Bank Capital, Credit Market Frictions and International Shocks Transmission

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Bank Capital, Credit Market Frictions and International Shocks Transmission*

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Abstract

Recent empirical evidence suggests that the state of banks' balance sheets plays an important role in the transmission of monetary policy and other shocks. This paper presents an open-economy DSGE framework with credit market frictions and an active bank capital channel to assess issues regarding the transmission of domestic and foreign shocks. The theoretical framework includes the financial accelerator mechanism developed by Bernanke et al. (1999), the bank capital channel and the exchange rate channel. Our simulations show that the exchange rate channel plays an amplification role in the propagation of shocks. Furthermore, with these three channels present, domestic and foreign shocks have an important quantitative role in explaining domestic aggregates like output, consumption, inflation and total bank's lending. In addition, results suggest that economies whose banks remain well-capitalized when affected by adverse shock experience less severe downturns. Our results highlight the importance of bank capital in an international framework and can be used to inform the worldwide debate over banking regulation.

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1 Introduction

The recent financial turmoil, which started with the meltdown of the U.S. subprime mortgage market, spread rapidly around the world and affected the world's economic system through a series of cross-country contagion mechanisms. As a consequence, GDP dropped around the world and global malfunctioning occurred in financial markets. Figure 1 illustrates these recent global downturns in the United States, Canada, Japan and the United Kingdom. The high degree of interdependence between the real economy and the financial markets in several countries simultaneously suggests a strong degree of international transmission of domestic and external shocks. This high interconnectedness between economic and financial markets may be viewed as a consequence of financial markets integration, globalization of trade, and the higher volume of cross-border assets held by economic agents.

Recent empirical and theoretical evidence has highlighted the importance of credit market imperfections in the transmission of shocks (Bernanke et al. (1999), Christiano et al. (2010), Gertler and Kiyotaki (2011), Meh and Moran (2010), and Dib (2010)). In these papers, credit market imperfections can be of two types: (i) corporate balance sheet (financial accelerator) channel models, which focus on the demand side of the credit market and (ii) bank balance sheet channel models, which focus on the supply side of the credit market. Together, they suggest that the financial health of banks and firms may significantly alter the transmission of monetary policy and others shocks.

This evidence underscores the need to develop a general equilibrium model with real-financial linkages in an international framework. Indeed, understanding and quantifying these real-financial linkages is an important step towards the identification of the best policy response to international developments. For example, understanding these linkages would allow Canadian authorities to examine whether international trade in goods and financial markets can explain the observed spillover effects of U.S. business cycles on the Canadian economy. In addition, a better knowledge of these linkages will allow central banks to assess the contribution of internal and external sources to the fluctuations observed in various OECD countries.

While the international transmission mechanism and the bank capital channel have both generated a large body of research with well-established contributions, the analysis of these two issues simultaneously has received less attention. This paper aims to bridge this gap by proposing a Dynamic Stochastic General Equilibrium (DSGE) for a small open economy with an active bank balance sheet channel to analyze the relative contribution of the bank balance sheets channel, the exchange rate channel, and the financial accelerator channel in the propagation of internal and external shocks. Specifically, this paper contributes to the growing literature aimed at understanding how countries react to an adverse foreign shock by assessing two major issues: first, how important is the banks' balance sheet channel relative to both the interest rate (financial accelerator) and exchange rate channels and as second, how does the bank capital channel affect the international transmission mechanism.

Although the fact that credit conditions can affect the real economy is widely documented, incorporating credit market frictions in quantitative general equilibrium models started relatively recently, with the seminal contributions of Carlstrom and Fuerst (1997), Kiyotaki and Moore (1997), and Bernanke et al. (1999). These models highlight the link between the cost of borrowing and the net worth of the borrower, a link now widely referred to as the financial accelerator mechanism. This so-called financial accelerator mechanism focuses on financial frictions caused by asymmetric information between entrepreneurs and banks (on the demand side), but is silent about the effects of financial frictions on the supply side. However, evidence suggests that the capitalization of the banking system can also affect the lending capacity of the financial sector. Quantitative modeling of this effect has been undertaken in Markovic (2006), Goodfriend and McCallum (2007), Gertler and Kiyotaki (2011), Meh and Moran (2010) and Dib (2010). These papers provided complementary contributions to the one by Bernanke et al. (1999) by showing that frictions on the supply side of credit also affect the propagation of shocks.

In this context, the starting point of our model is the framework developed by Meh and Moran (2010), Gertler and Kiyotaki (2011) and Dib (2010), to which we add cross-border goods distribution, the exchange rate channel,[1] a government and a capital accumulation process in the spirit of Christiano et al. (2005) and Christiano et al. (2010). In the model, banks intermediate funds between households and borrowing entrepreneurs and are responsible to monitor entrepreneurs' actions. Entrepreneurs have an incentive to choose projects with lower expected returns, because these allow them to consume private benefits. Banks can detect (imperfectly) the type of projects chosen using a costly monitoring technology. To discourage entrepreneurs from going after projects with private benefits, entrepreneurs are required to invest their own funds in the projects. Bankers may not, however dutifully monitor the entrepreneurs, in order to save the costs of monitoring. Consequently, households only lend to well-capitalized banks who have a lot to lose in case of loan default. As a result, the bank's capital position and the entrepreneurial net worth *jointly* constitute the lending constraint of banks and the borrowing constraint of entrepreneurs, and determine aggregate investment.

We conduct several quantitative experiments with the model, both in closed and open economy. The results of our simulations may be summarized as follow: (*i*) In the presence of the exchange rate channel, the propagation of domestic and foreign shocks is amplified when comparing our baseline economy to a closed economy. (*ii*) Depending of the level of bank capital in the economy, productivity and monetary policy shocks that originate domestically have an important quantitative role in explaining domestic output, investment, bank lending, entrepreneur and bank net worth, inflation and interest rates. (*iii*) External shocks (monetary policy and foreign demand shocks) also contribute to domestic aggregate fluctuations. (*iv*) Economies whose banks remain well-capitalized when affected by adverse shock experience less severe downturns, i.e., when the bank capital channel is

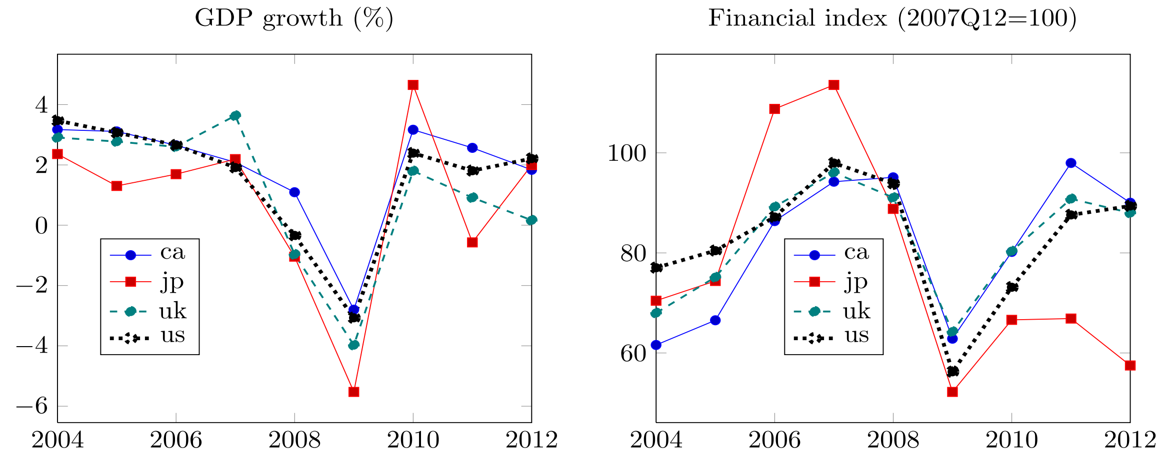
[1]The exchange rate channel operates through the relative prices and the elasticity of substitution between domestic and imported consumption goods.

active, an economy with more bank capital is better able to face adverse shocks than an economy with less bank capital. This last result, which remains valid for the transmission of international shocks, highlights the importance of bank capital in an international framework and can be used to inform the worldwide debate over banking regulation.

This paper contributes to two strands of literature. First, we provide a contribution to the literature on financial frictions in *open* economies by examining the role of bank capital in international business cycle fluctuations. Second, our paper complements the existing literature on the international transmission of business cycles by analyzing the relative contribution of three transmission channels. This literature includes Teng-Xu (2012) and Kamber and Thonissen (2012), in which the incorporation of credit provides significant improvement in modeling and forecasting output growth, changes in inflation and long run interest rates, for countries with developed banking sector; as well as, Kehoe and Perri (2002), Iacoviello and Minetti (2006), Smets and Wouters (2007), Devereux and Yetman (2010) and Guerrieri et al. (2012) whose framework explain some of the features of the international transmission of business cycles that cannot be explained by RBC models.

The rest of the paper is organized as follows. Section 2 describes the model and the financial contract between households, banks and entrepreneurs. In Section 3, we discuss aggregation and present the definition of the competitive equilibrium. Section 1 presents the calibration and describes the economy's steady state. In Section 5, we discuss our findings and conduct a set of experiments related to the bank capital channel, the international transmission of domestic shocks and the transmission of international shocks. Section 5 concludes.

Figure 1: Global economic downturns (Output and Financial index)



Note: This figure illustrates the recent global downturns in the U.S., Canada, UK and Japan. The left chart displays the dynamic of GDP growth, whereas the right chart presents the evolution of the main financial indexes in the aforementioned countries. Data are from Bloomberg, canadian socioeconomic database (Cansim) and International financial statistics.

2 The General Macroeconomic Environment

The economy is composed of a continuum of households of mass η^h, entrepreneurs of mass η^e, bankers (financial intermediaries) of mass η^b, with $\eta^h + \eta^b + \eta^e = 1$. In addition, there are firms (domestic and foreign), a domestic government and monetary authorities, both domestic and foreign. Households-workers supply differentiated labor and rent their accumulated physical capital. Their revenues include money received from the domestic monetary authority as lump-sum transfers, returns on physical capital, deposits, bonds holding and labour supply − while their expenses include bond purchases, consumption and taxes. Households divide their high-powered money into bonds, bank deposits and currency, which pays no interest and is held for the transactions services its provides.[2]

Entrepreneurs use their own resources and bank loans to finance projects of size I_t

[2]In this paper, we adopt a real money-in-the-utility-function approach to introducing currency, but a cash-in-advance version of the model yields qualitatively similar results.

that produce a new capital. An asymmetric information problem, discussed in detail below, exists between the borrowing entrepreneurs and the lending bank and is a key feature of the credit channel. The model also includes an intermediate goods production sector, located in the domestic country.[3] These firms operate under monopolistic competition and use labor and capital to produce the domestic intermediate goods. Next, perfectly competitive firms produce domestic and foreign composite goods, both at home and abroad. Part of the domestic composite goods produced is exported, and what remains locally is combined to foreign composite goods to produce the final goods, using a constant-elasticity-of-substitution (CES) production function. Finally, the final good is allocated to consumption and investment.

The model discussion is organized into five subsections. The first subsection describes the informational environment and the financial contract between entrepreneurs and bankers. Subsection 2.2 presents the preferences of households and Subsection 2.3 describes production of the final good and its distribution. The fourth Subsection highlights the structure of production for intermediate good. Finally, the fifth Subsection describes government and monetary authorities. Diagram [2] (in Appendix 1) summarizes the general structure of the model.

2.1 The Optimal Financial Contract

Our financial contract model is built following Holmstrom and Tirole (1997), Chen (2001) and Meh and Moran (2010). Each contract results from the interaction between households, entrepreneurs and bankers. Entrepreneurs have access to a stochastic investment technology that transforms I_t units of final goods into $\tilde{\omega} I_t$ ($\tilde{\omega} = R$ or 0) units of capital goods, with $\tilde{\omega} = R$ representing success and $\tilde{\omega} = 0$ representing failure of the project.

[3] Including this sector provides a channel to capture the transmission of technology shocks to the economy. It is worth mentioning that we do not permit an international mobility of labor between countries in this framework.

A project size of I_t will be financed by funds from the entrepreneur and the banker. Bankers finance their contribution with household deposits as well as their own equity (bank capital).

Entrepreneurs have access to different types of projects each producing the same return R_t in units of capital when the project succeeds and zero when it fails. The returns from entrepreneurial projects are publicly observable but the exante success probability of the projects depends on an unobservable action taken by the entrepreneurs. If an action a^h is undertaken, the probability of success is α^h and if an action a^l is undertaken, the probability of success is α^l (with $\alpha^h > \alpha^l$). The success of the project differs in the action undertaken by the entrepreneurs and therefore in the probability of success. Entrepreneurs will enjoy a private benefit b from choosing an action a^l and zero from choosing the action a^h. This behaviour introduces a moral hazard problem. Henceforth, without a proper incentive, entrepreneurs may deliberately choose an action a^l with low probability of success and high private benefit. Under this moral hazard problem and, in the way to reduce the entrepreneurs' incentives to choose an action a^l, bankers' have access to an imperfect monitoring technology, which can enforce entrepreneurs to choose a socially preferable action a^h. Therefore, if banker occurs a private monitoring cost μ, this will reduce the private benefit to entrepreneur from b to 0.

When successful, the project unit return, R, is shared among the entrepreneur (R_t^e), the banker (R_t^b) and the households (R_t^h). All agents receive nothing when the project fails. The optimal financial contract will allow us to determine the optimal project size I_t conditional on entrepreneurial net worth, deposits and bank capital.

Assumption [1]: Households are assumed to be neither able to monitor the activity of entrepreneurs nor of enforcing the financial contracts with entrepreneurs. Therefore, there is no feasible financial contract between entrepreneurs and households. We assume that there exists a feasible financial contract between entrepreneurs and bankers, where banks have an inventive to participate in the financial contract:

$$\alpha^h Q_t R_t^b I_t \geq (1 + r_t^a) A_t, \tag{2.1}$$

where A_t and r_t^a are the bank net worth and the rates of return on bank equity, respectively.

Assumption [2]: We assume that excluding the private benefit, the high probability action a^h is socially preferable and optimal.

$$\alpha^h Q_t R_t^h I_t \geq (1 + r_t^d) D_t. \tag{2.2}$$

This incentive constraint shows that the funds engaged by the investing households earn an expected return ($\alpha^h Q_t R_t^h I_t$ with Q_t the price of capital) sufficient to cover the market-determined required returns on deposits r_t^d.

Assumption [3]: An incentive compatibility condition requires that the expected return of the banker from the socially optimal action (a^h), net of monitoring cost incurred, should be greater than or equal to the expected return of net monitoring, which would ensure entrepreneurs engage in the non-socially optimal action (a^l):

$$\alpha^h Q_t R_t^b I_t - \mu Q_t I_t \geq \alpha^l Q_t R_t^b I_t. \tag{2.3}$$

This condition ensures that the bank has an incentive to monitor the entrepreneurial projects.

