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THE EFFECTS OF EXTERNAL AND INTERNAL SHOCKS ON INTERNATIONAL TRADE AND FINANCE

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Table of Contents

List of Figures **v**

List of Tables **viii**

Abstract **ix**

Acknowledgments **xii**

1 External Shocks under Different Exchange Rate Regimes in Low-Income Economies: Reserves and Precautionary Savings **1**

1.1 Introduction 2
1.2 Literature Review 4
1.2.1 Cost-Benefit Method Approach to Determining Reserves . 4
1.2.2 SOE Method Approach to Determining Reserves 8
1.2.3 Contributions to Literature 12
1.3 The Theoretical Model 16
1.3.1 Sectors in Model 16
1.3.2 Household Sector 17
1.3.3 Firm Sector 20
1.3.4 Central Bank 21
1.3.5 Equilibrium 23
1.3.6 Model in Full 25
1.3.7 Precautionary Savings 28
1.4 Results 31
1.4.1 Data 31
1.4.2 Impulse Response Function 33
1.5 Conclusion 37
Appendix 1.A Graphs 42
References 48

2 The Impact of U.S. Interest Rate Changes on Emerging Market Countries under Cost-Push Shocks and Natural Rate Shocks 51
2.1 Introduction 52
2.2 Literature Review 56
2.3 New Keynesian Small Open Economy Model 61
2.3.1 Model Setup 61
2.3.2 Calibration 72
2.3.3 Impulse Response Functions 74
2.4 Bayesian Local Projection Empirical Estimation 84
2.4.1 Data Description 84
2.4.2 Bayesian Local Projection Method 86
2.4.3 Empirical Results 88
2.5 Conclusion 103
Appendix 2.A Model 105
Appendix 2.B Data 110
Appendix 2.C IRFs 112
References 122

3 CNY-CNH Term Spread and Covered Interest Parity Deviations 126
3.1 Introduction 127
3.2 Literature Review 131
3.3 A Model of Onshore-Offshore Money Market and Currency Market Deviations 134
3.3.1 Bank Decision 135
3.3.2 Money Markets 137
3.3.3 Currency Forward Market 138
3.3.4 Summary of Equilibrium Conditions 140
3.4 Empirical Results 142
3.4.1 Dataset 142
3.4.2 Source of Shocks 143
3.4.3 Proposition 1 Test 147
3.4.4 Proposition 2 & 3 Tests 152
3.5 Conclusion 154
Appendix 3.A Daily Capital Control Index 157
Appendix 3.B VAR 159
Appendix 3.C IRFs 161
Appendix 3.D Koyck Model Derivation 163
References 164

List of Figures

1.1 70 low-income countries GDP per capita in 2014 (USD) 42
1.2 The reserves-to-imports ratio in months 42
1.3 The distribution of reserves-to-imports ratio in months 43
1.4 Floating regime - IR to external shocks 43
1.5 Floating regime - IR to external shocks 44
1.6 Floating regime - IR to external shocks 44
1.7 Floating regime - IR to external shocks 45
1.8 Pegged regime - IR to external shocks 45
1.9 Pegged regime - IR to external shocks 46
1.10 Pegged regime - IR to external shocks 46
1.11 Pegged regime - IR to external shocks 47

2.1 U.S. quarterly rates 54
2.2 Cost-push shock v.s. Natural rate shock with CPI-based Taylor rule 76
2.3 Cost-push shock v.s. Natural rate shock with CPI-based Taylor rule 77
2.4 Cost-push shock v.s. Natural rate shock with CPI-based Taylor rule 77
2.5 Cost-push shock v.s. Natural rate shock with Pegged exchange rate 79
2.6 Cost-push shock v.s. Natural rate shock with Pegged exchange rate 79
2.7 Cost-push shock v.s. Natural rate shock with Pegged exchange rate 80
2.8 Cost-push shock v.s. Natural rate shock with PPI-based Taylor rule 81
2.9 Cost-push shock v.s. Natural rate shock with PPI-based Taylor rule 82
2.10 Cost-push shock v.s. Natural rate shock with PPI-based Taylor rule 82
2.11 Cost-push shock with BLP method - ARG 89

