R_L+\delta\right)$. According to equation (14), we know $L = K$.

We assume that the steady-state excess banking capital has to be zero; therefore, combine the steady-state of equation (37) and (38) gives $D^W = \left(1-\gamma\right)L$. The steady-state of bank's consumption is $c_B = \left(1-\beta\right)\left[\left(1-\delta_E\right)\left(1+R_L\right)L - \left(1+R_D\right)D^W\right]$.

Substitute c_H, c_B, I, D^W, and L into the steady-state of the market-clearing condition of final goods, equation (29), and rearrange,

$$Y=\left(\frac{1-\dfrac{\alpha MC}{R_L+\delta}\left[(1-\beta)(1-\delta_E)(1+R_L)-(1-\beta)(1+R_D)(1-\gamma)+\delta+\Gamma_D(1-\gamma)+\Gamma_L\right]}{\dfrac{w}{\left(\dfrac{(1-\alpha)MC}{w}\right)^{\eta}}}\right)^{\frac{-1}{\eta-1}} . \quad \text{(A.3)}$$

Solving equation (A.2) and (A.3) simultaneously, we can obtain the steady-state output, Y, and an endogenous deposit rate, R_D.