Assumption [4]: We also impose that the entrepreneur has an inventive to choose a socially optimal action when bankers monitor, i.e :

$$\alpha^h Q_t R_t^e I_t \geq \alpha^l R_t^e Q_t I_t + b Q_t I_t. \tag{2.4}$$

This latest condition ensures that the expected return of entrepreneurs if they choose the socially optimal action with high probability of success is at least as high as the one they would get if the undertook a non socially optimal project with low probability of success but receives the private benefits bQ_tI_t.

Definition 1 (Optimal financial contract): *The optimal financial contract consists of the maximization of the entrepreneur's expected return, given the incentive compatibility and capital requirement constraints (2.1), (2.2), (2.3) and (2.4).* With $R_t^e + R_t^b + R_t^h \leq R$ (sharing condition), this maximization program can be written as

$$V^e(A_t, D_t) = \max_{I_t, R_t^h, R_t^b, R_t^e} \alpha^h Q_t R_t^e I_t \tag{2.5}$$

s.t.:

$$\begin{aligned}
\alpha^l Q_t R_t^e I_t + bQ_tI_t &\leq \alpha^h Q_t R_t^e I_t \\
\alpha^l Q_t R_t^b I_t &\leq \alpha^h Q_t R_t^b I_t - \mu Q_t I_t \\
(1 + r_t^a)A_t &\leq \alpha^h Q_t R_t^b I_t \\
(1 + r_t^d)D_t &\leq \alpha^h Q_t R_t^h I_t \\
L_t^s &\leq A_t + D_t - \mu I_t \\
L_t^d &\leq I_t - N_t
\end{aligned}$$

Proposition 1 (Optimal financial contract): *Solving the entrepreneur's maximization program yields:* $R_t^e = \frac{b}{\alpha^g - \alpha^l} = \frac{b}{\Delta\alpha}$*;* $R_t^b = \frac{\mu}{Q_t \Delta\alpha}$*;* $R_t^h = R - \frac{b}{\Delta\alpha} - \frac{\mu}{Q_t\Delta\alpha}$*. The amount of bank capital and household deposits, and investment level in equilibrium are given given by* $A_t = \alpha^h \mu I_t/(1 + r_t^a)\Delta\alpha$*,* $D_t = \frac{\alpha^h Q_t}{(1+r_t^d)}\left(R_t - \frac{b}{\Delta\alpha} - \frac{\mu}{Q_t\Delta\alpha}\right) I_t$ *and* $I_t = (N_t + A_t)/\left(1 + \mu - \frac{\alpha^h Q_t}{1+r_t^d}\left(R_t - \frac{b}{\Delta\alpha} - \frac{\mu}{Q_t\Delta\alpha}\right)\right) = (N_t + A_t)/Lev_t$*, where* Lev_t *is the bank's total leverage.*

Proof: see appendix (7.3).

The upshot of the financial contract shows that the shares of project return allocated to the entrepreneur (R_t^e) and the banker (R_t^b) are linked to the severity of the moral hazard problem associated with their decision, as captured by the monitoring cost μ and the private benefit b. As a result, the share of project return promised to households is decreasing as the severity of the moral hazard increases in the economy.[4]

2.2 Households

The model is composed of a continuum of infinitely-lived households of mass η^h indexed by $i \in (0, \eta^h)$. We assume that households in the domestic country are covered by perfect insurance contracts, which allows us to analyze the behaviour of a representative household. A representative agent maximizes a utility function that depends positively on consumption and negatively on work effort. In addition, households derive utility from holding currency, supply a differentiated labor input (used by domestic firms), and set nominal wage using Calvo's partial indexation mechanism. Lifetime utility is :

$$\mathcal{U}_0^h \equiv \mathbf{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t U \left(C_t^h - \gamma C_{t-1}^h, \frac{M_t}{P_t}, L_t \right) \right\}, \tag{2.6}$$

where the consumption basket and the labour supply at period t are represented by C_t^h and L_t, P_t is the domestic price level and M_t/P_t denotes real money balances at the end of period t. The period utility function $U(.)$ is separable in consumption, real money balances, and hours worked and has a constant-relative-risk aversion (CRRA) form. In equation (2.6), $\beta \in (0,1)$ denotes the household's discount factor whereas $\gamma \in (0,1)$ is the parameter that controls the extent of habit. Finally, $\mathbf{E}_0$ denotes the conditional expectation operator evaluated at time 0 and the single-period utility function is specified as:

$$\mathcal{U}(\cdot) = log \left(C_t^h - \gamma C_{t-1}^h \right) + \psi log \left(1 - L_t \right) + \zeta log \left(\frac{M_t}{P_t} \right). \tag{2.7}$$

Households own all domestic firms. Accordingly, they receive dividend payments and also earn income from their holdings of domestic and foreign bonds B_t^d and B_t^f. Domestic bonds yields a nominal return r_t^b and foreign bonds produces r_t^f as a nominal return.

[4]see Meh and Moran (2010) for more details concerning the optimal financial contract

Households also pay taxes on their wage with the taxe rate given by τ_w. Finally, households face a capital utilization rate decision: at the beginning of each period, they can offer capital services $u_t K_t^h$, where u_t is the utilization rate, such that rental income from capital will be $r_t^k u_t K_t^h$ and the convex utilization cost will be $\upsilon(u_t)$.[5] Incorporating all revenues and expenses, the typical household's budget constraint is given by

$$\begin{aligned}
&(1+r_t^d)D_{t-1} + (1+r_t^b)\frac{B_{t-1}^d}{\pi_t} + s_t\kappa_t(e_t b_t^f, \varepsilon_t^e)(1+r_t^f)\frac{B_{t-1}^f}{\pi_t^*} \\
&+ (1-\tau_w)\frac{W_t^h}{P_t}L_t + (r_t^k u_t - \upsilon(u_t))K_t^h + \frac{M_{t-1}}{P_t} + \Pi_t + X_t \\
&= C_t^h + Q_t I_t^h + D_t + \frac{M_t}{P_t} + B_t^d + s_t B_t^f.
\end{aligned} \tag{2.8}$$

In equation (2.8), D_t is the real bank deposits and r_t^d is the nominal interest rate. π_t and π_t^* are, respectively, the domestic and the foreign inflation rates. The real exchange rate is defined as $s_t = e_t P_t^*/P_t$, where e_t represents the nominal exchange rate expressed in terms of the domestic currency per unit of foreign currency. In the second line, $(1-\tau_w)\frac{W_t^h}{P_t}L_t$ denotes net labor earnings received by the household. Furthermore, the household receives a lump-sum transfer from the monetary authority, X_t, as well as dividend payments, Π_t, from retailer firms. Finally, P_t^* is the aggregate foreign price level and Q_t is price of the capital associated to the investment level I_t.

The function $\kappa(.)$ represents the premium associated with buying foreign bonds and it captures the costs (or benefits) for households of holding positions in international asset markets. In the case that the amount of debt issued by a foreign country is greater than its steady state value, then households are charged a premium on the foreign interest rate. As in Schmitt-Grohé and Uribe (2003), we assume that this function depends on per capita holdings of foreign bonds with respect to nominal output of the composite domestic goods, and a specific functional form of $\log(\kappa_t) = \varpi\varepsilon_t^e \left[exp\left(\frac{s_t B_t^f}{Y_t}\right) - 1\right]$, where

[5] This follows Christiano et al. (2005).

ϖ is a parameter that captures the risk premium of foreign bonds.[6] Finally, the law of motion of capital accumulation is expressed as $I_t^h = K_t^h - (1-\delta)K_{t-1}^h$.

Given the preferences of a representative household and its budget constraint, the Lagrangian function associated is

$$\mathcal{L}_0(.) = \mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t \begin{pmatrix} log\left(C_t^h - \gamma C_{t-1}^h\right) + \psi log\left(1 - L_t\right) + \zeta log\left(\frac{M_t}{P_t}\right) \\ -\Lambda_t \left\{ C_t^h + Q_t I_t^h + D_t + \frac{M_t}{P_t} + B_t^d + s_t B_t^f \right. \\ -(1+r_t^b)\frac{B_{t-1}^d}{\pi_t} - s_t \kappa_t(e_t b_t^f, \varepsilon_t^e)(1+r_t^f)\frac{B_{t-1}^f}{\pi_t^*} \\ -(1+r_t^d)D_{t-1} - (1-\tau_w)\frac{W_t^h}{P_t}L_t - \frac{M_{t-1}}{P_t} - \Pi_t \\ \left. -(r_t^k u_t - \upsilon(u_t))K_t^h - X_t \right\} \end{pmatrix} \tag{2.9}$$

where Λ_t is the Lagrange multiplier associated with the budget constraint.

The household's optimization problem consists of choosing $\left\{C_t^h, M_t, B_t^d, B_t^f, D_t, K_t^h\right\}$ for all $t \in [0, \infty)$ to maximize lifetime utility function given a budget constraint.

The household's first-order conditions (except for labor and wages, described below) are given by:

$$\frac{1}{C_t^h - \gamma C_{t-1}^h} - \beta\gamma \mathbf{E}_t \left[\frac{1}{C_{t+1}^h - \gamma C_t^h}\right] = \Lambda_t; \tag{2.10}$$

$$\frac{\zeta}{M_t/P_t} + \beta \mathbf{E}_t \left[\frac{\Lambda_{t+1}}{\pi_{t+1}}\right] = \Lambda_t; \tag{2.11}$$

$$\beta \mathbf{E}_t \left[\frac{\Lambda_{t+1}(1+r_{t+1}^b)}{\pi_{t+1}}\right] = \Lambda_t; \tag{2.12}$$

$$\beta \mathbf{E}_t \left[\frac{\Lambda_{t+1}(1+r_{t+1}^f)}{\pi_{t+1}^*}\kappa_{t+1}\frac{s_{t+1}}{s_t}\right] = \Lambda_t; \tag{2.13}$$

[6] Computationally, a premium on the foreign interest rate is introduced to help the system have a well-defined steady state.

$$\beta \mathbf{E}_t \left[\frac{\Lambda_{t+1} Q_{t+1}}{\Lambda_t} \left(1 - \delta + r^k_{t+1} u_{t+1} - v(u_{t+1}) + \phi \left(\frac{K^h_{t+1}}{K^h_t} - 1 \right) \frac{K^h_{t+1}}{K^h_t} \right) \right] = Q_t \left(1 + \phi \left(\frac{K^h_t}{K^h_{t-1}} - 1 \right) \right); \tag{2.14}$$

$$\beta \mathbf{E}_t \left[\Lambda_{t+1}(1 + r^d_{t+1}) \right] = \Lambda_t; \tag{2.15}$$

$$r_t = v'(u_t). \tag{2.16}$$

The decision related to labour effort and wage setting is absent from (2.10)–(2.16) and we now describe it. Following the New Keynesian paradigm models (Christiano et al. (2005), Smets and Wouters (2007) and Christiano et al. (2010)), each household supplies a differentiated labour type used by intermediate good producers. The household has monopoly power over its own-type wage and sets that wage using Calvo's partial indexation mechanism. This decision takes into account the production structure described below.

An aggregate composite labour input is supplied by competitive firms that hire the labor supplied by each household and aggregates the different types into one composite, using a constant-elasticity-of-substitution (CES) function given by: $L_t = \left(\int_0^{\eta_h} L_{it}^{\frac{\xi_w - 1}{\xi_w}} di \right)^{\frac{\xi_w}{\xi_w - 1}}$, where $0 \leq \xi_w \leq +\infty$ is the elasticity of substitution between different types. These firms maximize profits subject to the production function and given all differentiated labor wages, $W_t(i)$, and the aggregate wage, W_t. Their maximization problem is therefore as follows:

$$\max_{\{L_{it}\}} \left\{ \frac{W_t}{P_t} L_t - \int_0^{\eta_h} \frac{W_{it}}{P_t} L_{it} di \right\}, \quad \text{subject to } L_t = \left(\int_0^{\eta_h} L_{it}^{\frac{\xi_w - 1}{\xi_w}} di \right)^{\frac{\xi_w}{\xi_w - 1}}. \tag{2.17}$$

The first order condition leads to $L_{it} = \left(\frac{W_{it}}{W_t} \right)^{-\xi_w} L_t$, which represents the economy-wide demand for the labour type i. Further, the zero profit condition implied by perfect competition can be used to show that $W_t = \left(\int_0^{\eta^h} W_{it}^{1-\xi_w} di \right)^{\frac{1}{1-\xi_w}}$.

Following Calvo (1983), households' wage setting uses the following structure. In each period, a fraction $1-\phi_w$ of households are free to reoptimize their wage. The remaining households can only index their wage to the previous periods rate of overall price inflation, with the degree of indexation captured by $\chi_w \in (0,1)$. This nominal rigidity implies that for a household who has not reoptimized for k periods, its effective wage is given by $\prod_{s=1}^{k} \frac{\pi_{t+s-1}^{\chi_w}}{\pi_{t+s}} \frac{W_{it}}{P_t}$.

The part of the Lagrangian function in (2.9) used to set optimal hours worked L_{it} and wage W_{it}, is given by

$$\max_{\widetilde{W}_{it}} \mathbf{E}_t \sum_{k=0}^{\infty} \phi_w^k \beta^k \left\{ \psi log(1-L_{t+k}) + \Lambda_{t+k} \prod_{l=1}^{k} \frac{\pi_{t+l-1}^{\chi_w}}{\pi_{t+l}} (1-\tau_w) \frac{W_{it}}{P_t} L_{i,t+k} \right\}, \tag{2.18}$$

subject to the following constraint: $L_{i,t+k} = \left(\prod_{l=1}^{k} \frac{\pi_{t+l-1}^{\chi_w}}{\pi_{t+l}} \frac{W_{it}}{W_{t+k}} \right)^{-\xi_w} L_{t+k}$, which represents the demand faced by type i labour in the event the wage has not been reoptimized in period $t+k$. The first-order condition with respect to W_{it} leads to:

$$\widetilde{W}_t = \frac{\xi_w}{\xi_w - 1} \frac{\mathbf{E}_t \sum_{k=0}^{\infty} (\beta\phi_w)^k \frac{\psi}{1-L_{t+k}} L_{t+k} \left(\prod_{l=1}^{k} \frac{\pi_{t+l-1}^{\chi_w}}{\pi_{t+l}} \right)^{1-\xi_w} W_{t+k}^{\xi_w}}{\mathbf{E}_t \sum_{k=0}^{\infty} (\beta\phi_w)^k \Lambda_{t+k} (1-\tau_w) L_{t+k} \left(\prod_{l=1}^{k} \frac{\pi_{t+l-1}^{\chi_w}}{\pi_{t+l}} \right)^{-\xi_w} W_{t+k}^{\xi_w}}. \tag{2.19}$$

2.3 Distribution and Good Production

The distribution sector is composed of intermediate and final good producers. Intermediate good producers include domestic and foreign firms, each producing a differentiated product and operating under monopolistic competition. Output produced by the intermediate good producers is then converted into a composite domestic good and a composite foreign good by competitive firms. Finally, domestic and foreign composite goods are combined to produce final output, which is allocated to consumption and investment. This structure of good distribution, standard in the open-economy DSGE models literature (Ambler et al. (2004), Iacoviello and Minetti (2006) and Faia (2007) among others) is illustrated in Appendix (3).