2.12 Cost-push shock with BLP method - BRA 90
2.13 Cost-push shock with BLP method - KOR 90
2.14 Cost-push shock with BLP method - MEX 91
2.15 Cost-push shock with BLP method - ZAF 91
2.16 Natural rate shock with BLP method - ARG 92
2.17 Natural rate shock with BLP method - BRA 92
2.18 Natural rate shock with BLP method - KOR 93
2.19 Natural rate shock with BLP method - MEX 93
2.20 Natural rate shock with BLP method - ZAF 94
2.21 Cost-push shock with BLP method - AUS 95
2.22 Cost-push shock with BLP method - CAN 96
2.23 Cost-push shock with BLP method - NLD 96
2.24 Cost-push shock with BLP method - NZL 97
2.25 Cost-push shock with BLP method - SWE 97
2.26 Natural rate shock with BLP method - AUS 98
2.27 Natural rate shock with BLP method - CAN 99
2.28 Natural rate shock with BLP method - NLD 99
2.29 Natural rate shock with BLP method - NZL 100
2.30 Natural rate shock with BLP method - SWE 100
2.31 Cost-push shock with all methods - ARG 112
2.32 Cost-push shock with all methods - BRA 112
2.33 Cost-push shock with all methods - KOR 113
2.34 Cost-push shock with all methods - MEX 113
2.35 Cost-push shock with all methods - ZAF 114
2.36 Natural rate shock with all methods - ARG 114
2.37 Natural rate shock with all methods - BRA 115
2.38 Natural rate shock with all methods - KOR 115
2.39 Natural rate shock with all methods - MEX 116
2.40 Natural rate shock with all methods - ZAF 116
2.41 Cost-push shock with all methods - AUS 117
2.42 Cost-push shock with all methods - CAN 117

2.43 Cost-push shock with all methods- NLD 118
2.44 Cost-push shock with all methods - NZL 118
2.45 Cost-push shock with all methods - SWE 119
2.46 Natural rate shock with all methods - AUS 119
2.47 Natural rate shock with all methods - CAN 120
2.48 Natural rate shock with all methods - NLD 120
2.49 Natural rate shock with all methods - NZL 121
2.50 Natural rate shock with all methods - SWE 121

3.1 RMB/USD movement 130
3.2 Term spread and CIP deviations 130
3.3 Offshore-relative-to-onshore total cost 131
3.4 Monetary policy - changed reserve ratio $\varepsilon_c \downarrow$ 150
3.5 Investor preference - stock market substitution effect $\varepsilon_c \downarrow$ 150
3.6 Money market regulatory - reverse REPO of open market $\varepsilon_c \downarrow$ . . 150
3.7 Central bank policy - liquidity of currency market $\varepsilon_b \downarrow$ 151
3.8 Trader expectation - volatility of currency market $\varepsilon_b \downarrow$ 151
3.9 Currency market regulatory - capital control $\varepsilon_b \downarrow$ 152
3.10 Monetary policy - changed reserve ratio $\varepsilon_c \downarrow$ 161
3.11 Investor preference - stock market substitution effect $\varepsilon_c \downarrow$ 161
3.12 Money market regulatory - reverse REPO of open market $\varepsilon_c \downarrow$ . . 161
3.13 Central bank policy - liquidity of currency market $\varepsilon_b \downarrow$ 162
3.14 Trader expectation - volatility of currency market $\varepsilon_b \downarrow$ 162
3.15 Currency market regulatory - capital control $\varepsilon_b \downarrow$ 162

List of Tables

1.1 Calibration for the benchmark model 33
1.2 Moments of simulated variables 37

2.1 How would U.S. interest rate hikes by different shocks affect other economies 56
2.2 Calibration for the baseline model 72
2.3 Correlation with U.S. cost-push shocks 85
2.4 Correlation with U.S. natural rate shocks 85
2.5 Association Rule Learning 86
2.6 Data Sources 110

3.1 Data description 142
3.2 Correlation 147
3.3 Regression - 2SLS IV and Robust method 154

Abstract

The Effects of External and Internal Shocks on International Trade and Finance

by

Penghao Cheng

This dissertation has three chapters, with emphasis on the effects of external and internal shocks on international trade and finance from a different perspective. In the first chapter, the cash-in-advance model explores the precautionary savings against external shocks under different exchange rate regimes. The low-income countries mainly face external shocks from the current account, which includes productivity (internal), international aid, terms of trade, external demand, and foreign monetary policy. Agents hold assets to smooth the consumption under the floating exchange rate regime. However, the assets not only stabilize the exchange rate but also smooth consumption under the pegged exchange rate regime. Facing uncertainty, households put more weight on precautionary motive, instead of investment motive. The impulse response function reveals that the initial deviations are more significant with the pegged exchange rate regime because the nominal exchange rate can not absorb the macroeconomic shocks. The floating exchange rate regime could reduce the variance of domestic consumption, while the pegged exchange rate regime would be better to stabilize imported consumption. Furthermore, the foreign monetary policy shocks show significant differences between the two regimes.

