Essays in International Macroeconomics

Dissertation

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Abstract

Exchange rate regimes and invoicing currency play a crucial role in international macroeconomics due to their importance in the international transmission of monetary policy and the behavior of real exchange rates. In my dissertation, the first essay studies the process of exchange rate regime shifts during sudden stops in a small open economy, using the policy papers by the Bank of Korea to suggest the actual decision-making process within a central bank. The second essay examines the role of invoicing currency in a two-country model with state-dependent pricing (SDP).

While recent papers on the financial crisis often model the government as optimally choosing to exit from a fixed exchange rate regime, my first chapter, “Behind the Scenes of Abandoning a Fixed Exchange Rate Regime”, uses the Bank of Korea’s policy reports during the East Asian crisis to answer whether the Korean central bank optimally chose to abandon or was involuntarily forced to do. The Korean policy reports suggest that there was a discrepancy between the official foreign reserves and foreign reserves usable in defending the Korean currency. Despite a sizable reserve holding, the fixed exchange rate regime was forced to collapse due to the expected depletion of usable foreign reserves. Based on these findings, I suggest a small open economy model in which the credit policy of a central bank to support domestic banks in need of the foreign-currency liquidity, leads to the exhaustion of international reserves and consequent exchange rate regime shift during a sudden stop. This model
does well at capturing the regime switching in the Korean crisis and the observed contraction in aggregate variables.

In the second chapter, “Invoicing Currency and State-Dependent Pricing”, I consider the role of invoicing currency under SDP in the propagation of monetary shocks across countries. While invoicing currency has been extensively studied due to its importance on the international transmission mechanism of monetary policy, Dotsey and Duarte(2008) suggests that the currency denomination of exports doesn’t matter, because standard pricing regimes such as producer currency pricing(PCP) and local currency pricing(LCP) generate similar aggregate responses. However, this paper demonstrates the importance of invoicing currency in a two-country state-dependent pricing(SDP) model. To highlight the role of SDP, I contrast the SDP model’s responses across invoicing regimes with those from a time-dependent pricing(TDP) model identical to SDP except exogenous price adjustment. TDP shows little difference in the aggregate responses except trade balance across pricing regimes like Dotsey and Duarte(2008) which is also based on TDP. On the contrary, SDP makes the aggregate responses in PCP quantitatively different from those in LCP and asymmetric currency pricing(ACP). While the full exchange rate pass-through in PCP contributes to higher prices under both SDP and TDP, the absence of the extensive margin in TDP prevents making a difference.
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Borrowing conditions for Korean commercial banks

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Chapter 1: Behind the Scenes of Abandoning a Fixed Exchange Rate Regime

1.1 Introduction

Much of the literature that studies the quantitative feature of sudden stops in emerging economies introduces different kinds of financial constraints and tries to generate business cycle patterns similar to those in real aggregate data. While this strand of literature mostly focuses on the sovereign defaults widely observed in the sudden stops of Latin American countries\(^1\), the notably common but often understudied feature is a collapsing exchange rate regime.

While economic theory offers little policy guidance on the exchange rate regime shift, there exist the two opposing views on this issue. The conventional one in the spirit of Krugman (1979) and Flood and Garber (1984) is that the fixed exchange rate is abandoned only if the central bank exhausts its foreign exchange reserves. The recent papers, however, argue that the central bank *chooses* to exit from the fixed regime as opposed *being forced* to do. For example, Rebelo and Végh (2008) provide the empirical evidence on this optimizing view. From the official international reserves data, they find out how many reserve assets have been consumed until the collapse of exchange rate regime. In roughly 75% of currency crises episodes from 1970 to

\(^1\)For example, see Arellano (2008) and Cuadra, Sanchez and Sapriza (2010).
Figure 1.1: Monthly changes in international reserves of the East Asian crisis countries

1997 except the East Asian crisis, the reserve losses during the 12 months prior to the crisis were less than 40%. As “the peg was abandoned with plenty of ammunition left the central bank’s coffers” (Rebelo and Végh(2008), p.930), this evidence can be interpreted to support that the exit from the fixed regime is the result of optimal choice by the central banks. If we consider the East Asian countries as well, South Korea, Thailand and Indonesia were not an exception. As pointed out by Figure 1.1, they consumed less than 40% of initial reserve assets at the point of abandonment.²

²Figure 1 does not include the two other Asian crisis countries, Malaysia and Philippines, because they didn’t experience the regime shift during the crisis period.
In this chapter, my contribution is two-fold. From the Bank of Korea’s internal policy reports during the currency crisis in 1997, I find out what really happened in the process of regime shift and whether the Korean central bank optimally chose to abandon or were involuntarily forced to do so. Second, I suggest a quantitative small open economy model to incorporate those findings from the Korean policy papers and replicate the Korean crisis experience.

The Bank of Korea’s internal papers reveal the following two facts about the decision-making process during the exchange rate regime shift. First, as stressed by earlier literature on the Korean crisis such as Moon(2000) and Park(1998), the Korean policy reports confirm that there existed a discrepancy between publicly announced official foreign reserves and foreign reserves usable in defending the Korean won. When Korean commercial banks experienced the credit crunch as a reduction in foreign currency liquidity and the transaction in the foreign exchange market was significantly impeded due to strong expectation on the depreciation of the Korean currency, the Bank of Korea conducted the credit policy to save the banks from insolvency. The Bank of Korea deposited foreign currency in the foreign affiliates of financially distressed domestic banks. While these deposits were included in the official foreign reserves, they were not available for use in the crisis. Second, the fixed exchange rate regime was forced to collapse. At the point of abandonment, the Korean central bank expected usable foreign reserves to be completely depleted in the near future due to the continued demand from domestic banking sector, which could hardly finance their foreign debt.
Based on these findings, the goal of the suggested model in this chapter is to capture the foreign-currency credit policy during sudden stops in a small open economy. The model builds on Gertler, Gilchrist and Natalucci(2007) (hereafter, “GGN”) which considers the small open economy with financial frictions originally formulated by Bernanke, Gertler and Gilchrist(1999) (hereafter, “BGG”). This paper extends GGN into incorporating the credit policy following Gertler and Karadi(2011) and Gertler and Kiyotaki(2010) into an open economy setting. The central bank is assumed to deposit foreign currency at domestic commercial banks in response to the country risk premium. If international reserves are expected to be depleted as a result of the credit policy, the central bank is forced to switch to a floating regime with inflation targeting. This model does well at capturing the regime switching in the Korean crisis and the observed contraction in aggregate variables in response to the adverse country risk premium shock. In addition, a counterfactual experiment is provided to compare the impulse response of maintaining the fixed exchange rate regime by conservative credit policy with that of benchmark. The result suggests that even though the regime switching was unwanted, it actually brought better outcomes.

This chapter is naturally related to the literature that studies the effects of sudden stops on economic activity in emerging economies. Martins and Salles(2010) also study the credit policy in a small open economy, but the primary goal of their paper is to analyze the welfare effects of the credit policies by the Brazilian central bank during the recent financial crisis, while this paper focuses on exchange rate regime switching. As shown in this chapter, Céspedes, Chang, and Velasco(2004) and Devereux, Lane and Xu(2006) highlights the superiority of floating exchange rate regime for emerging economies in response to the negative world interest rate shock. Neumeyer and

In addition, there exist few preceding studies that use the policy papers of the Bank of Korea during the crisis as in this chapter. For example, Moon (2000) focuses on identifying the mistakes in a broad range of government policy including foreign exchange policy, financial policy and labor market policy, and points out rigid exchange rate policy as one of the policy mistakes.

The rest of this chapter is organized as follows. In the next section, I consider the findings from the Bank of Korea’s internal papers on the exchange rate policy during the East Asian crisis. In section 1.3, I present a quantitative small open economy model. In section 1.4, parameter values will be selected. I also suggest the aggregate response when the model economy is hit by the country risk premium shock. I conclude this chapter in section 1.5.

1.2 The Bank of Korea’s internal policy papers

On January 15, 1999, the National Assembly of Korea launched the ‘Special Investigation Commission on the Causes of the Economic and Currency Crisis’ which lasted until February 13, 1999. The commission, which consisted of 20 National Assembly members, held 25 meetings including 13 hearings. They requested the Ministry of Finance and Economy, the Bank of Korea, the Financial Supervisory Services, the Korea Depository Insurance Company, and even the commercial banks to submit documents related to the currency crisis. Among them, the documents from the Bank of Korea include 49 exchange rate policy reports from January 1996 to December

31 institutions were required to submit their reports which are now publicly available at the National Assembly of Korea Library.
1997 and the reports from the foreign offices of the Korean central bank regarding the borrowing conditions of foreign affiliates of Korean commercial banks.

1.2.1 ‘Usable’ international reserves

Before the currency crisis of 1997, Korea maintained a market average foreign exchange system, under which the Korean won exchange rate against the U.S. dollar was in principle decided by the interplay of market forces while a very narrow daily exchange rate fluctuation band was imposed.\(^4\) Given the low degree of exchange rate fluctuation, the daily band was set at ±2.25% of the market average rate of the previous trading day.
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Table 1.1: Borrowing conditions for Korean commercial banks

variability before the crisis, there was an apparent difference between *de jure* and *de facto* exchange rate regime in Korea.⁵

During the crisis, the Korean sovereign rating quickly deteriorated, mainly due to the two large conglomerate bankruptcies in January and July, Thai depreciation and the political instability on the Korean peninsula. Moody’s lowered the credit rating by 6 notches from A- in September 1997 to Ba1 in December and at the same time Standard & Poors(AA- → B+) and Fitch(AA- → B-) downgraded 10 and 12 notches, respectively. As a result, the country risk premium soared and the foreign borrowing condition of Korean commercial banks worsened. Credit limits from foreign investors were reduced⁶, and the commercial banks were refused when they attempted to renew their existing foreign short-term debts.

Thus, in order to save the domestic banks from insolvency, the Bank of Korea deposited foreign currency at their foreign branches, since the Korean government indemnified foreign lenders to Korean banks in August. Domestic banks, which couldn’t finance their foreign debt an hour before the New York market closed, came to ask the Bank of Korea to make deposits through its New York office.


⁶The credit line of the seven major commercial banks declined by $9.1 billion during February and March right after the bankruptcy of Hanbo in January and further declined by $9.0 billion during July and August after the bail-out of Kia motors in July.
As the size of this deposit increased in early 1997, the Bank of Korea started to distinguish the official reserve assets from the ‘usable’ reserve assets internally (See Figure 1.2). The usable reserve assets are the official reserves minus the foreign currency deposits in the foreign branches of domestic banks, which, the central bank acknowledged, were not available for use in a crisis.7

According to Keyster (2001), which is the official International Monetary Fund (IMF) guideline on the data template for measuring international reserves, the deposits at foreign branches of domestic banks should have been excluded since the central bank had no control over them. Considering the IMF’s continued effort to improve the transparency of international reserves data, this accounting practice may have prevailed among the crisis countries. Nevertheless, the official international reserves data of the Bank of Korea as well as provided to the IMF still include the deposits at foreign branches. These observation suggests that the surprisingly small loss of reserves at the point of regime shift reported by Rebelo and Végh (2008) may reflect overestimation of usable reserve assets.