2.3.1 Final Good Production

Progressing from aggregates to specifics, the final step of the distribution chain is the production of the final good, Z_t, which is produced by domestic firms using a CES technology. The representative firm combines the domestic composite good (Y_t^d) with an imported composite good (Y_t^f) as

$$Z_t = \left(\omega_d{}^{\frac{1}{\lambda_z}} (Y_t^d)^{\frac{\lambda_z - 1}{\lambda_z}} + (1 - \omega_d)^{\frac{1}{\lambda_z}} (Y_t^f)^{\frac{\lambda_z - 1}{\lambda_z}} \right)^{\frac{\lambda_z}{\lambda_z - 1}}, \tag{2.20}$$

where $0 < \omega_d < 1$ denotes the share of domestic goods in the final good production process (ω_d can also interpreted as the steady state degree of openness). The elasticity of substitution between domestic composite good and imported good is then captured by λ_z.

The typical final good producer maximizes profits subject to the production function in (2.20) taking as given the price of the domestic composite good (P_t^d), the price of the imported composite good (P_t^f) and the price of the final good (P_t). The maximization program is

$$\max_{Y_t^d, Y_t^f} \left\{ P_t Z_t - P_t^d Y_t^d - P_t^f Y_t^f \right\}, \text{ subject to } Z_t = \left(\omega_d{}^{\frac{1}{\lambda_z}} (Y_t^d)^{\frac{\lambda_z - 1}{\lambda_z}} + (1 - \omega_d)^{\frac{1}{\lambda_z}} (Y_t^f)^{\frac{\lambda_z - 1}{\lambda_z}} \right)^{\frac{\lambda_z}{\lambda_z - 1}}. \tag{2.21}$$

and the associated first-order conditions provide economy-wide demand schedules for the domestic composite good and the imported good:

$$Y_t^d = \omega_d \left(\frac{P_t^d}{P_t} \right)^{-\lambda_z} Z_t, \tag{2.22}$$

$$Y_t^f = (1-\omega_d)\left(\frac{P_t^f}{P_t}\right)^{-\lambda_z} Z_t. \tag{2.23}$$

In addition the zero-profit condition yields the following determination of the price of the final goods P_t:

$$P_t = \left[\omega_d (P_t^d)^{1-\lambda_z} + (1-\omega_d)(P_t^f)^{1-\lambda_z}\right]^{\frac{1}{1-\lambda_z}}. \tag{2.24}$$

2.3.2 Domestic Composite Good Production

The domestic composite good, Y_t^d, is produced by a continuum of competitive domestic firms using domestic intermediate goods as inputs. These producers aggregate domestic intermediate goods using the Dixit-Stiglitz aggregator

$$Y_t^d = \left(\int_0^1 Y_t^d(j)^{\frac{\xi_d-1}{\xi_d}} dj\right)^{\frac{\xi_d}{\xi_d-1}}, \tag{2.25}$$

where ξ_d denotes the elasticity of substitution across intermediate goods and $Y_t^d(j)$ denotes the quantity used of each variety. The maximization program of these producers is given by

$$\max_{Y_t^d(j)} \left\{P_t^d Y_t^d - \int_0^1 P_t^d(j) Y_t^d(j) dj\right\} \qquad s.t. \quad Y_t^d = \left(\int_0^1 Y_t^d(j)^{\frac{\xi_d-1}{\xi_d}} dj\right)^{\frac{\xi_d}{\xi_d-1}} \tag{2.26}$$

The input demand for each intermediate good of type j and the price of the domestic composite good are respectively given by

$$Y_t^d(j) = Y_t^d \left(\frac{P_t^d(j)}{P_t^d}\right)^{-\xi_{d,t}}, \tag{2.27}$$

$$P_t^d = \left(\int_0^1 P_t^d(j)^{1-\xi_{d,t}} dj\right)^{\frac{1}{1-\xi_{d,t}}}. \tag{2.28}$$

2.3.3 Foreign Composite Good Production

The foreign composite good, Y_t^f, is also assembled by a continuum of competitive firms using domestic intermediate goods, $Y_t^f(j)$, as inputs. Similarly to the domestic composite good, the foreign composite good producer aggregates foreign intermediate goods using the Dixit-Stiglitz form

$$Y_t^f = \left(\int_0^1 Y_t^f(j)^{\frac{\xi_f - 1}{\xi_f}} dj \right)^{\frac{\xi_f}{\xi_f - 1}}, \tag{2.29}$$

where the elasticity of substitution across foreign intermediate goods is captured by ξ_f. Taking all intermediate goods prices $P_t^f(j)$ as given, profit maximization implies a demand schedule for each intermediate good, as well as an overall price index for the foreign composite good given by

$$Y_t^f(j) = Y_t^f \left(\frac{P_t^f(j)}{P_t^f} \right)^{-\xi_f}, \tag{2.30}$$

$$P_t^f = \left(\int_0^1 P_t^f(j)^{1-\xi_f} dj \right)^{\frac{1}{1-\xi_f}}. \tag{2.31}$$

2.4 Intermediate Good Production

2.4.1 Domestic Intermediate Good Production

Domestic intermediate goods are produced by monopolistically competitive firms facing nominal rigidities à la Calvo (1983). The domestic intermediate good producer of the type j good combines capital stock $K_t(j)$ with labour $L_t(j)$ to produce the differentiated intermediate good $Y_t(j)$ using the production function:[7]

$$Y_t(j) = \begin{cases} A_t^Z K_t(j)^{\theta_k} L_t(j)^{\theta_h} - \Theta & \text{if } A_t^Z K_t(j)^{\theta_k} L_t(j)^{\theta_h} \geq \Theta \\ 0 & \text{otherwise} \end{cases}, \tag{2.32}$$

[7] The general functional form of the production technology is $A_t^Z K_t(j)^{\theta_k} L_t(j)^{\theta_h} H_t^e(j)^{\theta_e} H_t^b(j)^{\theta_b} - \Theta$, where $H_t^e(j)$ and $H_t^b(j)$ denotes respectively entrepreneurs and bankers labour supply. However, we omit $H_t^e(j)$ and $H_t^b(j)$ because of their very small quantitative contribution in the production mechanism.

where the non-negative parameter Θ represents the fixed costs of production and is calibrated to guarantee that economic profits are zero in steady-state (see Christiano et al. (2005)). Further, A_t^Z is a technology shock that follows the stochastic process given by

$$\log(A_t^Z) = (1-\rho_a)\log(A^Z) + \rho_a log(A_{t-1}^Z) + \epsilon_{A^Z t}. \tag{2.33}$$

The total cost function $TC_t(j)$ is defined as

$$TC_t(j) = r_t^k K_t(j) + W_t^h L_t(j), \tag{2.34}$$

and minimizing cots of producing a given level of output follows

$$\begin{aligned} &\min_{K_t(j),L_t(j)} \left\{TC_t = r_t^k K_t(j) + W_t L_t(j)\right\} \\ &\qquad s.t. \quad Y_t(j) = A_t^Z K_t(j)^{\theta_k} L_t(j)^{1-\theta_k} - \Theta, \end{aligned} \tag{2.35}$$

where r_t^k denotes the rental rate on capital services and W_t is the price of the composite labour input. Let mc_t be the Lagrange multiplier associated with the problem (2.35) which can be interpreted as the real marginal cost of producing one unit additional of output. The first-order conditions are given by

$$\begin{aligned} r_t^k &= mc_t A_t^Z \theta_k A_t^Z K_t(j)^{\theta_k - 1} L_t(j)^{1-\theta_k}, \\ W_t &= mc_t A_t^Z (1-\theta_k) A_t^Z K_t(j)^{\theta_k} L_t(j)^{-\theta_k}. \end{aligned} \tag{2.36}$$

Production is allocated to two uses: a part of this intermediate good is used in producing the composite domestic good (see (2.25)), and the remaining part $Y_t^x(j)$ is exported: we then have

$$Y_t(j) = Y_t^d(j) + Y_t^x(j). \tag{2.37}$$

Price-setting is organized as follows. Assume that in each period, a fraction $1-\phi_d$ of domestic firms can reoptimize their prices. When allowed to do so, a firm chooses a price

$\widetilde{P}_t^d(j)$, in order to maximize its discounted real profits. All other firms can only index their prices to past inflation, with the degree of indexation controlled by a parameter $\chi_d \in [0,1]$.[8] An intermediate good producer j allowed to reoptimize at time t realizes that the chosen price $\widetilde{P}_t^d(j)$ at time t, will, after l periods with no reoptimizing, be

$$P_{t+l}^d(j) = (\pi_{t+1}^d)^{\chi_d} \times (\pi_{t+2}^d)^{\chi_d} \times \cdots \times (\pi_{t+l-1}^d)^{\chi_d} \times P_t^d(j) = \prod_{s=1}^{l-1} (\pi_{t+s}^d)^{\chi_d} P_t^d(j), \quad (2.38)$$

where $\pi_{t+l}^d = P_{t+l}^d / P_{t+l-1}^d$. The maximization problem of this reoptimizing firm j is then:

$$\begin{aligned} &\max_{\widetilde{P}_t^d(j)} \mathbf{E}_t \sum_{l=0}^{\infty} (\beta\phi_d)^l \Lambda_{t+l} \left\{ \left(\prod_{s=1}^{l-1} (\pi_{t+s}^d)^{\chi_d} \frac{\widetilde{P}_t^d(j)}{P_{t+l}^d} - mc_{t+l} \right) Y_{t+l}(j) \right\} \\ &s.c. \quad Y_{t+l}(j) = \left(\prod_{s=1}^{l-1} (\pi_{t+s}^d)^{\chi_d} \frac{\widetilde{P}_t^d(j)}{P_{t+l}^d} \right)^{-\xi_{d,t}} Y_{t+l}, \end{aligned} \quad (2.39)$$

where Λ_{t+l} is the marginal utility of wealth for firm j in period $t+l$. Denote $\widetilde{p}_t^d = \widetilde{P}_t^d(j)/P_t$ and assume all reoptimizing firms adopt the same strategy; the first order conditions related to $\widetilde{p}_t^d(j)$ lead to:

$$\widetilde{p}_t^d = \frac{\xi_{d,t}}{\xi_{d,t}-1} \frac{\mathbf{E}_t \sum_{l=0}^{\infty} (\beta\phi_d)^l \Lambda_{t+l} mc_{t+l} \left(\prod_{s=1}^{l-1} \frac{(\pi_{t+s}^d)^{\chi_d}}{\pi_{t+s+1}^d} \right)^{-\xi_{d,t}} Y_{t+l}(j)}{\mathbf{E}_t \sum_{l=0}^{\infty} (\beta\phi_d)^l \Lambda_{t+l} \left(\prod_{s=1}^{l-1} \frac{(\pi_{t+s}^d)^{\chi_d}}{\pi_{t+s+1}^d} \right)^{1-\xi_{d,t}} Y_{t+l}(j)}. \quad (2.40)$$

Domestic composite output, Y_t, is divided into domestic use, Y_t^d, and exports, Y_t^x. The good bundle prepare for exports is aggregated by competitive firms using the functional form

$$Y_t^x = \left(\int_0^1 Y_t^x(j)^{\frac{\xi_{yx}-1}{\xi_{yx}}} dj \right)^{\frac{\xi_{yx}}{\xi_{yx}-1}}, \quad (2.41)$$

where the elasticity of substitution between intermediate-good types is denoted by ξ_{yx}. In

[8] $\chi_d = 0$ refers to a non-indexation case whilst $\chi_d = 1$ denotes a perfect indexation case.

this framework, domestic producers are not able to price discriminate between the part of their production that will be used for domestic production and what will be exported.[9]

In this context, profit maximization by exports assemblers leads to the following (foreign) demand for good j

$$Y_t^x(j) = \left(\frac{P_t^d(j)}{P_t^d}\right)^{-\xi_{yx}} Y_t^x. \tag{2.42}$$

We assume that overall foreign demand for domestic goods is proportional to foreign GDP. Following Ambler *et al.* (2004), this implies that foreign demand Y_t^x is

$$Y_t^x = \left(\frac{P_t^d}{e_t P_t^*}\right)^{-\tau} Y_t^* = s_t^\tau Y_t^x \qquad \text{where} \quad s_t = \left(\frac{e_t P_t^*}{P_t^d}\right). \tag{2.43}$$

In this expression, the parameter τ ($\tau > 0$) describes the elasticity of demand for domestic good and s_t denotes the real exchange rate. The foreign price, P_t^*, is an exogenous process and foreign GDP, Y_t^*, is assumed to follow a mean reverting stochastic process given by:

$$\log(Y_t^*) = (1-\rho_{y^*})\log(\overline{Y}^*) + \rho_{y^*} log(Y_{t-1}^*) + \epsilon_t^{y^*},$$

where $\overline{Y}^*$ is steady-state foreign production and $\epsilon_t^{y^*}$ is a zero-mean, serially uncorrelated shock.

2.4.2 Foreign Intermediate Good Production

Recall that the domestic economy imports foreign intermediate goods. These intermediates are imported and resold by a continuum of firms indexed by $j \in (0,1)$. Again, these firms operate under monopolistic competition and the imported intermediates are then assembled into the composite imported good, Y_t^f (see (2.29)). Price setting is again assumed to follow a nominal rigidity *à la Calvo*.[10] Each period, a fraction $1-\phi_f$ of firms

[9]This corresponds to the so called "producer pricing" paradigm.

[10]Note that introducing Calvo-type staggered price setting in the imported goods market allows the model to capture incomplete exchange rate pass-through in import prices.

can reoptimize its price. When allowed to do so, a firm chooses the price to solve the following program:

$$\max_{\widetilde{P}_t^f(j)} \mathbf{E}_t \sum_{l=0}^{\infty} (\beta\phi_f)^l \Lambda_{t+l} \frac{\Omega_{t+l}^f}{P_{t+l}^d},$$

with

$$\Omega_{t+l}^f = \left(\widetilde{P}_t^f(j) - e_{t+l} P_{t+l}^*\right) \left(\frac{\widetilde{P}_t^f(j)}{P_{t+l}^f}\right)^{-\xi_f} Y_{t+l}^f.$$

The first oder conditions lead to:

$$\widetilde{P}_t^f(j) = \frac{\xi_f}{1-\xi_f} \frac{\mathbf{E}_t \sum_{l=0}^{\infty} (\beta\phi_f)^k \Lambda_{t+k} Y_{t+k}^f(j) s_{t+l}}{\mathbf{E}_t \sum_{l=0}^{\infty} (\beta\phi_f)^k \Lambda_{t+k} Y_{t+k}^f(j)/P_{t+k}^d}, \tag{2.44}$$

where ξ_f represents the elasticity of substitution between differentiated imported goods.