The second chapter analyzes the impact of U.S. interest rate changes under cost-push shocks and natural rate shocks as well as these shocks' transmission to emerging market countries. The theoretical model of a small open economy finds

that changed exchange rate (exchange rate channel) is negative - USD depreciation under cost-push shock, while positive - USD appreciation under natural rate shock. The differences under the two shocks are amplified through domestic bonds (financial market channel) and terms of trade (trade market channel). Then, the real output of the emerging economy with PPI-based Taylor rule is positive under both shocks and less volatile under cost-push shock, given the same magnitude of shocks. This chapter also uses Bayesian local projections to test empirical sample that consists of five emerging and five developed countries. As the model predicts, the exchange rate channel has significant and different effects under both shocks. The empirical results reveal that cost-push shocks cause more substantial volatility than natural rate shocks for each country due to their characteristics - significant deviation and less persistence through three channels. Overall, inflation targeting is one of the essential objectives for emerging economies and contributes towards more stable economic growth.

The third chapter implements a simple model to explain Chinese onshore and offshore financial markets and fill the gap of the term spread differential of money market and CIP violation of currency market spillover effects with internal shocks. China has not only both onshore and offshore money (capital) markets but also both onshore and offshore currency markets. The differences between onshore and offshore RMB markets would cause many questions that are worth probing into. The empirical test also uses a new flexible econometric method - Bayesian local projections that can sensibly reduce the impact of compounded biases over the horizons and effectively deal with model misspecifications. The results are three-fold: First, one market shock can transmit to the other market through capital flows. The shocks from the forward currency market have a significant impact on the spot money market through capital flows. The effects on both markets would die away in a week after initial shocks, but the effect on capital flows is less persistent. Second, cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore. Third, a massive amount of debt issuance may decrease the absolute value of the net deviation.

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Chapter 1

External Shocks under Different Exchange Rate Regimes in Low-Income Economies: Reserves and Precautionary Savings

1.1 Introduction

Why do we care about international reserves? There are some reasons for holding international reserves. (1) When a negative shock impacts the current account or capital account, international reserves can buffer this shock and reduce the bad influence. Therefore, households or central bank would accumulate international reserves under precautionary purpose. (2) Using international reserves, the central bank can stabilize the exchange rate. For instance, China pegs the value of its currency to a basket of currencies, using its foreign reserves. (3) The central bank could devalue domestic currency to boost international trade by holding an excess amount of international reserves - Mercantilism. (4) Central bank provides confidence for foreign investors and prevents a sudden flight to quality and loss of capital for the country. (5) Central bank makes sure international reserves would meet external obligations of the country. (6) Central bank diversifies its portfolios and increases asset returns while holding international reserves. Therefore, one question of international finance is the appropriate level of international reserves.

Most papers use the cost-benefit method, by which reserves lower the probability of adverse shocks on current account or capital account and increase attendant costs, to quantify the level of international reserves. They find that the reserves level can be sensitive to country fundamentals and exchange rate regimes, instead of just maintaining reserves equivalent to three months of imports. In short, the cost-benefit method focuses on the role of international reserves in preventing and mitigating absorption drops triggered by large external shocks under considering the opportunity cost of holding reserves. However, other papers present small open economy models to analyze the related reserve levels through the precautionary saving motive of households. In other words, households would prefer to save more international reserves, facing the uncertainty, to smooth their consumption. Although the small open economy model with precautionary purpose is intuitive and explicable, it lacks entirely consideration of central bank monetary policy, such as the impact of different exchange rate regimes on international reserves. The objective of this paper is to combine the small open economy model with different exchange rate regimes and try to find consistent results as the cost-benefit method.