1.2.2 Collapse of the exchange rate regime

Even before the crisis unfolded, the Bank officials had continued to point out that the level of international reserves was not adequate for the size of imports and foreign debts. Therefore, the Bank of Korea considered several policy options to raise the reserve assets, but none of them had an impact substantial enough to revert the declining trend of foreign exchange reserves.

7 According to the memorandum from the Frankfurt office in the Bank of Korea on November 3, 1997, the Korean commercial banks’ branches in Germany made a request to the central bank not to withdraw the foreign-currency deposits, while the rumors about the shortage of Korean foreign reserves spread.
In November 1997, the usable reserve assets were expected to be exhausted within a quarter, considering the commercial banks’ repaying schedule for their short-term debts which were almost non-renewable at that point.\(^8\) In addition, the depreciation expectation and resulting excess demand for foreign currency caused the exchange rate to reach the daily depreciation tolerance and the trading in foreign exchange market to stop. The daily transaction of foreign exchange market declined from $2.5 billion in June to $1 billion for the first ten days of December. To help private companies pay for necessary imports such as petroleum, the central bank intervened in the foreign exchange market and supplied U.S. dollars out of its international reserves. However, the foreign-currency supply of liquidity to support domestic banks was a much greater cause of the depletion of international reserves than intervention in the foreign exchange market.\(^9\)

Realizing the significant shortage of foreign reserves and the need to minimize further loss of reserve assets resulting from the intervention, the Korean government and the Korean central bank were forced to initially widen the daily bandwidth of exchange rates from 2.25% to 10% and later to allow the Korean won to freely float. Also they had to ask the IMF for a bail-out.

As a part of the IMF conditionality, the Korean government was mandated to retain the international reserves above a certain level. Even though the short-term borrowing spread continued to increase in January and February 1998, the Bank of Korea stopped providing the commercial banks with the foreign-currency loans and even started to collect its deposits, after the Korean government had agreed with


\(^9\)In November 1997, the increase in foreign-currency deposit held in the overseas branches of Korean commercial bank was $16.9 billion, while exchange market intervention was $7.0 billion.
international investors about extending the maturity of the foreign debt in New York on January 28, 1998.

1.3 Model

In this section, the core framework closely follows the small open economy model of GGN with financial frictions and nominal price rigidities. A financial friction is that borrowers are subject to external financing premium due to default risk as in BGG. In comparison to GGN, the key difference arises from the introduction of a banking sector and a credit policy by the central bank in response to the country risk premium. The conduct of credit policy under the fixed regime and the expected exhaustion of international reserves provide the point of regime shift rather than the probabilistic regime shift of GGN.

There exist households, producers, a banking sector, a government and the rest of the world. Within the home country, there are three types of producers: entrepreneurs, capital producers and retailers. Households consume, work and save. Entrepreneurs purchase capital from capital producers and hire labor from households to produce the wholesale goods. Capital producers buy final goods to produce investment goods. Monopolistically competitive retailers buy wholesale goods and repackage and sell them to consumer and capital producers. Banks make loans to entrepreneurs. These loans are financed by the net equity of bankers, domestic and foreign-currency deposits. The central bank conducts credit policy by adjusting its foreign-currency deposits at banks in response to the country risk premium. It is also in charge of monetary policy and exchange rate policy. Figure 1.3 describes a flow chart of the structure of goods and assets markets.


1.3.1 Households

Households are infinitely-lived agents whose preferences are given by 

\[
E_0 \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\varsigma}(1 - H_t)^\varsigma}{1 - \sigma} 
\]  

(1.1)

with \(0 < \beta < 1, \sigma \geq 0,\) and \(\varsigma \in (0, 1).\) Households supply labor \(H_t\) at the real wage \(w_t,\) consume a composite consumption good \(C_t,\) save \(D_{t+1}\) as real deposits in banks in return for a risk-free real gross interest rate \(R_t,\) pay lump-sum real taxes \(T_t\) to the government and receive real dividends from retailers and banks denoted by \(\Pi_t.\) Thus,
their budget constraint in real term is

\[ C_t + D_{t+1} + \frac{\Theta}{2}(\bar{D} - D_{t+1})^2 = w_t H_t + R_{t-1} D_t + \Pi_t - T_t \]  

(1.2)

where the last term on the left hand side is the transaction fee for households to pay to the banks.

Aggregate consumption is defined as a constant elasticity of substitution (CES) composite of domestic and imported consumption

\[ C_t = \left[ \gamma \left( C_t^H \right)^{\frac{\rho-1}{\rho}} + (1 - \gamma) \left( C_t^F \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \]  

(1.3)

The coefficient \( \gamma \) measures the degree of home bias in consumption, while \( \rho \) denotes the elasticity of substitution between domestically produced goods \( C_t^H \) and imported foreign goods \( C_t^F \). The corresponding consumer price index (CPI), \( P_t \) becomes

\[ P_t = \left[ \gamma (P_t^H)^{1-\rho} + (1 - \gamma) (P_t^F)^{1-\rho} \right]^{\frac{1}{1-\rho}} \]  

(1.4)

The optimality conditions for the consumption allocation, labor supply and the consumption/saving decision are given by

\[ \frac{C_t^H}{C_t^F} = \frac{\gamma}{1 - \gamma} \left( \frac{P_t^H}{P_t^F} \right)^{-\rho} \]  

(1.5)

\[ (1 - \zeta) \frac{w_t}{C_t} = \zeta \left( \frac{1}{1 - H_t} \right) \]  

(1.6)

\[ \lambda_t = (1 - \zeta) C_t^{(\rho-1)(\zeta-1) - 1} (1 - H_t)^{\zeta(1 - \rho)} \]  

(1.7)

\[ \lambda_t [1 + \Theta(\bar{D} - D_{t+1})] = \beta E_t \{ \lambda_{t+1} R_t \} \]  

(1.8)

### 1.3.2 Domestic producers

Following the setup of BGG and GGN, I introduce three types of producers: entrepreneurs, capital producers and retailers.
Entrepreneurs

Entrepreneurs are risk-neutral. At time $t$, entrepreneurs start with capital $K_t$ carried over from the previous period and produce wholesale output $Y_t$ using labor $L_t$ and capital services $u_tK_t$, where $u_t$ is the capital utilization rate. The production employs a constant-returns-to-scale technology

$$Y_t = \omega_t A_t (u_t K_t)^\alpha (L_t)^{1-\alpha}$$  \hspace{1cm} (1.9)

where $A_t$ is a total factor productivity common to all entrepreneurs. The labor $L_t$ is a composite of household and managerial labor, $H^*_t$: $L_t = (H^*_t)^1-\Omega (H^*_t)^\Omega$. Managerial labor is inelastically supplied by entrepreneurs. Without loss of generality, the aggregate endowment of managerial labor is normalized to one.\(^{10}\) The idiosyncratic productivity shock $\omega_t$ is assumed to be an $i.i.d.$ random variable, distributed continuously with mean equal to one. The shock $\omega_t$ reflects the quality of entrepreneur’s overall capital investment.\(^{11}\)

As in Baxter and Farr(2005), the depreciation rate of capital is a function of capital utilization

$$\delta(u_t) = \delta + \frac{b}{1 + \xi} (u_t)^{1+\xi}$$  \hspace{1cm} (1.10)

with $\delta, b, \xi > 0$.

Let $p_{wt} = \frac{P_{wt}}{P_t}$ be the real price of wholesale output, $q_t$ the real price of capital, and $p_{it} = \frac{P_{it}}{P_t}$ the real replacement price of depreciated capital. The repair of the worn-out equipment costs entrepreneurs $p_{it}\delta(u_t)K_t$. At time $t$, conditional on $A_t$, $K_t$

\(^{10}\)The introduction of managerial labor allows entrepreneurs to begin their operation with some net worth.

\(^{11}\)Despite the heterogeneity in entrepreneurs, the entrepreneur-specific index is omitted for notational simplicity.
and $\omega_t$, the entrepreneur chooses labor and the capital utilization to maximize his profits. The labor demand satisfies

$$
(1 - \alpha)(1 - \Omega) \frac{Y_t}{H_t} = \frac{w_t}{p_{wt}}
$$

(1.11)

$$
(1 - \alpha)\Omega \frac{Y_t}{H_t^c} = \frac{w_t^c}{p_{wt}}
$$

(1.12)

where $w_t^c$ is the real managerial wage. The optimality condition for capital utilization is

$$
\alpha \frac{Y_t}{u_t} = \delta(u_t) \omega_t K_t \frac{p_{it}}{p_{wt}}
$$

(1.13)

At the end of period $t$, the entrepreneur purchases capital that will be used in the subsequent period. The capital purchase is financed with the entrepreneur’s real net worth $N_{t+1}$ and real borrowing from banks, $B_{t+1}$. Thus, the equation describing the balance sheet at the end of time $t$ can be expressed as

$$
q_t K_{t+1} = N_{t+1} + B_{t+1}
$$

(1.14)

To ensure that entrepreneurs never accumulate enough funds to fully self-finance, $1 - \phi_c$ of the entrepreneurs are assumed to go out of business and consume their equity in the market $C_{e,t}$ which will be defined later. Since new entrepreneurs replace those who exit, the entrepreneurs’ population is stationary.

The entrepreneurs’ demand for capital depends on the expected marginal real return and the expected marginal real external financing costs. The ex post marginal return to capital for entrepreneur, $R_{k,t+1}$ is the sum of marginal productivity of capital and the market value of the capital stock net of the cost of repairing.

$$
R_{k,t+1} = \frac{\omega_{t+1} \left[ p_{wt+1} \Omega \frac{Y_{t+1}}{K_{t+1}} + q_{t+1} - p_{it+1} \delta(u_{t+1}) \right]}{q_t}
$$

(1.15)
where $\bar{Y}_{t+1} = Y_{t+1}/\omega_{t+1}$ is the average level of output per entrepreneur. Since $E_t[\omega_{t+1}] = 1$, the expected marginal return on capital can be expressed as follows:

$$E_t R_{k,t+1} = \frac{E_t \left[ p_{wt+1} \alpha \bar{Y}_{t+1} + q_{t+1} - p_{it+1} \delta(u_{t+1}) \right]}{q_t}$$ (1.16)

The marginal cost of the capital acquired for the wholesale production is defined based on BGG-type financial accelerator framework. Since the idiosyncratic shock $\omega_t$ is private information for entrepreneurs, the lenders must pay a monitoring cost proportional to the entrepreneur’s realized gross payoff $R_{k,t+1}q_tK_{t+1}$ to observe entrepreneur’s output, if the entrepreneur defaults. The existence of an agency problem makes uncollateralized external funds more expensive than internal funds. In addition, since entrepreneurs with higher leverage ratio incur greater monitoring costs for the lenders, the external financing premium should rise. Under this setup, BGG shows that in the reduced form, the external finance premium $\chi_t(\cdot)$ is equal across all solvent entrepreneurs in equilibrium and an increasing function of the aggregate leverage ratio:

$$E_t \left[ \frac{R_{k,t+1}}{R_t} \right] = \chi_t = \chi \left( \frac{B_{t+1}}{N_{t+1}} \right)$$ (1.17)

where $\chi’(\cdot) > 0$, $\chi(0) = 0$, $\chi(\infty) = \infty$.  