2.5 Monetary Authorities and Government

Monetary policy is conducted by the home central bank, which manages the nominal interest rate $R_t^d = (1 + r_t^d)$, in response to fluctuations in domestic GDP and in consumer price inflation using a Taylor-type rule. Specifically, assume the following functional form:

$$\log\left(R_t^d/\overline{R}^d\right) = \lambda_r \log\left(R_{t-1}^d/\overline{R}^d\right) + (1-\lambda_r)\left(\lambda_\pi log\left(\pi_t/\overline{\pi}\right) + \lambda_y \log\left(Y_t/\overline{Y}\right)\right) + \rho_\mu \log\left(\vartheta_t\right), \tag{2.45}$$

with $\lambda_r \in (0,1)$ and where the variables $\overline{\pi}$ and $\overline{Y}$ represent the target level of inflation and the target level of output, respectively.[11] The term ϑ_t denotes a monetary policy shock that follows the first-order autoregressive process

$$\log(\vartheta_t) = \rho_{mp} \log(\vartheta_{t-1}) + \epsilon_t^{dmp}, \tag{2.46}$$

[11] The use of the previous period interest rate allow us to match the smooth profile of the observed interest rate in the data.

with $\epsilon_t^{dmp} \sim \mathcal{N}(0,1)$.

There are two foreign monetary policy variables, the interest rate on foreign bonds, R_t^f, and foreign inflation π_t^*.[12] We use the following stochastic process to capture their dynamics:

$$\log(R_t^f) = (1-\rho_{R^f})\log(\overline{R}^f) + \rho_{R^f}\log(R_{t-1}^f) + \epsilon_t^{fmp}, \tag{2.47}$$

where $\rho_{R^f} \in (0,1)$ denotes the persistence of the foreign monetary policy shock. The stochastic process for the evolution of the foreign price is likewise given by

$$log(\pi_t^*) = (1-\rho_{\pi^f})log(\overline{\pi}^*) + \rho_{\pi^f}log(\pi_{t-1}^*) + \epsilon_t^{\pi^*}. \tag{2.48}$$

Turning to fiscal policy, the domestic governments budget constraint is given by

$$G_t + (1+r_t^b)\frac{B_{t-1}^d}{\pi_t} + \frac{M_{t-1}}{P_t} + X_t = B_t^d + \tau_w W_t H_t + \frac{M_t}{P_t}, \tag{2.49}$$

where the right hand represents government income: new debt issued, B_t^d, tax revenue paid by households, $\tau_w W_t H_t$, and money creation, $M_t - M_{t-1}$. The left side describes uses of government revenue: government spending, G_t, money transfers X_t and debt repayments, $(1+r_t^b)B_{t-1}^d$. Government spending is exogenous and follows the stochastic process

$$\log(G_t) = (1-\rho_g)\log(\overline{G}) + \rho_g\log(G_{t-1}) + \epsilon_t^g, \tag{2.50}$$

where $\overline{G}$ denotes the steady-state value of government spending.

3 Aggregation and Competitive Equilibrium

Aggregate investment $\widetilde{I}_t$ is defined as a sum of all individual investment projects in the economy and is given by

[12] Recall an assumption of a small open economy, which explains why the foreign monetary variables are exogenously determined.

$$\widetilde{I}_t = \int I_t(j)dj = \int \frac{(a_t(j) + n_t(j))}{G_t}dj = \frac{\widetilde{A}_t + \widetilde{N}_t}{G_t}, \tag{3.1}$$

where $1/G_t$ denotes bank leverage (common to all individual projects) and $\widetilde{A}_t$ and $\widetilde{N}_t$ denote the aggregate levels of bank capital and entrepreneur net worth, respectively.

The capital stock held by each group of agents is $\widetilde{K}_t^h$ for households, $\widetilde{K}_t^b$ for bankers and $\widetilde{K}_t^e$ for entrepreneurs. Aggregation requires that

$$\widetilde{K}_t^h = \eta^h K_t^h, \quad \widetilde{K}_t^b = \eta^b K_t^b, \quad \widetilde{K}_t^e = \eta^e K_t^e, \tag{3.2}$$

where η^h, η^b and η^e represent the population masses of households, bankers and entrepreneurs, respectively. Considering the financial contract structure, the dynamic evolution of bank capital, A_t, and entrepreneur's net worth, N_t, are governed by

$$\widetilde{A}_t = (r_t^k + Q_t(1-\delta))\widetilde{K}_t^b + \eta^b W_t^b \quad \text{and} \quad \widetilde{N}_t = (r_t^k + Q_t(1-\delta))\widetilde{K}_t^e + \eta^e W_t^e. \tag{3.3}$$

As bankers and entrepreneurs are both assumed to be risk-neutral agents, capital accumulation at the beginning of the period $t+1$ can be written as[13]

$$\widetilde{K}_{t+1}^b = \tau^b \alpha^g R_t^b \widetilde{I}_t \quad \text{and} \quad \widetilde{K}_{t+1}^e = \tau^e \alpha^g R_t^e \widetilde{I}_t, \tag{3.4}$$

with τ^b and τ^e, the survival probability of bankers and entrepreneurs. These equation describes the inter-period evolution of bank total assets and entrepreneur net worth. With probability $1-\tau^b$, bankers exit the economy and become households. Similarly, entrepreneurs exit the economy with a probability $1-\tau^e$ to become households. This circular relationship between workers, entrepreneurs and bankers allows us to keep the total population to 1. Exiting banks and entrepreneurs consume the value of their available

[13] Successful entrepreneurs and banks survive to the next period with probability τ^e and τ^b, respectively. These agents save all their wealth, because of risk-neutral preferences and the high return on internal funds.

wealth. This implies the following for aggregate consumption of entrepreneurs, bankers and workers:

$$\widetilde{C}^b_{t+1} = (1-\tau^b)\alpha^g R^b_t \widetilde{I}_t, \quad \widetilde{C}^e_{t+1} = (1-\tau^e)\alpha^g R^e_t \widetilde{I}_t \quad \text{and} \quad \widetilde{C}^h_t = \eta^h C^h_t. \tag{3.5}$$

$$\widetilde{C}_t = \widetilde{C}^h_t + \widetilde{C}^e_t + \widetilde{C}^b_t; \tag{3.6}$$

Definition 3 (Competitive equilibrium) *A competitive equilibrium is defined as a set of functions for (i) households' policies $C^h_t(i)$, $I^h_t(i)$ and $K^h_t(i)$ that solve the maximization problem of the household; (ii) firms' policies $K_t(j)$, $L_t(j)$ and $W_t(i)$ that solves firms maximization problem; (iii) optimal financial contract I^h_t, R^e_t, R^b_t, R^h_t, A_t, D_t and N_t; (iv) aggregate prices P^d_t, P^f_t and P_t and (v) saving and consumption decision rules for bankers and entrepreneurs.*

Equilibrium in the goods markets requires that production be equal to aggregate demand:

$$Z = \widetilde{C}_t + Q_t\widetilde{I}_t + G_t + \mu Q_t \widetilde{I}_t; \tag{3.7}$$

The remain market-clearing conditions are given by:

$$\widetilde{K}_t = v_t\widetilde{K}^h_t + \widetilde{K}^e_t + \widetilde{K}^b_t; \tag{3.8}$$

$$L_t = \int_0^{\eta^h} L_t(i)di; \tag{3.9}$$

$$H^e_t = \int_0^{\eta^e} H^e_t(j)dj; \tag{3.10}$$

$$H^b_t = \int_0^{\eta^b} H^b_t(j)dj; \tag{3.11}$$

Equation (3.8) defines the total capital stock as the holdings of households, entrepreneurs and banks. The government faces a No-Ponzi constraint that requires the value of foreign debt to equal trade balance. This constraint is given by

$$B_t^f + \kappa_t(1 + r_t^f)\frac{B_{t-1}^f}{\pi_t^*} = \frac{Y_t^x}{s_t} - Y_t^f. \tag{3.12}$$

4 Model Calibration

To evaluate the relative contributions of the bank capital, exchange rate and interest rate channels in the propagation of shocks, we set the parameters of our model to reflect the key features of a small open economy like Canada. The parameter values are generally consistent to those used in the financial frictions literature as in Christiano et al. (2010), Dib (2010) and Meh and Moran (2010). In the representative household's utility function, the weight on leisure ψ is set to 9.05, which leads the steady-state value of household work effort to be 30% of available time. Following results in Christiano et al. (2010) and Meh and Moran (2010), the parameter governing habit formation, γ, is fixed to 0.65. The value of ζ is set in order to match the steady-state of the model for the average ratio $M2$ in Canada, which is about 128.8% in 2013.[14]

The household's discount factor, β, is set to 0.99, implying a long-run real interest rate of 4% in an annual basis. The share of capital in the production function for intermediate goods, θ^k, is set to 0.36 and the depreciation rate of capital is 0.025. As we want to reserve a small role in production for the work effort of bankers and entrepreneurs, we set the share of the labour input of the households, θ^h, to 0.6399. Then we choose $\theta^b = \theta^e = 0.00005$, reflecting an equal contribution of bankers and entrepreneurs in the production of intermediate goods and allowing entrepreneurs and bankers to always have non-zero net worth.

The capital utilization parameters are set as follows: we impose that $u = 1$ and $v(1) = 0$ in the steady state, which ensures that the steady state is independent of $v(.)$.

[14] Data are from annually monetary and financial statistics published by the OECD.

Next, we set $\sigma_u = v''(u)(u)/v'(u) = 0.01$ for $u = 1$ as in Meh and Moran (2010). The parameter capturing the fixed costs in the production function, Θ, is set to ensure that the steady state value of profits equals zero. The persistence of the technology shock, ρ_a, is set to 0.95 and its standard deviation is 0.0015, which ensure that the model's simulated output volatility equal that of observed aggregate data.

The price rigidity parameter, as well as its wage-setting counterpart, are set following Calvo's model of staggered price and wage adjustment. As in Christiano et al. (2005), the probability of not reoptimizing for price and wage setters in the domestic country, ϕ_d and ϕ_w, are fixed to 0.75 and 0.64, respectively. The elasticity of substitution between domestic intermediate goods, ξ_d, and the elasticity of substitution between domestic labour types, ξ_w, are set to 8 and 21, respectively. These values are estimated in Christiano et al. (2010) for the U.S. economy and are commonly used in the literature. In turn, the probability of not reoptimizing for foreign price setters, ϕ_f, is set to 0.5, while the elasticity of substitution between foreign intermediate goods production, ξ_f, is calibrated to 8. The elasticity of substitution between domestic composite good and imported good λ_z is set to 0.59.

The domestic monetary policy parameters λ_r, λ_π et λ_y are set to 0.8, 1.5 and 0.1/4, respectively. These values satisfy the Taylor principle and are consistent with those estimated in Clarida et al. (2000). The standard deviation of both domestic and foreign monetary policy shocks is fixed to 0.0016, $\rho_{mp} = \rho_{R^f} = 0.0016$, which ensures that a one-standard deviation shock moves the interest rate by 0.6 percentage points. This value is consistent with the empirical estimates reported in Christiano et al. (2005).

In the financial market, the parameters related to capital production and the optimal financial contract between bankers and entrepreneurs are set following Carlstrom and Fuerst (1997), Bernanke et al. (1999), and Meh and Moran (2010). Accordingly, the steady state value of the bank's capital asset ratio and the monitoring cost are respectively set to 14% and 0.025. We set the probability of default in the loan contract in the event that action a^h is undertaken to 1%. As a result, the quarterly probability of success is 99%, consistent with the results in Carlstrom and Fuerst (1997). The gap between the probability of success of the socially preferable action, a^h, and the *free riders* action, a^l, is set to 24%, consistent with the results in Meh and Moran (2010). The remaining parameters and steady-state ratios of the model are set in order to ensure that our model's steady state match standard New-Keynesian calibrations: household's consumption to GDP ratio is equal to 76%, investment to GDP ratio and Capital to GDP ratio equal to 0.2 and 12, and domestic good to final good ratio and imported good to final ratio equal to 70% and 30%. The persistence and the standard deviation parameters of all remaining shocks are set to 0.95 and 0.01, respectively. Table (1) and Table (2) report the calibration and the steady-state values of some key variables.

5 Findings

To assess the relative contribution of the bank capital channel in an international framework, we focus on the impulse response functions of some key variables following a variety of structural shocks. Throughout, we simulate and compare three versions of the model: *model (1)* describes the small-open economy model with the active bank capital channel and nominal rigidities; *model (2)* is a closed economy with an active bank capital channel, and is thus similar to Meh and Moran (2010); and finally, *model (3)* is a variant of the first model in which an exogenous capital endowment is given to all bankers. This economy is used to study a situation where banks are well-capitalized, to analyze the role of bank capital in the propagation of shocks. Specially, our third model provides a surplus of capital, e^b, to surviving and newborns banks. The value of e^b is set to ensure that the banker's asset-capital ratio in model (3) is 20% higher than in the steady-state for the baseline model. The only two equations that need to be modified to implement this "

Table 1: Parameter Calibration

	Parameters	Description	Values
Preferences	β	Discount factor	0.99
	γ	Habit formation	0.65
	ψ	Weight of leisure in utility	9.05
	ζ	Elasticity of money demand	0.00183
Technologies and final good production	θ_k	Capital share	0.36
	θ_h	Workers labor share	0.6399
	θ_e	Entrepreneur labor share	0.00005
	θ_b	Bankers labor share	0.00005
	ω_d	Share of domestic good in final good	0.7
	λ_z	Elasticity of domestic good	0.59
	δ	Depreciation rate of capital	0.02
	τ_w	Labor income tax rate	0.2
	ρ_z	Autocorrelation of home technology shock	0.95
	σ_z	Standard deviation of home technology shock	0.0015
Financial sector	α^h	High probability of success	0.99
	α^l	Low probability of success	0.75
	b	Private benefit	0.16
	μ	Monitoring cost	0.025
	τ_e	Entrepreneur's death probability	0.78
	τ_b	Banker's death probability	0.72
Nominal rigidities	ξ_w	Elasticity of labor supply	21
	ξ_d	Elasticity of substitution for domestic goods	8
	ξ_f	Elasticity of substitution for foreign goods	8
	ϕ_w	Wage reoptimization probability	0.64
	ϕ_d	Domestic price reoptimization probability	0.75
	ϕ_f	Foreign price reoptimization probability	0.5
	χ_w	Degree of wage indexation	0.1
	χ_h	Degree of price indexation	0.1
Monetary policy	λ_r	Taylor rule: Interest smoothing	0.8
	λ_π	Taylor rule: inflation coefficient	1.5
	λ_y	Taylor rule: GDP coefficient	0.025
	ρ_{mp}	Autocorrelation of home monetary policy shock	0.95
	ρ_{R^f}	Autocorrelation of foreign monetary policy shock	0.95
	ρ_{π^f}	Autocorrelation of foreign inflation shock	0.95
	σ_{mp}	Standard deviation of home monetary policy shock	0.01
	σ_{R^f}	Standard deviation of foreign monetary policy shock	0.01
	σ_{π^f}	Standard deviation of inflation shock	0.01