$R_t$ is the gross real cost of funds in the financial market without frictions. Then, the entrepreneur’s overall marginal cost of funds is given as the product of the gross premium for external funds and the frictionless real cost of funds:

$$E_t R_{k,t+1} = \chi \left( \frac{B_{t+1}}{N_{t+1}} \right) E_t R_t$$ (1.18)

\[12\] The specific form of $\chi(\cdot)$ depends on the primitive parameters of the optimal contract problem. In the log-linearized reduced form, what matters for the dynamics is the (constant) elasticity of the external finance premium with respect to change in the aggregate leverage position of entrepreneurs, which is calibrated from the structural parameters. See the appendix of NBER working paper version of GGN for details.
The above equation relates the financial condition of the entrepreneur to the marginal cost of funds, and to the demand of capital. At the margin, the entrepreneur considers acquiring a unit of capital financed by debt. However, the additional debt raises the leverage ratio, which in turn increases the external finance premium and the overall marginal cost of funds.

The aggregate net worth of entrepreneurs is the sum of the value of surviving entrepreneurs net of borrowing costs carried over from the previous period, \( V_t \) and the managerial wage.

\[
N_{t+1} = \phi_e V_t + w^e_t \tag{1.19}
\]

where \( V_t \) is given by

\[
V_t = p_{wt}Y_t + (q_t - p_{it}\delta(u_t))K_t - w_tH_t - w^e_t H^e_t - \chi_{t-1}R_{t-1}B_t
\]

\[
= R_{k,t}q_{t-1}K_t - \chi_{t-1}R_{t-1}B_t \tag{1.20}
\]

Finally, since entrepreneurs going out of business consume their remaining resources, the aggregate consumption composite of entrepreneurs, \( C_{e,t} \) can be expressed as

\[
C_{e,t} = (1 - \phi_e)V_t \tag{1.21}
\]

The preference of entrepreneurs for domestic and foreign final goods is assumed to be identical to that of households specified in equation (1.3).

**Capital producers**

Competitive capital producers engage in the repair of depreciated capital and the construction of new capital goods. To repair the depreciated capital, producers
require $\delta(u_t)K_t$ units of the investment good, which may be purchased at a cost of $p_{it}\delta(u_t)K_t$. As explained previously, this cost is borne by entrepreneurs who own the capital stock. For new capital goods, each capital producers operates a constant-returns-to-scale technology $\Xi(\cdot)$. In the steady state, $\Xi(0) = 0$ and $\Xi'(0) = 0$. The economy-wide capital accumulation equation is

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

(1.22)

An investment good for capital good production is composed of domestic and foreign final goods:

$$I_t = \left[\gamma_i \frac{1}{\rho_i} \left(I_t^H\right)^{\rho_i-1} + (1 - \gamma_i) \frac{1}{\rho_i} \left(I_t^F\right)^{\rho_i-1}\right]^{\frac{\rho_i}{\rho_i-1}}$$

(1.23)

The production parameter $\gamma_i$ measures the relative weight that domestic and foreign inputs receive in the investment composite. The nominal investment price index, $P_{it}$ is given by

$$P_{it} = \left[\gamma_i (P_t^H)^{1-\rho_i} + (1 - \gamma_i) (P_t^F)^{1-\rho_i}\right]^{\frac{1}{1-\rho_i}}$$

(1.24)

To capture the delayed response of investment$^{13}$, we assume that capital producers make their plans to produce new capital one period in advance. From the capital producers’ decision problem, the optimality condition for net investment satisfies

$$E_{t-1} \left[ q_t \Xi'\left(\frac{I_t - \delta(u_t)K_t}{K_t}\right) - p_{it} \right] = 0$$

(1.25)

**Retailers**

A continuum of monopolistically competitive retailers buy the wholesale goods from entrepreneurs and produce differentiated final products with a fixed resource

$^{13}$As shown by BGG, investment delays contribute to generating the hump-shaped response of output.
cost which captures distribution costs and marketing efforts. Let $Y^H_t(z)$ be the good sold by retailer $z$. Final domestic output is

$$Y^H_t = \left[ \int Y^H_t(z) \frac{e^{-\theta z}}{\pi} dz \right]^{\frac{\beta}{\beta - 1}} - \kappa$$ (1.26)

where $\kappa$ is the fixed resource cost. The fixed cost is assumed to be proportional to the steady state value of wholesale output such that the profits to the retailer sector are zero in the steady state. These CES aggregates are converted into consumption and investment goods and the aggregate price levels are defined accordingly.

As the source of nominal stickiness in the economy, the retailers set nominal prices on the Calvo-style staggered basis. With probability $1 - \theta$, the retailers reset their prices to the optimal price. Otherwise, they keep their prices unchanged. Within the neighborhood of a zero-inflation steady state, the gross inflation rate for domestically produced goods is

$$\frac{P^H_t}{P^H_{t-1}} = \left( \frac{P^H_{wt}}{P^H_t} \right)^\lambda E_t \left( \frac{P^H_{t+1}}{P^H_t} \right)^\beta$$ (1.27)

where $\lambda = \frac{1 - \theta(1 - \theta)}{\beta}$. $\mu = 1/(1 - (1/\beta))$ is the retailers’ desired gross mark-up over wholesale prices. This Phillips curve relates inflation to movements in real marginal cost and expected inflation.

Retailers in the import sector also operate in a monopolistic manner. They purchase foreign wholesale goods for which the law of one price holds and then differentiate them into imported final goods. Let $P^F_{wt}$ denote the wholesale price of foreign goods in domestic currency, and $P^F_t$ the foreign currency price of such goods. The law of one price implies

$$P^F_{wt} = S_t P^F_t \tag{1.28}$$
In order to generate incomplete exchange rate pass-through, retailers in the import sector are also assumed to face an exogenous probability of \(1 - \theta_f\) each period to reoptimize prices. The gross inflation rate of foreign final goods is

\[
\frac{P_t^F}{P_{t-1}^F} = \left( \mu_f \frac{S_t P_t^{F*}}{P^F_t} \right)^{\lambda_f} E_t \left( \frac{P_{t+1}^F}{P_t^F} \right)^{\beta}
\]  

(1.29)

where \(\lambda_f = \frac{(1-\theta_f)(1-\beta_f)}{\theta_f}\).

Equation (1.27) and (1.29) implies that the gross inflation rate CPI is

\[
\frac{P_t}{P_{t-1}} = \left( \frac{P_t^H}{P_{t-1}^H} \right)^{\gamma} \left( \frac{P_t^F}{P_{t-1}^F} \right)^{1-\gamma}
\]  

(1.30)

### 1.3.3 Banking sector

Banks are risk-neutral and owned by households. With probability \(\phi_b\), each bank will survive until next period. The population of the banking sector is also stationary with new banks entering the banking sector to replace those who exit. The exiting banks transfer retained earnings back to the household as a dividend, while the small fraction will be redistributed to the new entrants as a start-up fund.

At the end of period \(t\), the real bank loan \(B_{t+1}\) is financed with the banker’s real net worth \(N_{b,t+1}\), the deposits from households, \(D_{t+1}\) and the foreign-currency deposits \(B_{t+1}^f\).

\[
B_{t+1} = N_{b,t+1} + D_{t+1} + e_t B_{t+1}^f
\]

\[
= N_{b,t+1} + D_{t+1} + e_t (B_{p,t+1}^f + B_{g,t+1}^f)
\]  

(1.31)

where \(e_t\) denotes the real exchange rate. The foreign-currency deposits consist of the debt issued in international financial market, \(B_{p,t+1}^f\) and the central bank deposits, \(B_{g,t+1}^f\). Figure 1.4 describes the balance sheet of entrepreneurs and bankers at the end of period \(t\).
The cost that bank bears on its liabilities is the domestic-currency deposit rate, \( R_t \), the foreign-currency deposit rate for the central bank \( R^f_t \), and the borrowing rate from the international market, \( \Psi_t R^f_t \). \( \Psi_t \) is the country risk premium and assumed to follow the stochastic process

\[
\Psi_t = \Psi^\zeta_{t-1} \left( \frac{e_t B_{p,t+1}}{N_{b,t+1}} \right)^\eta \varepsilon_t
\]

where \( \zeta \) represents the persistence of the country risk premium.\(^{14}\) Following the chained credit contracts of Ueda(2012), \( \eta \) controls the sensitivity of country risk premium to the level of foreign borrowing and changes in real exchange rate. \( \varepsilon_t \), which follows AR(1) process, is an exogenous shock in the country risk premium.

The domestic and foreign gross real interest rates are related in conjunction with the uncovered real interest parity condition by

\[
E_t\{R_t\} = E_t\{\Psi_t R^f_t e_{t+1} / e_t\}
\]

\(^{14}\)Neumeyer and Perri(2005) and Uribe and Yue(2006) both empirically show that the process for country risk premium in emerging economies is persistent.
Thus, at the end of time \( t \), the net equity in the banking sector can be the difference between earnings on loans to entrepreneurs and interest payments on liabilities, the deposit transaction receipts from households and a start-up fund.

\[
N_{b,t+1} = \phi_b [x_{t-1}R_{t-1}B_t - \left( R_{t-1}D_t + R_{t-1}^f \Psi_{t-1}e_{t-1}B_{p,t}^f + R_{t-1}^f e_{t-1}B_{g,t}^f \right)
+ \frac{\Theta}{2} (\bar{D} - D_t)^2] + \tau B_t
\]

(1.34)

1.3.4 Rest of the world

Following Gali and Monacelli(2005), goods produced in the small economy represent a negligible fraction of the world’s consumption basket and the rest of the world can be treated as an approximately closed economy, which implies \( P_t^F = P_t^* \) where \( P_t^* \) represents the exogenous consumer price index in the rest of the world. We assume that a demand for the domestic final good is given by

\[
C_t^{H*} = \left[ \left( \frac{P_t^{H*}}{P_t^*} \right)^{-\kappa} Y_t^* \right]^\psi \left( (C_t^{H*})^{1-\psi} \right)
\]

(1.35)

where \( 0 < \psi < 1 \) and \( \kappa > 0 \). \( Y_t^* \) is real foreign output. For simplicity, \( Y_t^* \) is assumed to be exogenously given and follow AR(1) process.

1.3.5 Government

The government is a single entity composed by the Treasury and the central bank. Together, they control fiscal policy and determine monetary and exchange rate policy. They also conduct credit policy by supplying the domestic banks with foreign-currency liquidity in response to the country risk premium.
Fiscal Policy. The government pursues a balanced budget policy by adjusting lump-sum tax to equal the expenditure.

\[
\frac{P_t^{\text{H}}}{P_t} G_t^{\text{H}} = T_t
\]  

(1.36)

where the government expenditure evolves exogenously as an AR(1) process and goes exclusively on domestic goods.

Monetary Policy and Exchange Rate Regimes. I consider a pure fixed exchange rate regime and a floating exchange rate regime, where the central bank manages the nominal interest rate according to a Taylor rule.

Under the fixed exchange rate regime, the central bank keeps the nominal exchange rate, \( S_t \) pegged at a predetermined level,

\[
S_t = \bar{S}
\]  

(1.37)

By doing so, the central bank sets the interest rate to satisfy the uncovered interest parity condition given by (1.33).

Under the flexible exchange rate regime, the central bank adopts a feedback rule that has the nominal interest rate, \( R_{n,t} \), adjust to CPI inflation and domestic output.

\[
\frac{R_{n,t}}{R_{ss}} = \left( \frac{P_t}{P_{t-1}} \right)^{\gamma_\pi} \left( \frac{Y_t^{\text{H}}}{Y_{ss}^{\text{H}}} \right)^{\gamma_y}
\]  

(1.38)

where \( \gamma_\pi > 1 \) and \( \gamma_y > 0 \). \( R_{ss} \) and \( Y_{ss}^{\text{H}} \) are the steady state values of the gross real interest rate and output.

Credit Policy and International Reserves. The government is assumed to fund a fraction \( \Phi_t \) of foreign-currency deposits in the banking sector.

\[
B_{t+1}^f = \Phi_t B_{t+1}^f
\]  

(1.39)
Following Gertler and Karadi(2011), the credit policy of the government is to determine the fraction \( \Phi_t \) in response to the country risk premium as follows

\[
\Phi_t = \Phi_{ss} + v(I)[\Psi_t - \Psi_{ss}]
\]

(1.40)

\[
v(I) = \begin{cases} 
  v_{Fix} & \text{if } I = \text{fixed regime}, \\
  v_{Float} & \text{if } I = \text{floating regime} 
\end{cases}
\]

(1.41)

where \( \Phi_{ss} \) is the steady state fraction of government deposits and \( \Psi_{ss} \) the steady state country risk premium. By taking \( v_{Fix} > v_{Float} > 0 \), the credit policy under the fixed exchange rate regime is assumed to expand foreign-currency credit more aggressively but the central bank will loosen the credit policy after the regime shift in order to describe the different intensities in the credit policy of the Korean central bank, as mentioned in the previous section.

The foreign-currency liquidity is supplied out of international reserves.

\[
FA_{t+1} = R_{t-1}^f (FA_t + B_{g,t}^f) - B_{g,t+1}^f - \varpi, \quad FA_t \geq 0
\]

(1.42)

where \( \varpi \) is the management cost of international reserves. We choose the level of the management cost so that the international reserves are stationary in steady-state.

**Regime switching.** The benchmark case is that the central bank initially maintains the fixed exchange rate regime. If the external shock raises the country risk premium, the central bank increases the fraction of their deposits in the banking sector by replacing the foreign-currency borrowing from international financial market. However, if the international reserves are expected to be exhausted in the next period due to the credit policy, they are forced to switch to the floating exchange rate regime. In addition, the central bank will loosen the credit policy.
1.3.6 Resource constraint

The resource constraint for the domestic economy is

\[ Y_t^H = C_t^H + C_t^{eH} + I_t^H + G_t^H + C_t^{H*} + \Gamma_t \]  \hspace{1cm} (1.43)

where \( Y_t^H \) is the final domestic output net of fixed costs, \( G_t^H \) government consumption and \( C_t^{eH} \) entrepreneur consumption of the domestic good. \( \Gamma_t \) reflects aggregate monitoring costs for BGG-type optimal contract, which is negligible under realistic parameter values.

The balance of payment accounting identity (in the home-currency) is given as

\[ C_t^{H*} - \varepsilon_t(C_t^F + I_t^F + C_t^{eF}) = \varepsilon_t(R_{t-1}^F \Psi_{t-1} B_{p,t}^F - B_{p,t+1}^F) + \varepsilon_t(FA_{t+1} - R_{t-1}^F FA_t) \]  \hspace{1cm} (1.44)

where the left-hand side is the trade surplus and the right-hand side is change in foreign debt position and international reserves.

1.4 Crisis experiment

1.4.1 Solution method and parameterization

The only exogenous shock in the model is an unanticipated increase in the innovation in country risk premium, \( \varepsilon \) in equation (1.32). As in GGN, Braggion, Christiano, and Roldos(2009) and Martins and Salles(2010), the crisis experiment is studied under perfect foresight. To solve for the dynamic equilibrium, I start from the fixed exchange rate regime and check whether \( FA_{t+1} \geq 0 \) as of the beginning of \( t \). If the international reserves are expected to be below zero in the next period, the regime switching takes place irrevocably.

The chosen parameter values are reported in Table 1.2. I follow the values of structural parameters generally accepted in the macroeconomics and open-economy
literature. The financial stocks at the steady state follow the Korean data before the crisis. A time frequency is one quarter of a year.

Preferences. The discount factor is set to give an annual real interest rate of 4%. At the steady-state, households are assumed to devote 1/3 of their time endowment to work and $\varsigma$ is chosen accordingly. The elasticity of substitution between domestic and foreign consumption, $\rho$ is taken as 1. The share of domestic goods in the consumption composite, $\gamma$ is 0.5. For the export demand, I set $\kappa$ and $\psi$ to 1 and 0.25 respectively. Following Aydin and Volkan(2011), the deposit transaction fee coefficient $\Theta$ is equal to 0.00074.

Production. As in GGN, I set the capital share, $\alpha$ equal to 0.5. The elasticity of substitution between domestic and foreign investment, $\rho_i$ is set 0.25. The share of domestic goods in the investment composite, $\gamma_i$ is also 0.5. The share of entrepreneurial labor, $\Omega$ is 0.01. While the steady state capital utilization rate is normalized at 1, the steady state quarterly depreciation rate, $\delta(u_{ss})$ is 0.025. In the functional form of depreciation, $\xi$ is 1 and $b$ is derived as a result. The steady state mark-up value, $\mu$ is 1.2. The fixed resource cost, $\kappa$ is assumed to be 20% of wholesale output. While the functional form of investment good technology, $\Xi(\cdot)$ is implicit, the elasticity of the price of capital with respect to the investment-capital ratio is taken to be 2. The probability of the price not adjusting, $\theta$ is 0.75. The entrepreneur and banker’s death rate are both 0.025. As in BGG, the idiosyncratic productivity variable, $\omega_i$ is log-normally distributed with variance equal to 0.28. From the calibration of the optimal financial contract in BGG and GGN, the elasticity of external finance premium
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.99</td>
<td>discount factor</td>
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<tr>
<td>$\rho$</td>
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<td>elasticity of consumption substitution</td>
</tr>
<tr>
<td>$\gamma$</td>
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<td>share of domestic goods in consumption composite</td>
</tr>
<tr>
<td>$H$</td>
<td>1/3</td>
<td>steady-state hours worked</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>1</td>
<td>elasticity of export demand</td>
</tr>
<tr>
<td>$\psi$</td>
<td>0.25</td>
<td>weight of inertia in export demand</td>
</tr>
<tr>
<td>$\Theta$</td>
<td>0.00074</td>
<td>deposit transaction fee</td>
</tr>
<tr>
<td>$C_{H^s}/Y^H$</td>
<td>0.40</td>
<td>steady-state share of export to output</td>
</tr>
<tr>
<td>$\rho_i$</td>
<td>0.25</td>
<td>elasticity of investment substitution</td>
</tr>
<tr>
<td>$\gamma_i$</td>
<td>0.50</td>
<td>share of domestic goods in investment composite</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.50</td>
<td>share of capital in production</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>0.01</td>
<td>share of entrepreneurial labor</td>
</tr>
<tr>
<td>$u_{ss}$</td>
<td>1</td>
<td>steady-state share of utilization rate</td>
</tr>
<tr>
<td>$\delta_{ss}$</td>
<td>0.025</td>
<td>steady-state share of (quarterly) depreciation rate</td>
</tr>
<tr>
<td>$\mu$</td>
<td>1.2</td>
<td>steady-state markup</td>
</tr>
<tr>
<td>$\kappa$</td>
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<td>steady-state fixed costs</td>
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<td>$\theta$</td>
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<td>probability of price non-adjustment</td>
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<td>elasticity of marginal depreciation with respect to utilization rate</td>
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<tr>
<td>$\eta_x$</td>
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<td>elasticity of the price of capital with respect to investment-capital ratio</td>
</tr>
<tr>
<td>$\phi_e$</td>
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<td>entrepreneur’s survival rate</td>
</tr>
<tr>
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<td>steady-state country risk premium</td>
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<td>$P/N_b$</td>
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<td>steady-state loan-to-equity ratio</td>
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<tr>
<td>$D/N_b$</td>
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<td>steady-state deposit-to-equity ratio</td>
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<tr>
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<td>elasticity of country risk premium with respect to foreign debt</td>
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<td>bank’s survival rate</td>
</tr>
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<td>share of exiting banks’ assets transferred to new banks</td>
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<tr>
<td>$\zeta$</td>
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<td>weight of inertia in country risk premium</td>
</tr>
<tr>
<td>$\Phi_{ss}$</td>
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<td>steady-state fraction of government deposit at the bank</td>
</tr>
<tr>
<td>$\gamma_x$</td>
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<td>Taylor rule coefficient on inflation</td>
</tr>
<tr>
<td>$\gamma_y$</td>
<td>0.75</td>
<td>Taylor rule coefficient on output</td>
</tr>
<tr>
<td>$\varpi$</td>
<td>0.0273</td>
<td>steady-state management cost of reserve assets</td>
</tr>
<tr>
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<td>credit policy coefficient under fixed exchange rate regime</td>
</tr>
<tr>
<td>$u_{Float}$</td>
<td>5</td>
<td>credit policy coefficient under floating exchange rate regime</td>
</tr>
</tbody>
</table>

Table 1.2: Parameters
with respect to leverage, and the steady-state leverage ratio are derived based on the values of production parameters.\footnote{See the NBER working paper version of GGN for details.}

*Banking Sector.* The steady state country risk premium, 30 b.p. is the average level of Korea in 1996. The steady state loan-to-equity ratio and deposit-to-equity ratio are 15.33 and 10.31. Both are based on the data of Korean banking sector at the end of 1996. The elasticity of country risk premium comes from GGN. Its persistence parameter value, 0.62 is based on the estimated result of Otsu(2008) using the Korean data. This value is also close to Sarquis(2010) for the Brazilian data and Neumeyer and Perri(2005). Following Gertler and Karadi(2011), the share of exiting banks’ assets transferred to new banks is set 0.002.