Table 2: Steady-state values and ratios

Parameters	Description	Values
	Steady-state values	
$\overline{\pi}$	Inflation	$1.02^{1/4}$
R	Gross real interest rate of investment projects	1.2118
$\overline{R}^b$	Gross real interest rate of domestic bonds	1.015
$\overline{R}d$	Gross real interest rate of deposits	1.0101
$1/G$	Bank leverage	1.75
	Steady-state ratios	
$\widetilde{C}^h/Y$	Household consumption to GDP ratio	76%
$\widetilde{C}^b/Y$	Banker consumption to GDP ratio	0.57%
$\widetilde{C}^e/Y$	Entrepreneur consumption to GDP ratio	2.76%
$\widetilde{I}/Y$	Investment to GDP ratio	20%
$\widetilde{K}/Y$	Capital to GDP ratio	12
Y^d/Z	Domestic good to final good ratio	70%
Y^f/Z	Imported good to final good ratio	30%

well-capitalized" economy are

$$\widetilde{A}_t = (r_t^k + Q_t(1-\delta))\widetilde{K}_t^b + \eta^b W_t^b + \eta^{\mathbf{b}}\mathbf{e}^{\mathbf{b}}, \tag{5.1}$$

$$Z + \eta^{\mathbf{b}}\mathbf{e}^{\mathbf{b}} = \widetilde{C}_t + Q_t\widetilde{I}_t + G_t + \mu Q_t\widetilde{I}_t. \tag{5.2}$$

Figure 4 displays the impulse responses of key domestic aggregates following a negative shock to bank capital. Next, Figures 5 and 6 depict impulse responses following a negative technology shock, while Figures 7 and 8 display responses following a domestic monetary policy shock. Figures 9 and 10 illustrate the relative contribution of the bank capital in the transmission of international shocks by comparing our baseline model (model (1)) to model (3). Finally, Figures 11, 12 and 13 display the impulse responses following a domestic technology shock, a domestic monetary policy and a government spendings shock while assessing the role of the bank capital in the mechanism of international transmission of domestic shocks.[15]

5.1 Bank Capital Channel and bank capital shocks

Empirical evidence suggests that bank capital, in addition to entrepreneurial net worth, has important impacts on the propagation of shocks. The purpose of this subsection is to investigate the relative contribution of this bank capital channel and in this context, Figure 4 displays the impulse responses following a negative shock to bank capital in model (1) and model (2). This shock may be interpreted as a 'credit crunch' caused by a sudden deterioration in banks' balance sheet that leads to decline in the net worth of bank (bank capital). To implement this sudden deterioration in bank net worth, we assume that bank capital is subject to episodes of accelerated depreciation, as in

$$\widetilde{A}_t = (r_t^k + Q_t(1 - \delta\vartheta_t^\delta))\widetilde{K}_t^b + \eta^b W_t^b, \tag{5.3}$$

where ϑ_t^δ is characterized by an $AR(1)$ process given by

$$log(\vartheta_t^\delta) = \rho_\delta log(\vartheta_{t-1}^\delta) + \epsilon_t^\delta. \tag{5.4}$$

With (5.3), a positive value of ϑ_t^δ leads to an unexpected decrease in the value of bank capital, consistent with the experience during the recent financial crisis. Owing to the financial frictions present in the model, such a decrease in bank capital leads to credit rationing and a decrease in bank lending. The downward effect is much more important in model (2) (3.5%) (the closed economy) than in the baseline model (2.5%) (the open economy).[16] In addition, aggregate investment declines by 2% in the baseline model and by 3% in the closed economy. The exchange rate appreciates and imports react positively while exports decline, but less than the increasing imports. Output and investment de-

[15] Each variable's response is expressed as the percentage deviation from its steady-state level.

[16] A sudden scarcity in the lending market drives down entrepreneur's net worth by around 10%, which moves up the external financial premium and domestic prices.

crease by more in the closed economy than in the baseline open-economy model.[17] Apart from consumption, following a negative bank capital shock, key economic aggregates react negatively and a part of this negative effect is transferred to the foreign economy through the exchange rate channel. The results points out the dampening role of the exchange rate channel in the propagation mechanism.

5.2 International Transmission of Shocks

5.2.1 Negative Technology Shock

Figures 5 and 6 display responses for the open-economy model (model 1) and for its closed-economy counterpart (model 2) following a 1% negative technology shock. Model (1) and model (2) display some common characteristics. Indeed, with a negative technology shock, the realized capital return is less than expected, which generates a negative effect on firms' net worth and forces an increase in the leverage ratio, exacerbating agency costs in the financial contract. As a consequence, the external finance premium increases and creates a negative effect on the credit demand side. On the other hand, a negative technology shock generates unexpected loss on the loan portfolio and weakens banks' capital positions. The deterioration in bank's balance sheets produces a negative signal to households about the financial health of banks. As a consequence, households are less willing to place deposits with banks. This increases the banks' external cost of funding and creates a negative impact on the credit supply side. Given these two negative effects, aggregate lending declines, which pushes down investment and output.

Although model (1) and model (2) display common characteristics, responses for the small open economy are more amplified than responses for the closed economy, especially for aggregate output and consumption, and effects are smaller in the closed economy model. Domestic prices are driven up, which makes domestic good more costly than

[17] Output drives down by more than 0.4% in the model (2) and by 0.2 in the baseline model. Aikman and Paustian (2006) shown that a 10% decreasing in bank's capital asset ratio leads to a 0.6% decreasing in output.

foreign goods. Immediately after the shock, the exchange rate depreciates suddenly but appreciates back and persistently a few periods later. The appreciation of the exchange rate leads to a rise in imports and a decrease in exports. With a negative technology shock, our model highlights both wealth and substitution effects. Substitution effects which is a consequence of the appreciation of the exchange rate, include the increases in imports. Wealth effects lead to a reduction of household's consumption in short run. All things considered, aggregate output, investment and consumption decrease sharply following the shock with the exchange rate channel playing an important amplification role in propagating the effects of the initial shock.

Expansionary Monetary Policy (decrease in interest rates)

Figures 7 and 8, which display impulse responses following a 1% domestic monetary policy easing, illustrates that monetary policy has direct effects on aggregate spending and output, that operate through the interest rate and exchange rate channels. A decrease in the domestic interest rate drives down the cost of deposits, and the supply of bank credit as well as increases. Household consumption, as well as bankers' and entrepreneurs' consumption, aggregate investment, move up. The exchange rate depreciates which helps create an increase in exports and a decrease in imports.

5.3 Transmission of International Shocks

The contagion phenomena that accompanied the recent financial crisis has made it more important than ever to understand the transmission of international shocks. This section illustrates the contribution of the banking sector, especially the role of bank capital, in the transmission of international shocks. For this task, we focus on the impact of a foreign monetary policy and a foreign demand shocks in model (1) and model (3). As indicated before, model (3) is a small open economy with additional sources of bank capital. Figures 9 and 10 display impulse responses functions for a tightening foreign monetary policy and a negative foreign demand shocks, respectively.

5.3.1 Foreign Demand Shock

Figure 9 depicts impulse responses following a negative foreign demand shock (a shock to foreign output). This shock leads to a decrease in exports of 1%, a decrease in output of 0.8% and a decrease in household consumption of 0.15%. The decrease in domestic output produces a negative output gap and a rise in the prices, which creates an inflationary pressure. As result, the home central bank reacts by tightening monetary policy, which leads to higher interest rate and a higher cost of deposits. The supply of bank credit declines and the return from lending goes up, which deteriorates the balance sheets of banks. As a consequence, banks' net worth falls and so does the net worth of the entrepreneurs, which produces a rise of the leverage ratio. Overall, the foreign demand shock has a negative impact on aggregate lending and drives investment down by 4%. Higher prices and interest rates are followed by an appreciation of the real exchange rate, which leads to a decrease in imports by substituting foreign factors by domestic factors of production. In absolute value, exports decrease by more than imports following the negative foreign demand shock, leading to a negative impact on the current account. The negative impact of the foreign demand shock is smaller in the model with more bank capital than in the baseline model, and the return to equilibrium is also faster than in the baseline model. These results highlight the dampening effects of a strong bank capital buffers and are consistent with those found in Meh and Moran (2010) and Dib (2010) in a closed economy.

5.3.2 Foreign Monetary Policy Shock

Figure 10 depicts the impulse responses following a tightening of foreign monetary policy. Foreign monetary policy affects domestic aggregates through the exchange rate channel. An increase in the foreign interest rate increases foreign prices, which depreciates the domestic real exchange rate in short run. As a consequence, imports decrease and exports increase, which positively affects the current account. However, the decrease in imports is much more important than the increase in exports, causing a decrease in domestic output and investment. In the short term, household wealth increases, which produces an increase in household's consumption. As in the case of negative foreign output shock, return to equilibrium is faster in the model with more bank capital than in the baseline model. However, effects following to a tightening foreign monetary policy are small than those of a negative foreign demand shock.

5.4 Sensitivity of the Bank Capital

The aim of this section is to highlight the relative contribution of bank capital in the dynamic of international shocks transmission. For this purpose, we compare the impulse responses of model (1) and model (3) following a negative domestic technology shock, a tightening of domestic monetary policy, and a negative government spending shock. Figures 11, 12 and 13 display the impulse responses of key domestic aggregates following to these aforementioned shocks, respectively. Overall, results suggest that bank capital plays a crucial role in the transmission of shocks as well as in the velocity of return to equilibrium. These results, which are consistent to those highlighted by Meh and Moran (2010) and Dib (2010) show that following a negative shock, bank capital plus a dampening effect. However, following a positive shock, bank capital plays an amplification role in the dynamic of shocks propagation. An economy with more bank capital has a better capacity to face against adverse shocks than an economy with less bank capital. This result, which remains valid for both the transmission of international shocks, highlights the importance of bank capital.

6 Concluding Remarks

Recent empirical evidence suggests that the health of banks' balance sheets plays an important role in the transmission of monetary policy and other shocks. This paper presents an international DSGE framework with an active bank capital channel to assess issues regarding the transmission of domestic and foreign shocks. The starting point of our model is the microfounded framework developed by Meh and Moran (2010), Gertler and Kiyotaki (2011) and Dib (2010), to which we include cross-border trade in goods, the exchange rate channel and a government. We analyze the relative contribution of the bank balance sheets channel, the exchange rate channel, and the interest rate channel in the propagation of internal and external shocks.

The results of our simulations may be summarized as follow: (*i*) In the presence of the exchange rate channel, the propagation of both domestic and foreign shocks are amplified when comparing our baseline economy to a closed economy. (*ii*) Depending of the level of bank capital in the economy, productivity and monetary policy shocks that originate domestically have an important quantitative role in explaining domestic output, investment, bank lending, entrepreneurs and banks net worth, inflation and interest rates. (*iii*) External shocks (monetary policy shock and foreign demand shock) also contribute to domestic aggregate fluctuations. (*iv*) Economies whose banks remain well-capitalized when affected by adverse shock experience less severe downturns, i.e., when the bank capital channel is active, an economy with more bank capital is better able to face adverse shocks than an economy with less bank capital. This last result, which remains valid for the transmission of international shocks, highlights the importance of bank capital in an international framework and can be used to inform the worldwide debate over the banking regulation.

Future, research could allow the model to take into account the heterogeneity in banks' capitalization that characterizes banking sectors, by developing a two-country model with financial frictions and endogenous portfolio choice in both domestic and foreign economy.