*Government policy.* The steady state share of central bank’s deposits at domestic banks is 1/3 which is close to 37% as of the end of 1996 in Korea. I set the Taylor rule coefficients on CPI inflation and output 2 and 0.75 respectively. While Gertler and Karadi(2011) and Gertler and Kiyotaki(2010) offer little explanation on the feedback coefficient of credit policy, $v_{Fix}$ and $v_{Float}$ are taken as 40 and 5 respectively, because they generate the realistic responses of international reserves and the government deposit at domestic banks as discussed in the next subsection. This benchmark case will be compared with the case of $v$ initially set to be 5.

### 1.4.2 Crisis experiment

A crisis in the model begins with a large shock to the exogenous country risk premium. This shock produces a reversal on the foreign credit supply by making
foreign borrowing more costly. I assume that the initial shock to the country risk premium is 280 b.p. which is close to the average size of short-term borrowing spread for Korean commercial banks in November and December, 1997.\textsuperscript{16}

In the wake of the shock, the foreign-currency deposits of the central bank at commercial banks replace the foreign borrowing and the international reserves decline as a result, as shown in Figure 1.5. The international reserves are expected to be below 100\% of the steady-state level in the third period, which means that reserve assets will be completely exhausted. Thus, the government is forced to abandon the fixed regime and shift to the floating regime before the depletion of international reserves becomes realized. After the regime shift, the central bank loosens credit policy and actually starts to withdraw the foreign-currency deposits held in the commercial banks and accumulate international reserves. Consistent with the data, the international

\textsuperscript{16}GKN considers 500 b.p. increase in the country risk premium. Since their model assumes that the debt is solely financed by (home-currency denominated) domestic deposits, they needed greater shocks to have a realistic impact on aggregate variables.
reserves and the central bank’s deposits both become close to the original level in one quarter.

Now, Figure 1.6 shows the impulse response of output, consumption, investment, net exports, inflation and real exchange rate in comparison with the data. Following the increase in the country risk premium, the domestic real interest rate rises through the interest parity condition. The financial accelerator magnifies the contractions in the aggregate variables. The model does well at capturing the drops in output and consumption in Korea over the crisis period. The Korean real GDP was down by 8% in the second quarter of 1998 and the model generates similar reduction in output. In the data, consumption falls by roughly 12% in the peak, while the model implies a roughly 7% decrease. On the contrary, the actual drop in investment is larger than the model’s response. In the data, investment experienced a 40% contraction in the first quarter of 1998, before falling another 10% in the subsequent quarter. However, the model generates approximately 60% of actual contraction. The model predictions of net export and CPI inflation both are well matched with the data for the initial phase, even though the data quickly revert to the trend. Finally, the model couldn’t generate the real depreciation similar to the data, but still accounts for half of real depreciation, which significantly improves the original result of GGN with smaller degree of shock.

17The data series of output(real GDP), consumption(real private consumption), investment(real gross capital formation) and real exchange rate are shown on a log scale and are detrended by H-P filter. Net export is relative to GDP. CPI inflation is annualized. All these data are from International Financial Statistics(IFS) of IMF and Economic Statistics System(ECOS) of the Bank of Korea.

18Cho and Doblas-Madrid(2011) use business cycle accounting to show that investment plays an important role in the East Asian crisis, which differs distinctively from the Latin American crises.
Figure 1.6: Korean crisis experiment (b)
1.4.3 Counterfactual experiment

During the investigation by the National Assembly in 1999, there was a controversy on whether the intervention in the foreign exchange market and the bail-out for the financially distressed banks exacerbated the burden of the currency crisis. Critics argued that the arbitrary intervention and heavy bail-out only wasted the international reserves and hastened the crisis.\textsuperscript{19} To provide insight into this debate, the two scenarios are compared. The first case is the benchmark and the second one is sticking to the fixed regime by conservative foreign-currency credit policy. In the benchmark case shown in the previous subsection, the feedback parameter of credit policy, $v$ is 40 under the fixed exchange rate regime and switched to 5 under the floating exchange rate regime. In the alternative case, the feedback parameter is initially set to 5 at the beginning and this value is maintained since there are no depletion of international reserves and no resulting regime switching under this scenario, even after the same shock arrives.

Figure 1.7 compares the impulse responses to aggregate variables by different scenarios. The conservative credit policy described by the alternative scenario does not deliver the regime switching but its impulse response shows that the contraction of output, consumption and investment prolonged while maintaining the fixed regime, so sticking to the fixed exchange rate regime is suboptimal.

The better outcome under floating exchange rate regime is attributable to the accommodative monetary policy and shock-absorbing effect of exchange rates. On

\textsuperscript{19}The official report by the special investigation commission also reflects this view. (See pp.196-197 of National Assembly of Korea (1999).)
Figure 1.7: Credit policy experiment
the contrary, without a sufficient real depreciation and the independence of monetary policy, the fixed exchange rate regime cannot cushion the negative effect of the shock, which causes a larger decline in domestic absorption and a larger trade surplus under pegs than under floats. This results is consistent with theoretical results of GGN, Céspedes, Chang, and Velasco(2004) and Devereux, Lane and Xu(2006), which argue that in response to the world interest rate shock, floating exchange rate regime is superior to the fixed one for small open economies in terms of welfare.\textsuperscript{20} It is also empirically supported by Hoffman(2007) which uses a panel vector autoregression(PVAR) to show that the recession driven by the adverse world interest rate shock is more pronounced under fixed exchange rates than floats.

1.5 Conclusion

In this chapter, I study the process of exchange rate regime shifts during sudden stops in a small open economy, using the policy papers by the Bank of Korea to suggest the actual decision-making process within a central bank. Despite the recently popular modelling assumption that a central bank optimally chooses to abandon the fixed regime, the Bank of Korea’s case suggests that the conventional exit rule - the regime is abandoned if the reserve assets are exhausted, is more descriptive and that the official foreign reserves during sudden stops in emerging economies may be overestimated, due to the lack of transparency.

I also develop a small open economy model with the credit policy of a central bank to support domestic banks in need of foreign currency liquidity. In the model, a crisis

\textsuperscript{20}However, Choi and Cook(2004) derive the opposite conclusion under full liability dollarization by comparing the fixed exchange rate regime keeping traded goods inflation constant with the floating exchange rate regime aiming the stabilization of non-traded goods inflation.
begins with a large shock to the country risk premium under the fixed exchange rate regime. If foreign reserve assets are expected to be depleted as a result of the credit policy, the central bank is forced to switch to the floating exchange rate regime before reserve assets are exhausted. This model does well at capturing the regime switching in the Korean crisis and the observed drop in aggregate variables.
Chapter 2: Invoicing Currency and State-Dependent Pricing

2.1 Introduction

In open-economy macroeconomic models with nominal price rigidities, the role of invoicing currency has been extensively studied due to its importance on the international transmission mechanism of monetary policy. In this class of models, there are two standard price-setting regimes for exporters: producer currency pricing (PCP) and local currency pricing (LCP). Under PCP, exporters set prices in their own currency.\(^\text{21}\) In this price setting, the law of one price holds for traded goods, so the foreign price of home exports moves one-to-one with nominal exchange rate. Under LCP, however, price-discriminating firms set prices in the consumer’s currency.\(^\text{22}\) Then, with realistic nominal price rigidities, prices of imports respond slowly to exchange rate changes. This specification is more in accord with the empirical evidences of incomplete pass-through of exchange rate to consumer prices and substantial deviations from the law of one price.\(^\text{23}\)

\(^{21}\)See Obstfeld and Rogoff(2000) and Clarida, Gali and Gertler(2002) for early contributions.

\(^{22}\)See Betts and Devereux(2000) and Chari, Kehoe and McGrattan(2002). Devereux and Engel(2003) consider the both cases and concludes that the degree to which an optimal monetary policy requires a flexible exchange rate depends on invoicing currency.

\(^{23}\)See, for instance, Campa and Goldberg(2005) and Gopinath and Rigobon(2008).
While many open-economy macro models assume the symmetric PCP and LCP in trade between countries, recent literature on the invoicing currency provides us with the different perspectives. First, Gopinath and Rigobon(2008) and Goldberg and Tille(2008) report that U.S. imports and exports are heavily invoiced in U.S. dollar and emerging economies use U.S. dollar as the vehicle currency in their international trade.\textsuperscript{24} Thus, empirical data suggest \textit{asymmetric currency pricing}(ACP) for U.S. trade is appropriate: while the U.S. follows PCP, its trade counterparts follow LCP. Second, a series of Dotsey and Duarte(2008 and 2009) show that pricing regimes do not matter, because the two polar invoicing regimes generate similar aggregate response, despite the difference in innate mechanism.

In this chapter, I consider the implications of different invoicing currency assumptions in a quantitative two-country model. The model features state-dependent pricing(SDP): firms will adjust their prices when doing so is more valuable. In particular, the framework used in this chapter is the two-country dynamic stochastic general equilibrium(DSGE) model of Landry(2010) which extends Dotsey, King and Wolman(1999)(hereafter, “DKW”) and Dotsey and King(2005)(hereafter, “DK”) into an open economy setting.

The impulse response analysis based on the parameter values of U.S. and Canada, shows that under asymmetric invoicing currency, the U.S. aggregate variables respond to a monetary expansion in the quantitatively analogous way to LCP, because the slow exchange rate pass-through plays a substantial role in the business cycles of both

\textsuperscript{24}From the micro data collected by the Bureau of Labor Statistics(BLS), Gopinath and Rigobon(2008) reports that 90% of U.S. imports and 97% of U.S. exports are priced in U.S. dollars. Using the official statistics in each country, Goldberg and Tille(2008) documents that more than 80% of export and import in Korea and Thailand are invoiced in dollar. Likewise, according to the survey results of Bernard(2008), Chinese textile and apparel sectors extensively use dollar, even though the U.S. only corresponds to roughly a quarter of their export destinations.
pricing regimes. However, this chapter still demonstrates the importance of invoicing currency in SDP. I contrast the SDP model’s responses with those from a TDP model which is identical for, except the exogenous timing of price adjustment. Except trade balance, the TDP model shows little difference in the aggregate responses across pricing regimes like Dotsey and Duarte(2009) which is also based on TDP. However, the SDP makes the aggregate responses in PCP quantitatively different from those in LCP and ACP. While the full exchange rate pass-through in PCP contributes to higher prices under both SDP and TDP, the absence of the extensive margin in TDP prevents making a difference at the aggregate level.

This chapter is related to the literature with respect to the asymmetric currency invoicing. Based on the one-period predetermined price setting, Devereux, Shi and Xu(2006) and Goldberg and Tille(2009) analyze the equilibrium condition of ‘dollar standard’ in international trade and welfare implications. Bhattarai(2009) also considers this type of currency invoicing. From Calvo pricing, he shows that asymmetric invoicing currency can arise as an equilibrium even between the two symmetric countries and the asymmetric equilibrium is more likely when the country using PCP has a larger market share. While the aforementioned papers mainly focus on the equilibrium conditions and assume the exogenous timing of price adjustments, this chapter discusses the implication of different pricing regimes on the business cycle transmission following monetary expansion and emphasizes the role of SDP in it. Even some papers consider endogenous invoicing currency. In Floden and Wilander(2006) and Gopinath, Itskhoki, and Rigobon(2009), firms choose to adjust their prices and currency choice simultaneously. But, these models are partial equilibrium where firm’s decision-making is driven by productivity or exchange rate shocks. Midrigan(2007)
uses a two-country DSGE framework with a fixed menu cost under PCP, but the primary goal of his paper is to analyze the relationship between real and nominal exchange rate volatility.

The rest of this chapter is organized as follows. In the next section, I present the SDP model of Landry(2010) and consider the different pricing regimes. In section 2.3, data source and parameter values will be provided. In section 2.4, I compare the results from different pricing regimes and also present the results from TDP. I conclude this chapter in section 2.5.

2.2 State-dependent pricing model

The SDP model in this chapter is based on Landry(2010) which extends DKW and DK into the two-country setting. While his model follows local currency pricing, I also consider the two other cases of the producer currency pricing and asymmetric currency pricing.

In the model, each country is populated by a representative household, a continuum of monopolistically competitive firms selling final goods and a monetary authority. Following DKW, firms are subject to stochastic menu costs of adjusting their prices. A variable demand elasticity suggested by Kimball(1995) is introduced to make it more costly for price-adjusting firms to deviate their prices from the prices set by other firms.

When three subscripts are present in this section, the first denotes the location of production, the second denotes the location of consumption or investment and the third denotes time.
2.2.1 Underlying monopolistic competition setting

Households

A representative household in each country \( i \) makes consumption \( c_{i,t} \) and labor \( n_{i,t} \) decisions to maximize expected lifetime utility

\[
\max_{c_{i,t}, n_{i,t}} E_0 \sum_{t=0}^{\infty} \beta^t U(c_{i,t}, n_{i,t}), \text{ for } i = 1, 2
\]

(2.1)

where \( U(c, n) = \log c - \chi n \). This specification follows Hansen(1985) and Rogerson (1988) by assuming indivisible labor decisions implemented with lotteries. The parameter \( \beta \) represents the discount factor and \( \sigma \) the intertemporal elasticity of substitution.

Aggregate consumption is defined as a constant elasticity of substitution(CES) composite of domestic and imported consumption

\[
c_{i,t} = \left[ (1 - \theta_i)^{\frac{\gamma}{\gamma-1}} c_{i,i,t} + \theta_i^{\frac{\gamma}{\gamma-1}} c_{j,i,t} \right]^{\frac{\gamma-1}{\gamma}}, \text{ for } i, j = 1, 2 \text{ and } i \neq j
\]

(2.2)

The coefficient \( \theta_i \) measures the degree of home bias in consumption, while \( \gamma \) denotes the elasticity of substitution between domestically produced goods \( c_{i,i,t} \) and imported foreign goods \( c_{j,i,t} \).

Households also choose an optimal amount of capital through its choices of investment \( i_{i,t} \). Investment decisions are made as the following equation

\[
k_{i,t+1} = (1 - \delta(x_{i,t}))k_{i,t} + \phi \left( \frac{i_{i,t}}{k_{i,t}} \right) k_{i,t}, \text{ for } i = 1, 2
\]

(2.3)

where \( k_{i,t} \) denotes the capital stock, \( \delta(\cdot) \) the depreciation function with \( \delta' > 0 \) and \( \delta'' < 0 \), \( x_{i,t} \) the utilization rates of capital and \( \phi(\cdot) \) the capital adjustment cost with

\[\text{25 Following Christiano, Eichenbaum and Evans(2005), the assumption that households make the capital accumulation and utilization decisions is a matter of convenience.}\]
\( \phi' > 0 \) and \( \phi'' < 0 \). The household’s investment allocations are identical to the consumption allocations (2.2).

Aggregate consumption and investment prices are a weighted sum of domestic and imported goods prices

\[
\begin{align*}
P^c_{1,t} & = P^I_{1,t} = [(1 - \theta_1)(P^p_{1,1,t})^{1-\gamma} + \theta_1(P^p_{2,1,t})^{1-\gamma}]^{\frac{1}{1-\gamma}} \\
P^c_{2,t} & = P^I_{2,t} = [(1 - \theta_2)(P^p_{2,2,t})^{1-\gamma} + \theta_2(P^p_{1,2,t})^{1-\gamma}]^{\frac{1}{1-\gamma}}
\end{align*}
\tag{2.4}
\]

where aggregate producer prices, \( P^p_{1,1,t}, P^p_{2,1,t}, P^p_{2,2,t}, P^p_{1,2,t} \) will be defined later.

In this economy, the asset structure is represented by complete, contingent, one-period nominal bonds \( b_{i,t} \) denominated in the home currency. Let \( D_t \) the stochastic discount factor such that

\[
E_t(D_{t+1}b_{i,t+1}) = \sum_{s_{t+1}} \mu(s_{t+1}|s_t)D(s_{t+1}|s_t)b_i(s_{t+1})
\]

where \( \mu(s_{t+1}|s_t) \) denotes the probability of the state of nature \( s_{t+1} \) given \( s_t \). The households also receive capital payments \( Q_{i,t} \) from capital services, nominal wages \( W_{i,t} \) from labor services and dividend payments \( Z_{i,t} \) from firms. For simplicity, the claims to the ownership of firms in each country are held by the households of that country and cannot be traded across the border. The sequence of intertemporal budget constraints can be represented in terms of aggregates as

\[
P^c_{i,t}c_{i,t} + P^I_{i,t}i_{i,t} + E_t(D_{t+1}b_{i,t+1}) \leq b_{i,t} + Q_{i,t}k_{i,t}x_{i,t} + W_{i,t}n_{i,t} + Z_{i,t}, \quad \text{for } i = 1, 2 \tag{2.5}
\]

The problem for households is to choose consumption, investment, labor and portfolio holdings to maximize lifetime utility (2.1) subject to a sequence of intertemporal budget constraints (2.5). Defining the real exchange rate as \( q_t = S_t(P^c_{2,t}/P^c_{1,t}) \), where the nominal exchange rate, \( S_t \) is the dollar price of one unit of foreign currency, we obtain

\[
q_t = \kappa \frac{\lambda_{2,t}}{\lambda_{1,t}} \tag{2.6}
\]

40
from the maximization problem. In (2.6), \( \lambda_{i,t} \) denotes the marginal utility of consumption and \( \kappa \) reflects initial wealth differences.\(^{26}\)

The level of nominal aggregate demand must be equal to the money supply

\[
M_{i,t} = P_{i,t}^c c_{i,t} + P_{i,t}^f i_{i,t}, \text{ for } i = 1, 2
\]

Following Chari, Kehoe and McGrattan(2002), the money supply growth is assumed to be exogenous and follows an autoregressive process of the form

\[
\Delta M_{i,t} = \omega_i \Delta M_{i,t-1} + \varepsilon_{i,t}, \text{ for } i = 1, 2
\]

where \( \omega_i \) represents the coefficients of autocorrelation and \( \varepsilon_{i,t} \) are i.i.d. zero-mean disturbances.

**Variable demand elasticity**

Following the work of Kimball(1995), a variable demand elasticity is introduced. In contrast to a constant elasticity demand, firms facing a variable demand elasticity, have a strong incentive not to deviate from other firms’ prices.

Consider the following expenditure minimization problem of DK for each country

\[
\min_{d_{i,j,t}(z)} \int P_{i,j,t}(z)d_{i,j,t}(z)dz \text{ subject to } \int \Gamma(\frac{d_{i,j,t}(z)}{d_{i,j,t}}; \varphi, \rho)dz = 1, \text{ for } i, j = 1, 2
\]

where

\[
\Gamma(\frac{d_{i,j,t}(z)}{d_{i,j,t}}) = \frac{1}{(1 + \varphi)^\rho} \left[ (1 + \varphi)(\frac{d_{i,j,t}(z)}{d_{i,j,t}}) - \varphi \right]^\rho + \left[ 1 - \frac{1}{(1 + \varphi)^\rho} \right]
\]

In these equations, \( d_{i,j,t} \) denotes the demand for goods produced in country \( i \) and purchased in country \( j \). A continuum of monopolistically competitive firms produce

\(^{26}\)See Chari, Kehoe and McGrattan(2002) for the details.
differentiated products indexed by \( z \). In the demand aggregator \( \Gamma \), the parameter \( \varphi \) determines the curvature of the demand function, while \( \rho \) determines the elasticity of demand at average product prices.

The demand aggregator defines firm’s relative demand as a function of relative prices and the curvature parameters

\[
\frac{d_{i,j,t}(z)}{d_{i,j,t}} = \frac{1}{(1 + \varphi)} \left[ \left( \frac{P_{i,j,t}(z) P_{i,j,t}^P}{\Psi} \right)^{1/(\rho-1)} + \varphi \right], \text{ for } i, j = 1, 2 \tag{2.11}
\]

where the Lagrange multiplier is given by \( \Psi_{i,j,t} = \left[ \int \frac{P_{i,j,t}(z) P_{i,j,t}^P}{\Psi} dz \right]^{(\rho-1)/\rho} \). Then, the aggregate producer prices are defined by

\[
P_{i,j,t}^P = \int P_{i,j,t}(z) \frac{d_{i,j,t}(z)}{d_{i,j,t}} dz, \text{ for } i, j = 1, 2 \tag{2.12}
\]

**Firms**

At any date \( t \), a firm is identified by its current price \( P_{i,j,t}(z) \) and its current menu cost \( \xi_{i,t}(z) \in [0, \bar{B}] \). The menu cost is denominated in labor hours and drawn from a time-invariant \( i.i.d. \) distribution \( G(\xi_{i,t}) \) which is common across all firms in country \( i \). Firms evaluating their prices weigh the expected benefit from price adjustment against the price adjustment cost realized in the current period. Conditional on the current adjustment costs, some firms do adjust, while others don’t.\(^{27}\) Since a common technology and common factor market lead to the same real marginal costs for all firms in a country, price-adjusting firms in the same country find it optimal to charge a common price in each market.