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7 Appendix

7.1 Structure of the model

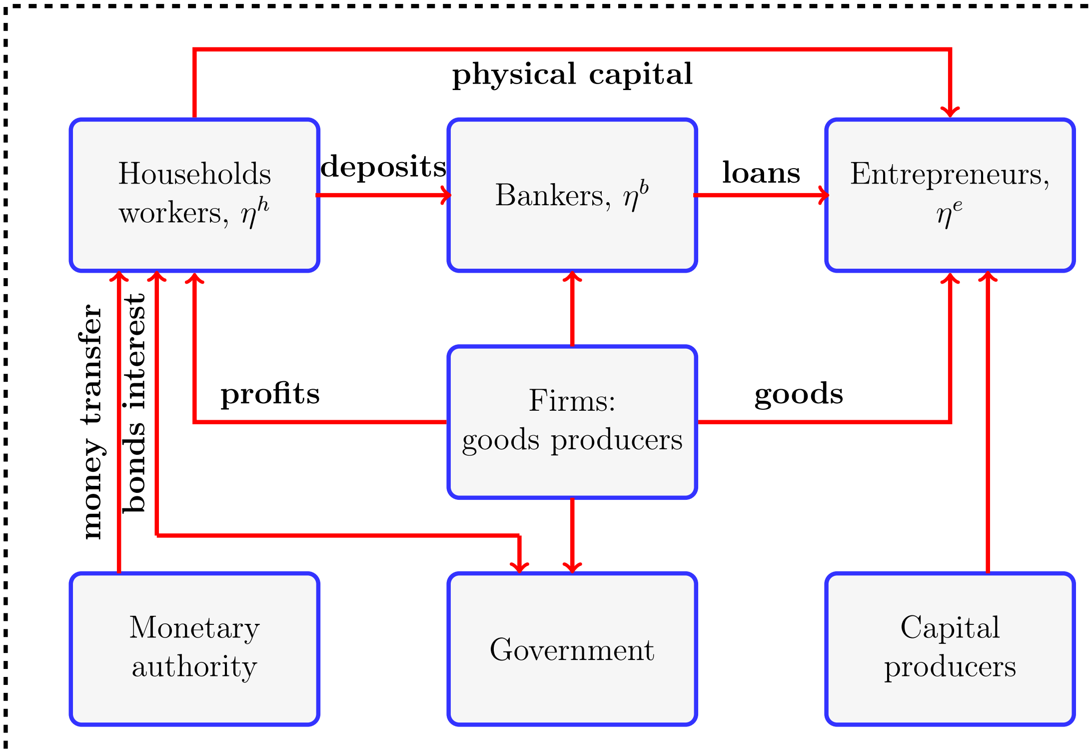


Figure 2: General structure of the model

7.2 Good market

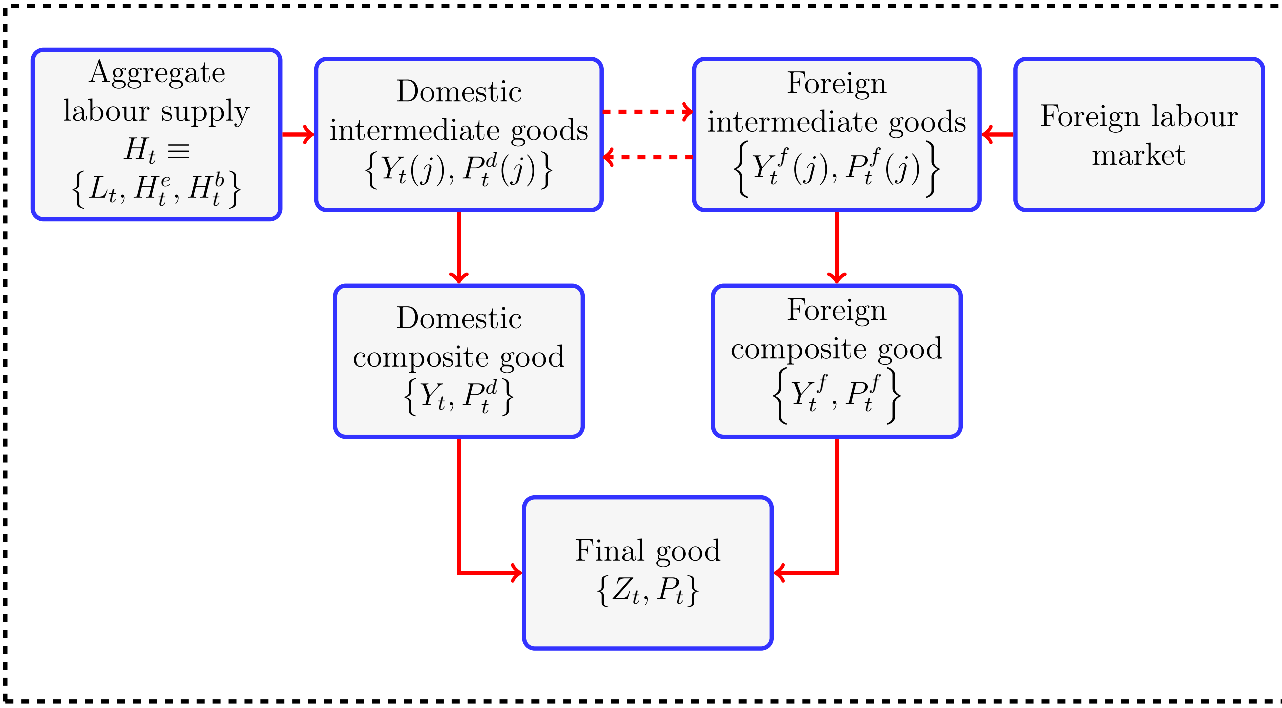


Figure 3: Structure of good distribution

7.3 Proof of the proposition 1

In equilibrium, (2.3) and (2.4) hold with equality; therefore, solving for the shares R_t^e and R_t^b, and using these results into the sharing condition yields:

$$R_t^e = \frac{b}{\Delta\alpha}, \qquad R_t^b = \frac{\mu}{Q_t \Delta\alpha}, \qquad R_t^h = R - \frac{b}{\Delta\alpha} - \frac{\mu}{Q_t \Delta\alpha}, \tag{7.1}$$

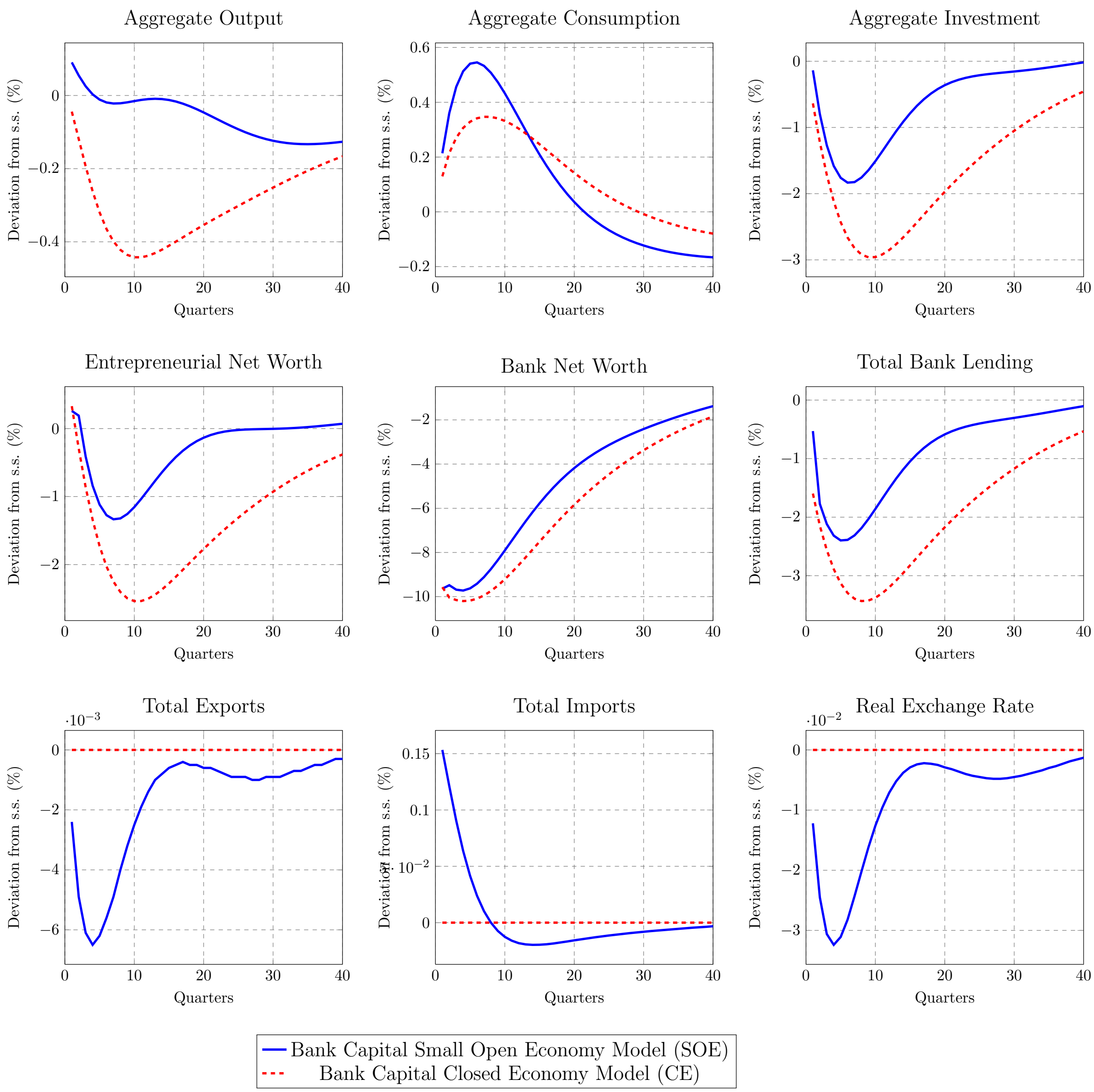
where $\Delta\alpha \equiv \alpha^h - \alpha^l$. Introducing (7.1) into the participation constraints (2.1) and (2.2), which hold with equality, yields:

$$A_t = \alpha^h \mu I_t / (1 + r_t^a) \Delta\alpha \qquad \text{and} \qquad D_t = \frac{\alpha^h Q_t}{(1 + r_t^d)} \left(R_t - \frac{b}{\Delta\alpha} - \frac{\mu}{Q_t \Delta\alpha} \right). \tag{7.2}$$

Finally, solving for I_t in (7.2) leads to:

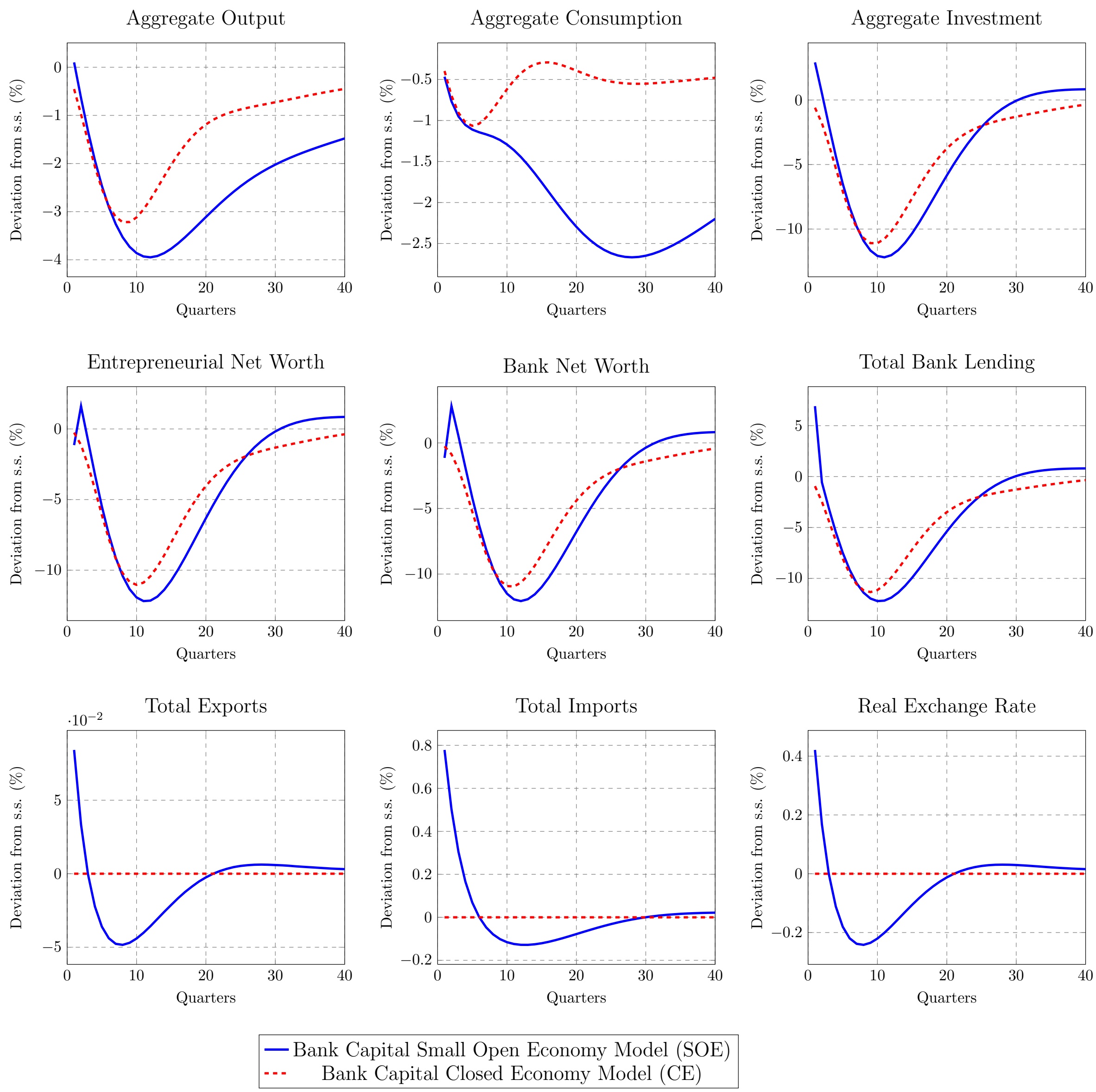
$$I_t = (N_t + A_t) / \left(1 + \mu - \frac{\alpha^h Q_t}{1 + r_t^d} \left(R_t - \frac{b}{\Delta\alpha} - \frac{\mu}{Q_t \Delta\alpha} \right) \right) = (N_t + A_t)/Lev_t, \tag{7.3}$$

Figure 4: IRF from a decrease in bank capital



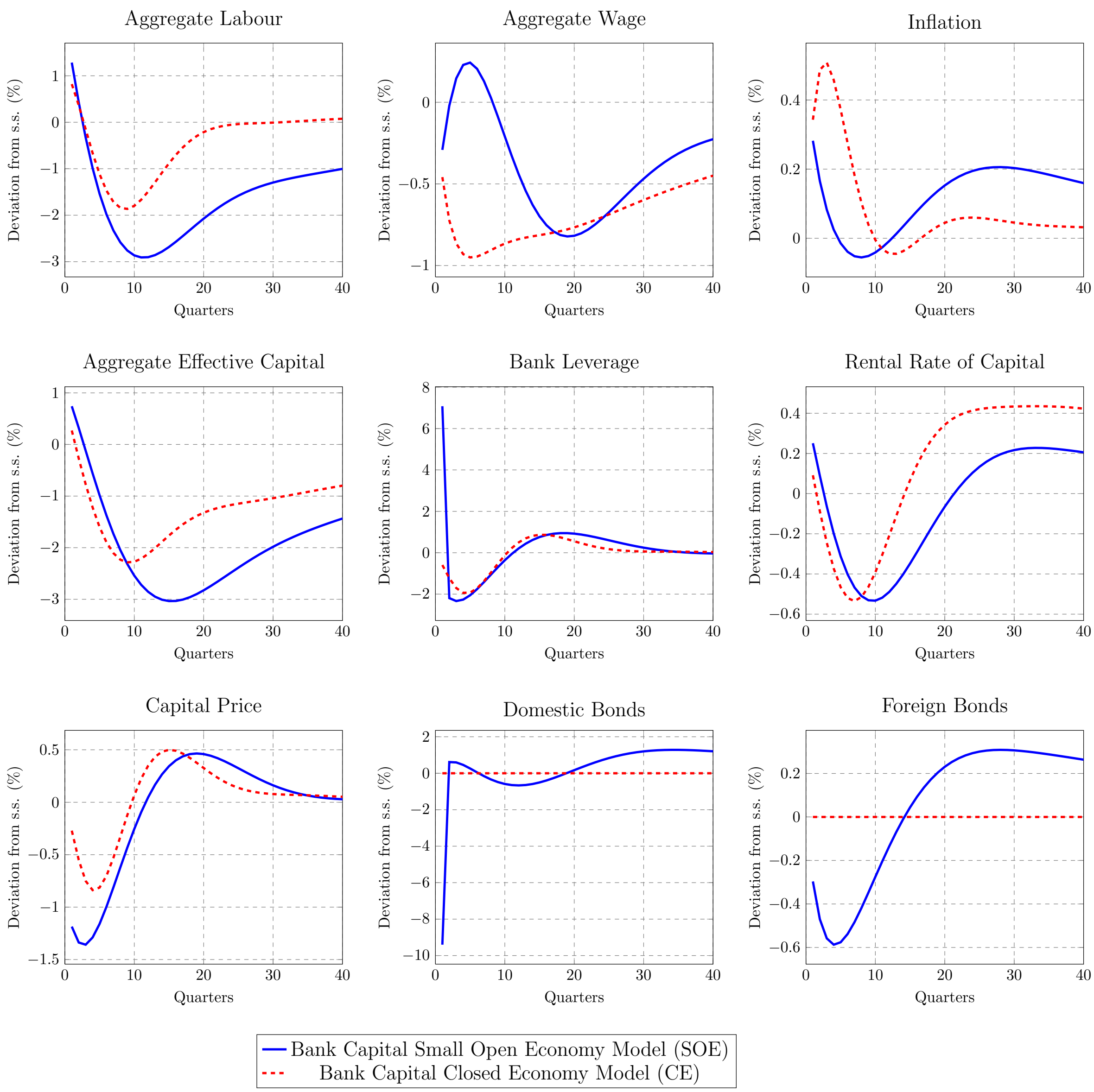
Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effect of the bank capital channel in the closed economy (CE, model 2), and in our small open economy (SOE, model 1). Responses are expressed in percentage deviation from steady-state values.