\(^{27}\) Under the positive steady-state inflation rates, the benefit of price adjustment rises as the number of periods for which the price has been unchanged, grows. Given the bounded support of the menu cost distribution, there is a finite fraction of vintages in each country. On the contrary, Calvo(1983) model can be interpreted as taking stochastic menu cost either 0 with probability \( p \) or \( \infty \) with probability with \( 1 - p \).
Firm supply is demand-driven and production by an individual firm is the sum of demand in the domestic and export markets.

\[ y_{i,t}(z) = y_{i,i,t}(z) + y_{i,j,t}(z) = d_{i,i,t}(z) + d_{i,j,t}(z), \text{ for } i, j = 1, 2, i \neq j \]  \hfill (2.13)

Labor used for price adjustment is denoted by \( n_{i,t}^a(z) \), and labor used for production is denoted by \( n_{i,t}^p(z) \). Thus, total amount of labor used by firm \( z \) is thus

\[ n_{i,t}(z) = n_{i,t}^a(z) + n_{i,t}^p(z). \]

Production by an individual firm is

\[ y_{i,t}(z) = (k_{i,t}(z)x_{i,t}(z))^{1-\alpha}(n_{i,t}^p(z))^\alpha, \text{ for } i = 1, 2 \]  \hfill (2.14)

where \( \alpha \) represents the labor share in production.

Finally, market demand is determined by the sum of consumption and investment demand such that \( d_{i,j,t} = c_{i,j,t} + i_{i,j,t} \), for \( i, j = 1, 2 \).

2.2.2 Currency invoicing regimes

In this subsection, I’ll focus on the key value functions that each firm in each country confronts under the different invoicing currency regimes. Country 1 and 2 represent the U.S. and Canada respectively.

Local currency pricing

Under the local currency pricing, firms that adjust their prices set domestic prices and export prices simultaneously, after realizing the current menu costs of price adjustment. Given the demand, the current menu cost of price adjustment, the current real price and real wage, each firm \( z \) that has changed its price \( h \) periods ago(vintage-\( h \) firms) has a real value function of the following form

\[ v(p_{i,i,h,t}, p_{i,j,h,t}, \xi_{i,t}(z)|s_t) = \max\{v_{i,h,t}, v_{i,0,t}\}, \text{ for } i, j = 1, 2 \text{ and } i \neq j \]  \hfill (2.15)
where

\begin{align}
v_{i,h,t} &= \pi(p_{i,i,h,t}, p_{i,j,h,t}|s_t) + \beta E\Lambda_{i,t,t+1} v(p_{i,i,h+1,t+1}, p_{i,j,h+1,t+1}, \xi_{i,t+1}(z)|s_{t+1}) \quad (2.16a) \\
v_{i,0,t} &= \max_{p_{i,i,t}, p_{i,j,t}} \pi(p_{i,i,t}^*, p_{i,j,t}^*|s_t) + \beta E\Lambda_{i,t,t+1} v(p_{i,i,t}^* \frac{P_{i,i,t}}{P_{i,i,t+1}}, p_{i,j,t}^* \frac{P_{i,j,t}}{P_{i,j,t+1}}, \xi_{i,t+1}(z)|s_{t+1}) \\
&- w_i \xi_{i,t}(z) \quad (2.16b)
\end{align}

with real profits \(\pi(p_{i,i,h,t}, p_{i,j,h}|s_t) = (p_{i,i,h,t} - \psi_{i,t})d_{i,i,h,t} + (p_{i,j,h,t} - \psi_{i,t})d_{i,j,h,t}\), real prices \(p_{i,i,h,t} = P_{i,i,h,t}/P_{t}^c\) for \(i = 1, 2\), \(p_{1,2,h,t} = S_t P_{2,2,h,t}/P_{t}^c\) and \(p_{2,1,h,t} = P_{2,1,h,t}/S_t P_{2,2,t}\). Both the optimal real price and current real price are relative to domestic CPI.

\(\Lambda_{i,t,t+1} = \lambda_{i,t+1}/\lambda_{i,t}\) denotes the ratio of future to current marginal utility of consumption and \(\psi_{i,t}\) is the real marginal cost.

In this model, the fraction of vintage-\(h\) firms in country \(i\) that choose to adjust is \(\alpha_{i,h,t}\). This fraction is determined by the menu cost of marginal firms indifferent between adjustment and nonadjustment, which satisfies

\[\xi(\alpha_{i,h,t}) = \frac{v_{i,0,t}(s_t) - v_{i,h,t}(s_t)}{w_i(s_t)}, \text{ for } i = 1, 2\]  

(2.17)

The first order condition of the dynamic problem of (2.16b) and recursive differentiation of (2.16a) lead to the formula for the optimal relative prices as follows.

\begin{align}
p_{i,0,t}^* &= \frac{\sum_{h=0}^{J_i-1} \beta^h E_t \{\Omega_{i,t,t+h} \Lambda_{i,t,t+h} \psi_{i,t+h} P_{i,i,t+h}^P \varepsilon_{i,i,t+h,h} d_{i,i,h,t+h}\}}{\sum_{h=0}^{J_i-1} \beta^h E_t \{\Omega_{i,t,t+h} \Lambda_{i,t,t+h} (\varepsilon_{i,i,t+h,h} - 1) \frac{P_{i,i,t+h}^P}{P_{i,i,t+h}} d_{i,i,h,t+h}\}}, \text{ for } i = 1, 2 \quad (2.18a) \\
p_{2,1,t}^* &= \frac{\sum_{h=0}^{J_i-1} \beta^h E_t \{\Omega_{2,t,t+h} \Lambda_{2,t,t+h} \psi_{2,t+h} P_{2,1,t+h}^P \varepsilon_{2,1,t+h,h} d_{2,1,h,t+h}\}}{\sum_{h=0}^{J_i-1} \beta^h E_t \{\Omega_{2,t,t+h} \Lambda_{2,t,t+h} (\varepsilon_{2,1,t+h,h} - 1) \frac{P_{2,1,t+h}^P}{S_{t+h} P_{2,2,t+h}} d_{2,1,h,t+h}\}} \quad (2.18b) \\
p_{1,2,t}^* &= \frac{\sum_{h=0}^{J_i-1} \beta^h E_t \{\Omega_{1,t,t+h} \Lambda_{1,t,t+h} \psi_{1,t+h} P_{1,2,t+h}^P \varepsilon_{1,2,t+h,h} d_{1,2,h,t+h}\}}{\sum_{h=0}^{J_i-1} \beta^h E_t \{\Omega_{1,t,t+h} \Lambda_{1,t,t+h} (\varepsilon_{1,2,t+h,h} - 1) \frac{P_{1,2,t+h}^P}{P_{1,1,t+h}^P S_{t+h}} d_{1,2,h,t+h}\}} \quad (2.18c)
\end{align}

where \(\Omega_{i,t,t+h} = \prod_{n=1}^{h} (1 - \alpha_{i,n,t+n})\) represents the probability of nonadjustment from \(t\) to \(t + h\) and \(J_i\) denotes the finite fraction of vintages in the country \(i\). \(\varepsilon_{i,j,h,t+h}\) is the
elasticity of demand for the individual firm facing the relative demand of \( \frac{d_{i,j,t+h+h}}{d_{i,j,t+h}} \) for \( i, j=1,2 \). Firms that reset prices in the current period may choose to price-discriminate across markets by choosing prices such that the law of one price price does not hold, \( p_{1,1,t} \neq S_t p_{1,2,t}^* \) and \( p_{2,2,t}^* \neq p_{2,1,t}/S_t \).

**Producer currency pricing**

Under the producer currency pricing, exporters charge a single price in their own currency across countries. Therefore, the aggregate producer prices become as follows

\[
P_{1,1,t}^P = P_{1,t}^P \quad P_{2,1,t}^P = S_t P_{2,t}^P \quad P_{1,2,t}^P = P_{1,t}^P / S_t \quad P_{2,2,t}^P = P_{2,t}^P
\]

(2.19)

where \( P_{i,t}^P = \int P_{i,t}(z) \frac{d_{i,t}(z)}{d_{i,t}} dz \), for \( i = 1,2 \), following the equivalent problem of (2.9) for non-segmented demand \( d_{i,t}(z) \).

A vintage-\( h \) firm in PCP has a real value function of the following form

\[
v(p_{i,h,t}, \xi_{i,t}(z)|s_t) = \max\{v_{i,h,t}, v_{i,0,t}\}, \quad \text{for } i = 1, 2
\]

(2.20)

where

\[
v_{i,h,t} = \pi(p_{i,h,t}|s_t) + \beta EL\varepsilon_{i,t,t+1} v(p_{i,h+1,t+1}, \xi_{i,t+1}(z)|s_{t+1})
\]

(2.21a)

\[
v_{i,0,t} = \max_{p_{i,t}} \pi(p_{i,t}^*|s_t) + \beta EL\varepsilon_{i,t,t+1} v(p_{i,t}^*, \xi_{i,t+1}(z)|s_{t+1}) - w_{i,t} \xi_{i,t}(z)
\]

(2.21b)

with real profits \( \pi(p_{i,h,t}|s) = (p_{i,h,t} - \psi_{i,t})d_{i,t}(z) \). The optimal real price chosen by adjusting firms \( p_{i,t}^* \), is derived to be

\[
p_{i,t}^* = \frac{\sum_{h=0}^{J_i-1} \beta^h E_t \{ \Omega_{i,t,t+h} \Lambda_{i,t,t+h} \psi_{i,t,t+h} P_{i,t}^{P} d_{i,t,t+h+h} \}}{\sum_{h=0}^{J_i-1} \beta^h E_t \{ \Omega_{i,t,t+h} \Lambda_{i,t,t+h} \varepsilon_{i,t,t+h} d_{i,h,t+h} \}} \quad \text{for } i=1,2
\]

(2.22)
**Asymmetric currency pricing**

Just like PCP, U.S. exporters charge a single price in U.S. dollar but Canadian exporters price-discriminate between the U.S. and Canada. Thus, the aggregate producer price of U.S. is the same as PCP such that $P_{1,1,t}^P = P_{1,t}^P$ and $P_{1,2,t}^P = P_{1,t}^P / S_t$, but there exist two different aggregate producer prices for Canada, $P_{2,1,t}^P$ and $P_{2,2,t}^P$ following LCP.

Real value functions of vintage-$h$ firms in Canada and U.S. are identical to the equation of (2.15) and (2.20) respectively. Likewise, the optimal real prices of Canada become (2.18a) for domestic demand and (2.18b) for export demand and that of U.S. becomes (2.22).

### 2.3 Data and parameter choices

The data in this chapter cover the period from 1976Q1 to 2009Q4. U.S. data from the Bureau of Economic Analysis (BEA) include gross domestic output (GDP), personal consumption expenditures, private fixed investment, the implicit price deflators for GDP and private consumption, exports and imports of goods and services. Quarterly averages of the monetary aggregate M1, nonseasonally adjusted in both countries are from International Financial Statistics (IFS) of International Monetary Fund. Canadian GDP and exchange rates are also from IFS. Canadian private consumption expenditures, private fixed investment and implicit deflators for GDP and private consumption are from OECD.

The chosen parameter values are reported in Table 2.1. The parameters related to trade are chosen to replicate the relationship between the U.S. and Canada over the sample period.
<table>
<thead>
<tr>
<th>Preference</th>
<th>U.S.</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$ Discount rate</td>
<td>0.99</td>
<td>0.99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trade</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$ Degree of home bias</td>
<td>0.13</td>
<td>0.25</td>
</tr>
<tr>
<td>$\gamma$ Elasticity of substitution - Country</td>
<td>1.5</td>
<td>1.5</td>
</tr>
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<table>
<thead>
<tr>
<th>Production</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$ Labor share</td>
<td>$2/3$</td>
<td>$2/3$</td>
</tr>
<tr>
<td>$\delta$ Quarterly depreciation rate</td>
<td>0.02</td>
<td>0.02</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Demand</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$ Elasticity of demand at 1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>$\varphi$ Demand curvature</td>
<td>1.02</td>
<td>1.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Monetary Shocks</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega$ Money growth autocorrelation</td>
<td>0.52</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Table 2.1: Parameters

A time frequency is one quarter of a year. The discount factor $\beta$ is set to give an annual real interest rate of 4%. At the steady-state, households are assumed to devote 1/3 of their time endowment to work and $\chi$ is chosen accordingly. The U.S. and Canadian degree of home bias $\theta_1$, $\theta_2$ are 0.13 and 0.25 respectively, which correspond to imports relative to GDP.

The elasticity of substitution between domestic and imported goods, $\gamma$ is a critical parameter in two-country setting, because it determines the degree of expenditure switching effect. In the calibration, I set this elasticity to 1.5, which is consistent with Backus, Kehoe and Kydland(1994) and Chari, Kehoe and McGrattan(2002). The labor share in production is $2/3$. The steady-state quarterly depreciation rate
equals 0.02. I set $\phi = 1, \phi' = 1$ to ensure that the steady state is unaffected by the capital adjustment cost and the elasticity of marginal depreciation is set to be 1.

Following DK, the variable elasticity demand curves are parameterized by choosing value of $\rho$ so that demand curves have elasticities of 10 at $d(z)/d = 1$. Setting $\varphi$ to 1.02 implies that a 2% increase in price decreases demand by 34%, which is intermediate between the responses implied by Kimball(1995) and Bergin and Feenstra(2001).\footnote{The original Kimball(1995) demand implies that 2% rise in the relative price of good lowers demand by 78%, whereas Bergin and Feenstra(2001)’s translog demand generates 5% decrease.}

The parameter values governing price adjustment costs imply that the mean duration of domestic and import prices is 9 months, which is broadly consistent with empirical studies such as Klenow and Kryvtsov(2008) and Gopinath and Rigobon(2008).\footnote{Bakhshi, Khan and Rudolf(2007) consider the different specifications of cumulative distribution function(CDF) in DKW’s setting, and report that the difference is not transmitted to the distribution of price vintages in the steady state. Thus, overall price dynamics become similar across the different adjustment cost settings.}

To estimate the exogenous monetary supply rule, the logarithms of M1 quarterly data for the U.S. and Canada are used to run a regression of (2.8). The coefficients are estimated to be 0.52 for U.S. and 0.41 for Canada. The standard deviation of the shocks are 1.65 percent in the U.S. and 3.05 percent in Canada. The cross-correlations of these shocks are chosen to minimize the distance between the estimated moments and the model-based moments. The moments are the correlation between U.S. and Canada output, and the correlation between U.S. output and U.S. trade balance.\footnote{During the sample period, the correlation between U.S. and Canada GDP is 0.79 and the correlation between U.S. GDP and trade balance with Canada is -0.11.}

Finally, I set the steady-state money growth rate to 4 percent, which corresponds to the average inflation rates observed in the countries over the sample period.
2.4 Results

In this section, I compare the aggregate responses to the 1% increase in the U.S. money stock under the different pricing regimes. In addition, I contrast the SDP model’s response with those from a TDP model in which the fraction of price-adjusting firms is held fixed at steady-state value in Figure 2.1. Unlike the Calvo-style flat adjustment hazards, the adjustment hazards are conditional on the time elapsed since a firm’s last price adjustment. Firm-level responses to the shock will be also discussed to highlight the role of SDP and TDP.

2.4.1 Comparison with other invoicing currency regimes

Figure 2.2 displays the aggregate response to a U.S. monetary expansion in the asymmetric invoicing which is the benchmark. The model generates a hump-shaped
response of output in the U.S. and Canada. It also brings initial inertia and delayed 
response in CPI inflation. In the benchmark, the U.S. monetary expansion induces 
a depreciation in U.S. dollar. Short-run responses of the nominal exchange rates are 
from the movement in real exchange rate. A relative increase in the U.S. consumption

Figure 2.2. Aggregate response to a U.S. monetary expansion under asymmetric 
currency pricing with state-dependent pricing
leads to an increase in real exchange rate by reducing the ratio of marginal utility of consumption from the equation of (2.6). At longer horizon, the relative price level affects the nominal exchange rate.\textsuperscript{31} The U.S. trade balance displays a J-curve.

![Graphs of U.S. CPI Inflation, Canadian CPI Inflation, U.S. Output, Canadian Output, U.S. Trade Balance, and Nominal Exchange Rates](image)

Figure 2.3: Comparison of aggregate response to a U.S. monetary expansion (SDP)

\textsuperscript{31}A shortcoming of the benchmark is the counterfactual negative correlation between real and nominal exchange rates. While real exchange rate declines since the U.S. consumption reaches its peak at 2 quarter, nominal exchange rate rises.
It initially worsens, then starts to improve gradually and becomes positive after 12 quarters. The initial increase in U.S. consumption raises import demand and explains the short-run worsening of the trade balance, which leads to the increase in Canadian output and consumption. Improvement in the trade balance arises as domestic prices rise and contract consumption. Overall, these results are consistent with the VAR analysis of Holman and Neumann(2002) to study the effect of the U.S. monetary shock on the U.S. and Canada business cycles.

Figure 2.3 compares the aggregate responses across three different pricing assumptions. While each invoicing currency regime shares some qualitative similarities including hump-shaped responses of output and inflation and the depreciation in the U.S. dollar, the U.S. aggregate responses of the benchmark(ACP) are quantitatively close to those of LCP. Even though it’s not reported here, the similarities of the U.S. responses between the benchmark and LCP also arise in response to the monetary expansion of Canada. However, PCP generates greater responses of CPI inflation and nominal exchange rates than ACP and LCP. In addition, the difference of output responses between PCP and the other two cases are rising over time. Canadian aggregate responses differ in all three case.

2.4.2 Comparison with time-dependent pricing model

From Figure 2.4, the TDP model shows the same qualitative features as the SDP model. This reflects the similarity of the hazard function to that in Figure 2.1.

However, the quantitative implications of the two models are different. TDP displays strikingly similar responses across different pricing regimes except trade balance.\textsuperscript{32} This result is consistent with the works of Dotsey and Duarte(2008 and

\textsuperscript{32}Note that the scales of Figure 2.3 and 2.4 are identical.
2009), in that invoicing currency makes little difference in the impulse responses to the shocks. In contrast to the TDP model, the SDP model’s responses are larger than the TDP models across pricing regimes and the difference in aggregate responses between PCP and the two others is more distinctive.

Figure 2.4: Comparison of aggregate response to a U.S. monetary expansion (TDP)
Figure 2.5: Firm-level reaction to a U.S. monetary expansion (SDP)

This contrasting result comes from the absence of extensive margin in TDP. It can be illustrated more clearly by comparing the firm-level responses in Figure 2.5 (SDP) and Figure 2.6 (TDP). Under SDP, combined with Kimball demand in which the profit decreases quickly as the price deviates from others, the initial responses of optimal prices show inertia, compared to TDP models. It’s because firms do not want to lose profit by raising price too aggressively and they know they can change price later when it is more valuable to do so. Over time, however, the increase in demand raises the value of price-adjusting firms and induces more firms to adjust prices. While the aggregate price rises accordingly, the Kimball demand quickly undermines the
Figure 2.6: Firm-level reaction to a U.S. monetary expansion (TDP)

values of non-adjusting firms, which provides them with strong incentive to adjust their prices. These collective actions of price-adjusting firms feed into the aggregate price level, and the increase in price level and exchange rate depreciation, in turn, lead to other actions.

During this price adjustment, ACP firms and LCP firms in the U.S. react similarly, while the PCP firms respond more aggressively. As stressed by a standard international macroeconomics literature, this result comes from difference in exchange rate pass-through (ERPT). When ERPT is measured as the percentage change in import prices relative to a change in currency value, Figure 2.7 illustrates slower exchange
rate pass-through to the U.S. import prices in ACP and LCP and full exchange rate pass-through in PCP. As inflation rises fast in PCP due to full exchange rate pass-through, the benefit of price adjustment also grows quickly. This is reflected by higher optimal prices and fraction of adjustment in Figure 2.5, which leads to greater CPI inflation in PCP.

While full exchange rate pass-through in PCP also contributes to higher optimal prices of firms even in TDP, the relatively muted response of TDP-PCP firms fails to make the differences in the aggregate level. Since the firms in TDP have no control over the timing of price adjustments, we can’t expect the same interplay between intensive and extensive margins of price adjustment which contribute to greater amplification of monetary shocks in SDP.

Now, let’s turn to the Canadian aggregates. On impact, the depreciation of U.S. dollar should cause U.S. firms to reduce prices in the Canadian market. Under both SDP and TDP, the initial full exchange rate pass-through of ACP and PCP leads to
deflation in Canadian CPI. Despite the similarity in exchange rate pass-through to Canada import prices, the difference in nominal depreciation between the two pricing regimes in SDP leads to different responses in the business cycles of Canada. In ACP, the effect of an expected increase in marginal cost induces firms to increase their optimal prices. In PCP, however, since the effect of U.S. dollar depreciation dominates, the optimal prices of Canadian market remain low for a considerable period of time.

2.5 Conclusion

This chapter addresses the role of different assumptions on currency denomination in exports with a two-country SDP model. The asymmetric currency invoicing or dollar pricing shows little difference in the aggregate responses in U.S. from the symmetric LCP, because the slow exchange rate pass-through plays a substantial role in the business cycle of both pricing regimes. Importantly, this chapter still demonstrates the importance of invoicing currency which was rejected by recent qualitative open-economy literatures based on TDP, by showing that SDP makes the aggregate responses in PCP quantitatively different from those in LCP and ACP. Both the full exchange rate pass-through in PCP and extensive marign of price adjustment in SDP contribute to this result.

Besides invoicing currency, recent micro-founded research sheds more light on the export price setting behavior. From the producer price micro-data, Schoenle(2010) documents that the domestic and export pricing decisions for the same products lack synchronization. This finding may suggest that the standard assumption of
simultaneous adjustment of prices across markets should be carefully modified. I’ll leave this for future research.
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