Figure 5: IRF from a negative technology shock (panel B)



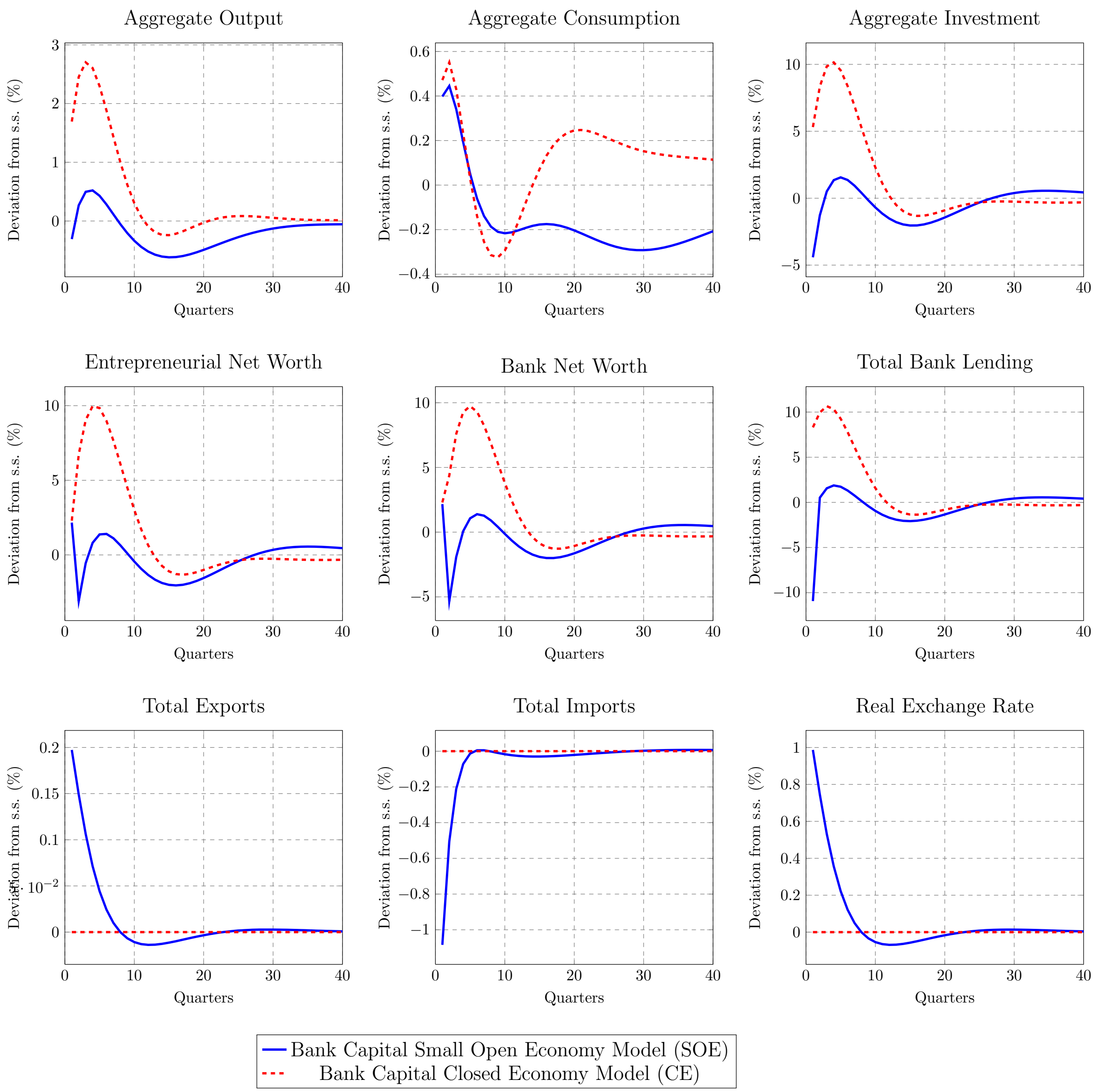
Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effect of a negative home technology shock, comparing the closed economy (CE, model 2) and our small open economy (SOE, model 1). Responses are expressed in percentage deviation from the steady-state values.

Figure 6: IRF from a negative technology shock (panel B)



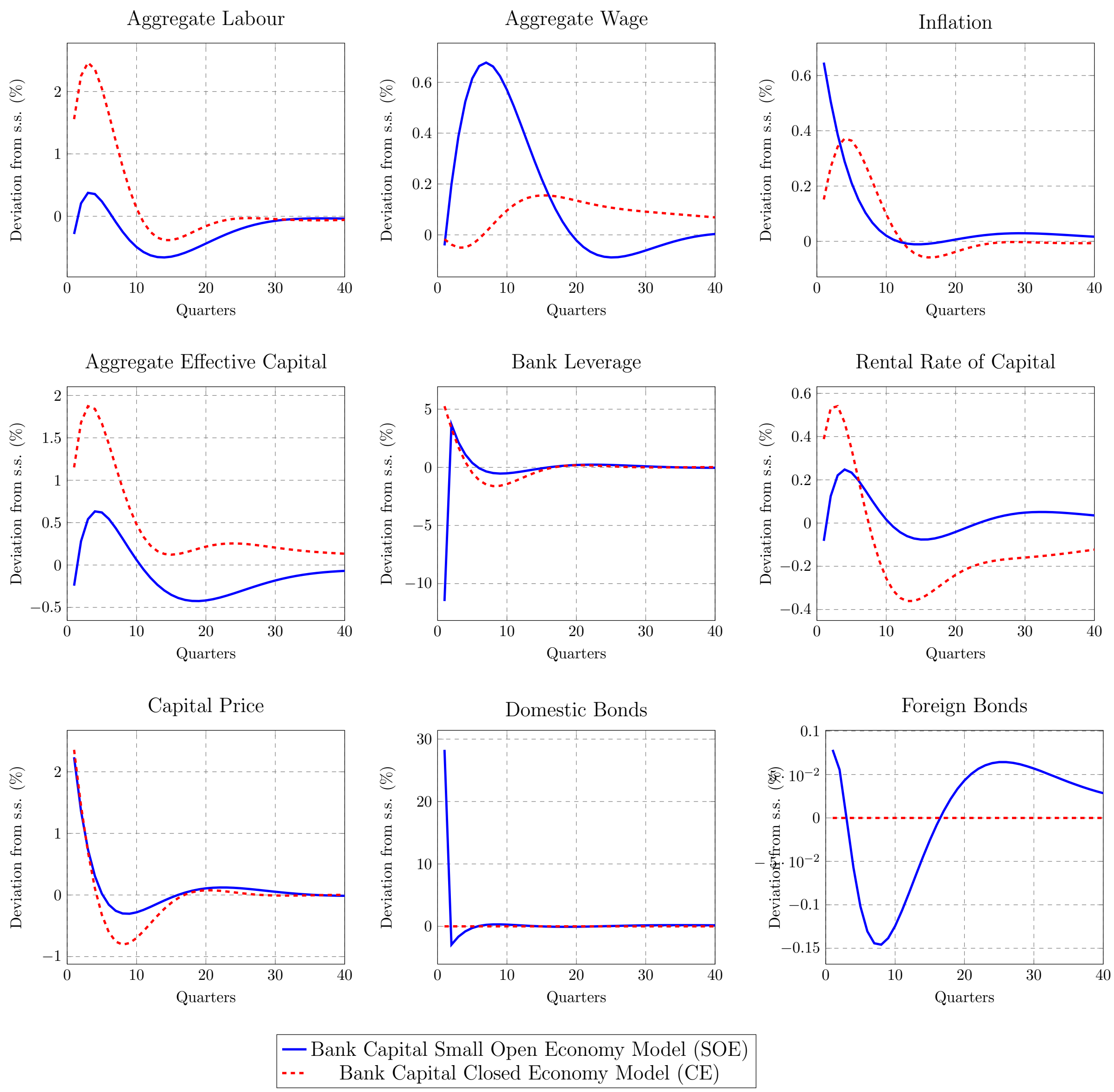
Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effect of a negative home technology shock, comparing the closed economy (CE, model 2) and our small open economy (SOE, model 1). Responses are expressed in percentage deviation from the steady-state values.

Figure 7: IRF from a monetary policy shock (panel A)



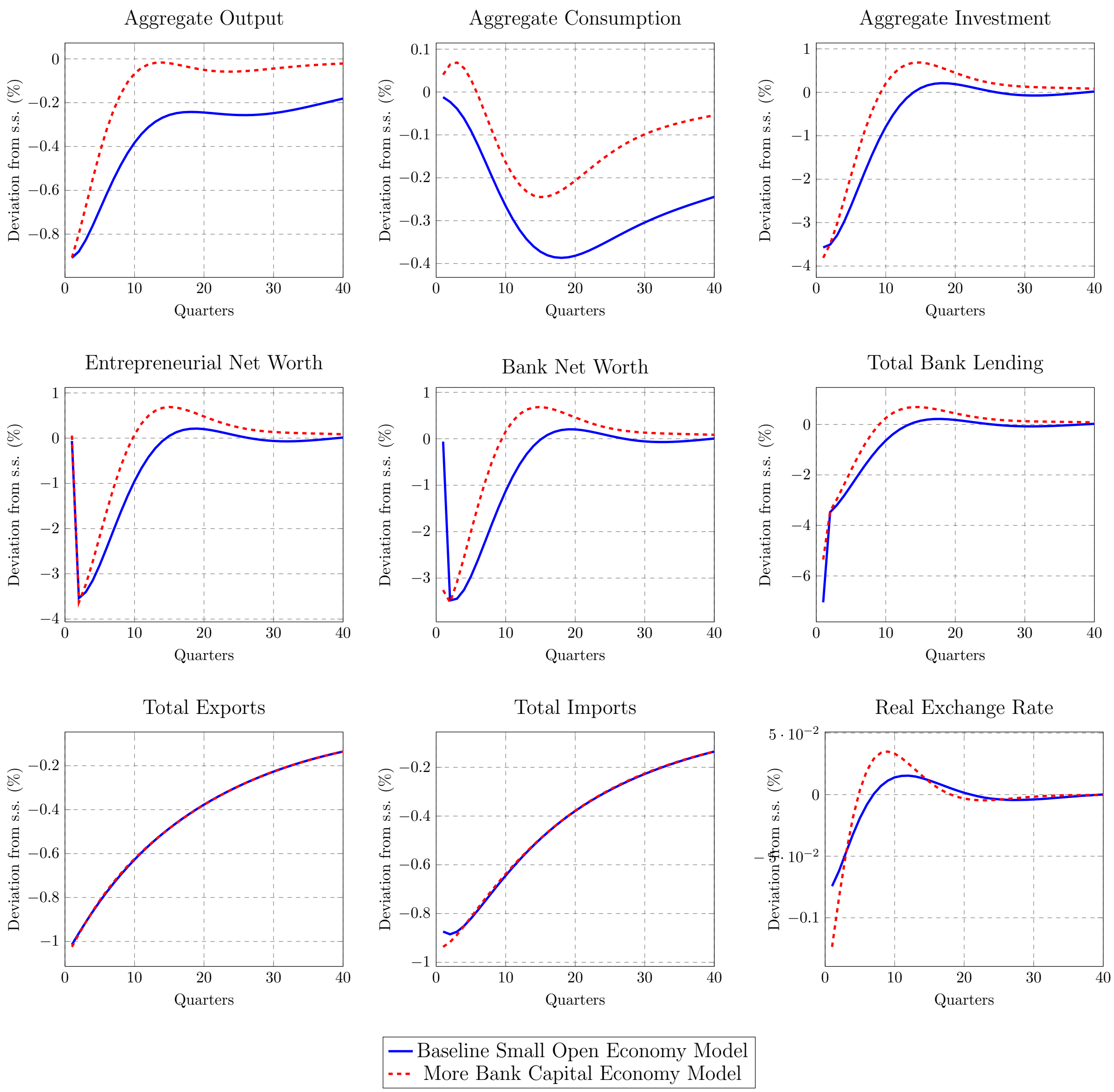
Note : This figure presents impulse response functions from the simulated DSGE model to illustrate the effect of a home monetary easing, comparing the closed economy (CE, model 2) and our small open economy (SOE, model 1). Responses are expressed in percentage deviation from the steady-state values.

Figure 8: IRF from a monetary policy shock (panel B)



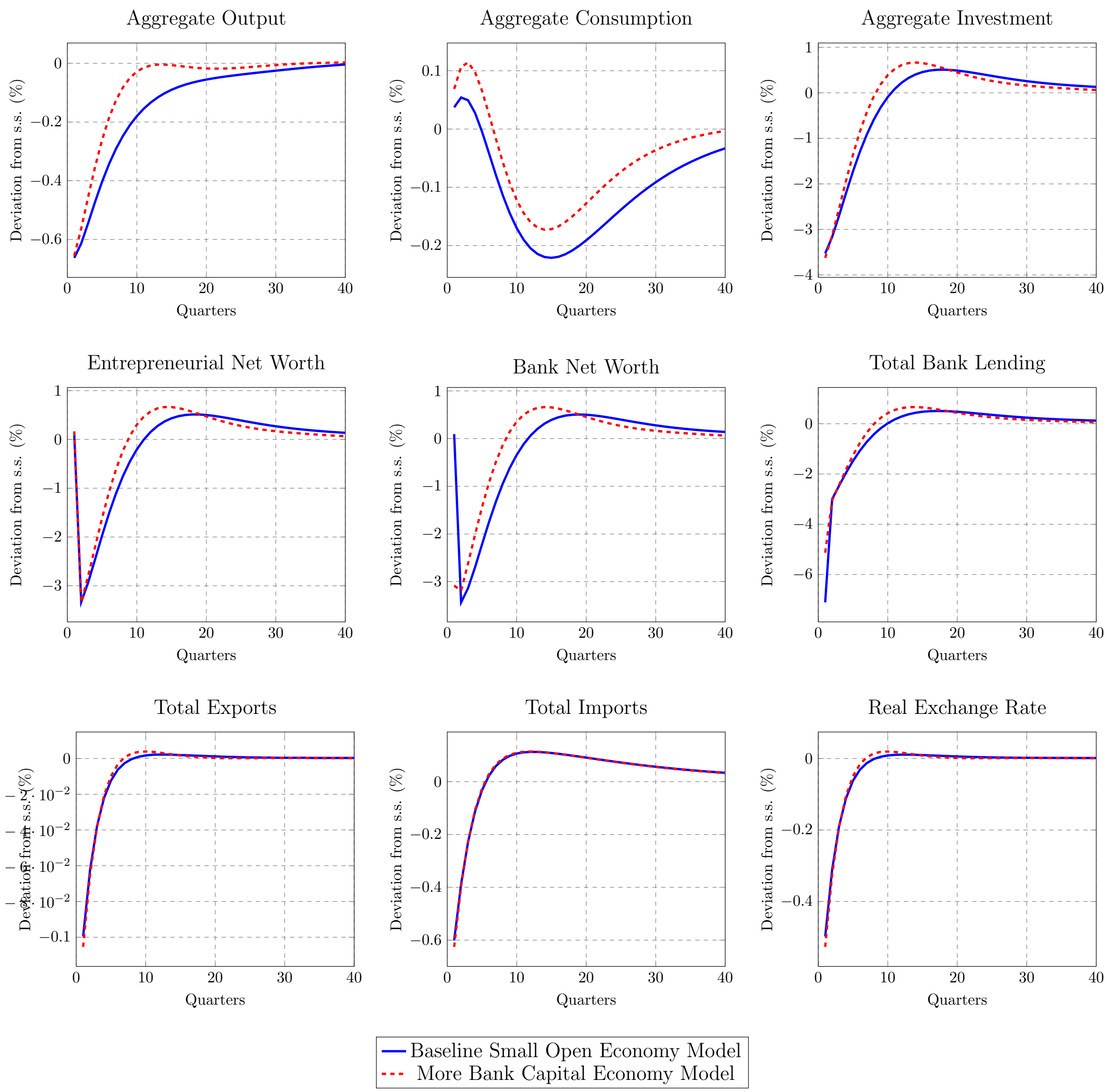
Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effect of a home monetary easing, comparing the closed economy (CE, model 2) and our small open economy (SOE, model 1). Responses are expressed in percentage deviation from the steady-state values.

Figure 9: IRF from a negative foreign output shock



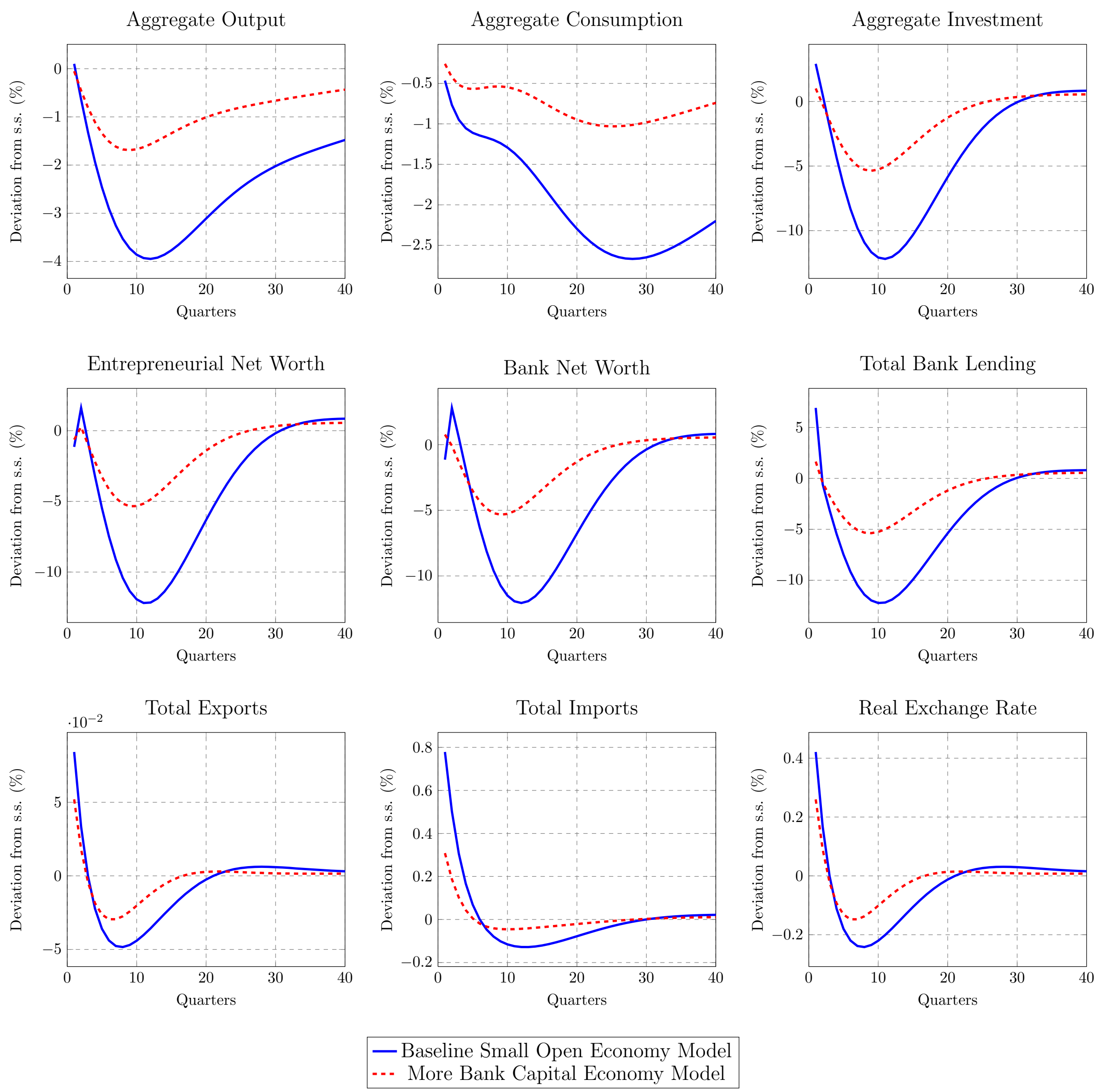
Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effects of bank capital in the transmission of international shock. The shock is a negative foreign output shock, and the Figure compares our small open economy (SOE, model 1) and the economy with more bank capital (model 3). Responses are expressed in percentage deviation from the steady-state values.

Figure 10: IRF from a foreign monetary policy shock



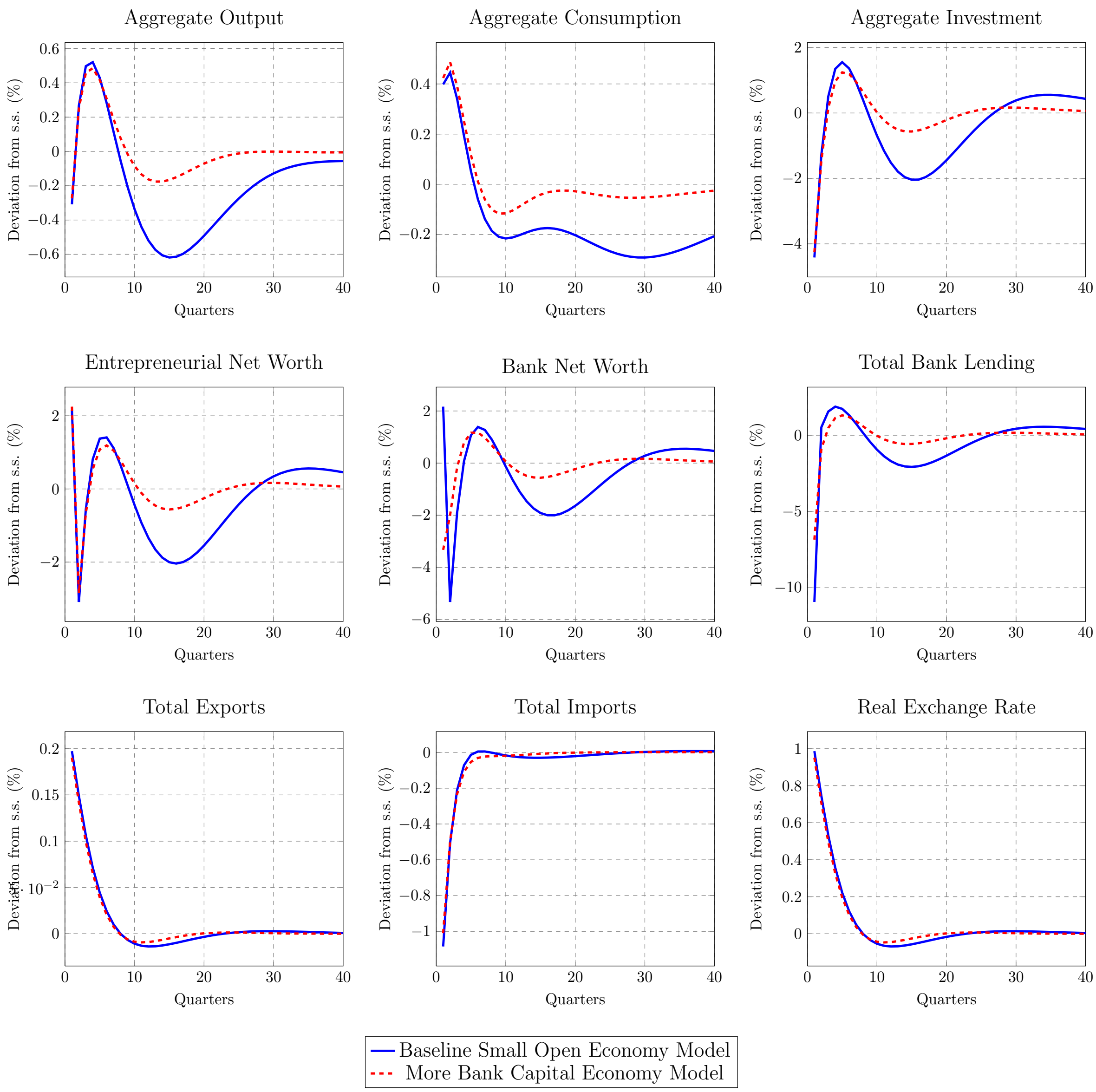
Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effects of bank capital in the transmission of international shock. The shock is a foreign monetary policy shock and the Figure compares our small open economy (SOE, model 1) and the economy with more bank capital (model 3). Responses are expressed in percentage deviation from the steady-state values.

Figure 11: IRF from a negative technology shock



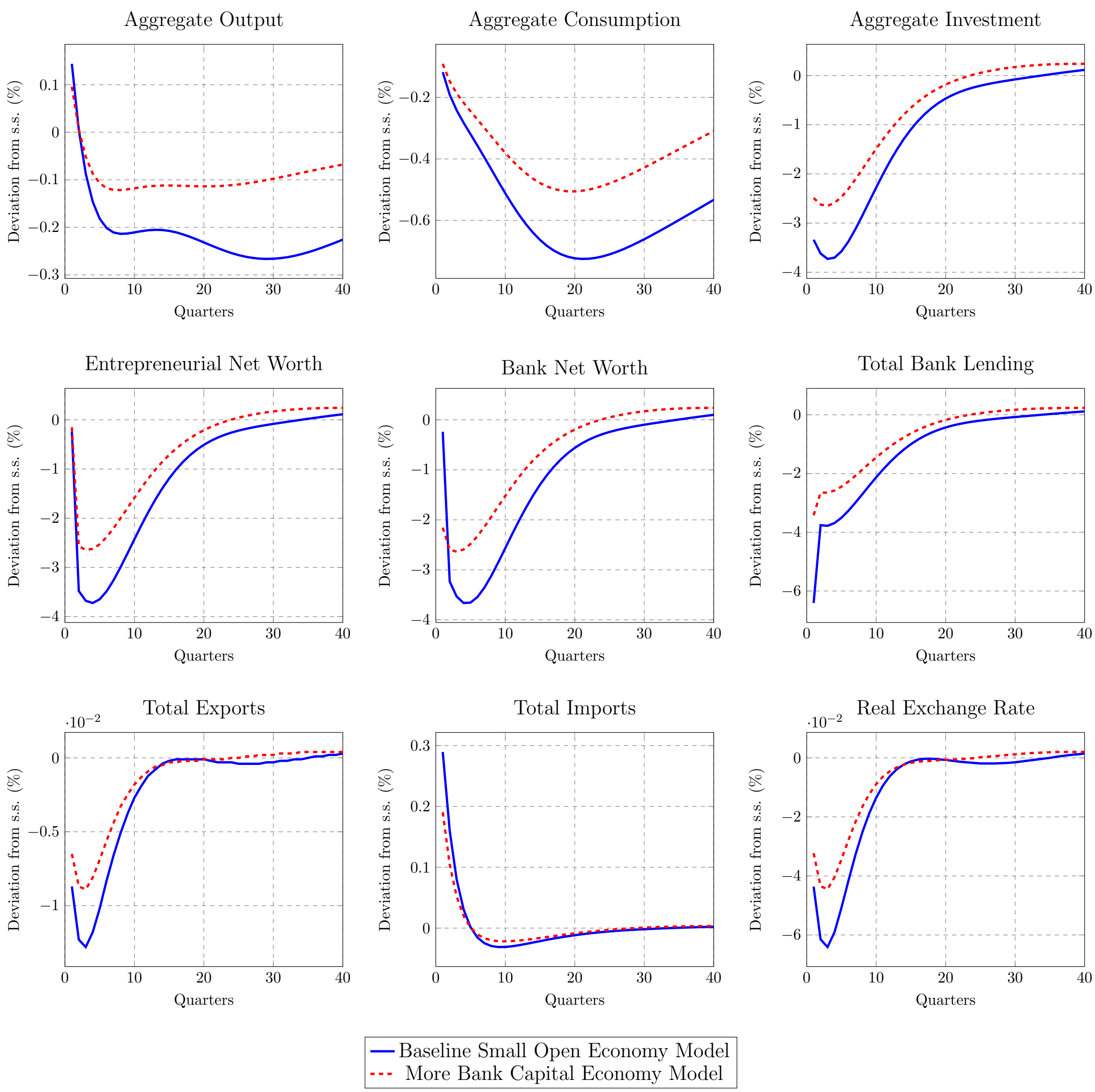
Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effects of bank capital in the international transmission of domestic shocks. The case is that of a negative technology shock in the home country, comparing our small open economy (SOE, model 1) and the economy with more bank capital (model 3). Responses are expressed in percentage deviation from the steady-state values.

Figure 12: IRF from a monetary policy shock



Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effects of bank capital in the international transmission of domestic shocks. The case is that monetary policy easing in the home country, comparing our small open economy (SOE, model 1) and the economy with more bank capital (model 3). Responses are expressed in percentage deviation from the steady-state values.

Figure 13: IRF from a a negative government spending shock



Notes : This figure presents impulse response functions from the simulated DSGE model to illustrate the effects of bank capital in the international transmission of domestic shocks. The case is that of a negative government spending shock in the home country, comparing our small open economy (SOE, model 1) and the economy with more bank capital (model 3). Responses are expressed in percentage deviation from the steady-state values.