This paper seeks to fill this gap by evaluating precautionary saving under different exchange rate regimes with a small open economy model. As the cost-benefit method found, the exchange rate regime would affect the level reserves. In the following model, the central bank would choose between "floating exchange rate and monetary autonomy" and "pegged exchange rate and renunciation of monetary autonomy". The first strategy is that the central bank conducts an independent policy rule, such as Jeanne and Sandri [2016], to help households to fulfill the precautionary saving. Whereas, the second strategy includes central bank using international reserves to stabilize the exchange rate. The above allows this paper to address the question, under different exchange rate regimes, what should the level of reserves be? How does each sector (household, firm, and central bank) respond differently, when the negative shock impacts on the economy?

More specifically, the paper examines the dynamic implications of reserves in the context of a simple intertemporal three-sector optimizing real business cycle (RBC) model for low-income countries with external shocks. Compared with emerging market countries, low-income countries are much more financially closed economies. Moreover, emerging market countries and low-income countries are faced with different types of shocks. The shocks from the capital account generally impact emerging market countries, while the shocks from the current account primarily influence low-income countries with limited access to the international financial market.

The model includes productivity shocks, aid shocks, terms of trade shocks, external demand shocks, and foreign monetary policy shocks as exogenous stochastic processes from the current account.[1] Also, it is calibrated using macroeconomic data for 70 low-income countries[2] between 1966 and 2015. The benchmark calibration shows the reserves around the target level, which is close to three months of imports. The prospectus is organized as follows: Section 1.2 reviews existing literature on cost-benefit and small open economy methods; Section 1.3 presents the model, highlights the key ingredients, and explains assumptions; Section 1.4 shows some results from this model with empirical data; Section 1.5 illustrates the improved model and conclusion.

1.2 Literature Review

1.2.1 Cost-Benefit Method Approach to Determining Reserves

First of all, the cost-benefit method found that country fundamentals and exchange rate regimes are essential factors when we try to quantify the level of reserves. Heller [1966] introduced the first formal cost-benefit study of international reserve demand. He found that optimal reserves should satisfy the following

[1] Kim et al. [2011] identified the exogenous current account shocks of low-income countries.

[2] In this paper, low-income countries refer to all countries shown on the IMF's list of countries eligible for the Poverty Reduction and Growth Trust (PRGT) in October 2015.

condition: reserves should be accumulated until the marginal benefit equals the marginal cost. The marginal benefit of holding reserves is the reduced economic cost of adjusting to a deficit not covered by reserves. The marginal cost of holding reserves is the rate of return foregone by not transforming reserves into real physical capital.

Kim et al. [2011] developed Heller's methodology and presented a simple cost-benefit framework of precautionary reserve holdings warranted by country characteristics and fundamentals for low-income countries. The basic idea is that international reserves could reduce the likelihood and magnitude of abrupt drops in consumption arising from large external shocks. Also, the cost of holding reserves is the difference between the return in risky but high-yielding domestic capital and safe but low-yielding international reserves. The low-income country seeks to maximize the following function, which involves the trade-off between cost and benefit of holding international reserves.

$$\max_{R} NBR = -qP(R,Z)C(R,Z) - rR$$

Countries would maximize the net benefit of holding reserves (NBR), where P is the conditional probability of a crisis given a large shock, and C is the utility cost (drop in consumption) of a crisis, both depending on reserves R and control variable Z. The parameter q is the unconditional probability of a large shock, and the parameter r is the unit cost of holding reserves. The authors empirically estimated the conditional probability of a crisis P and the utility cost of a crisis C in the event of large external shocks. The external shocks include (i) external demand; (ii) terms-of-trade; (iii) FDI; (iv) aid; (v) remittances; (vi) climatic shocks (large natural disasters) for low-income countries. Control variables include the ratio of government balance to GDP, the World Bank's CPIA index as a proxy for policy and institutional quality, a dummy for flexible exchange rate regime, and a dummy for Fund-supported programs. Finally, the authors found that the traditional rule of thumb of 3 months of imports is more appropriate for countries with flexible exchange rate regimes, but the traditional rule of thumb is likely to be inadequate for countries with fixed exchange rate regimes.

However, Calvo et al. [2012] used a similar cost-benefit method to explore the reserves of emerging economies. During the recent financial crises[3], largely unexpected cut in international capital flows that happened in emerging economies, which gave them strong incentives to self-insure by accumulating international reserves. The optimal international reserves would balance the probability of sudden stop and carry cost. Their control variables include foreign direct investment, portfolio integration, terms of trade growth, government balance, the exchange rate regime, the ratio M2-to-reserves, and foreign debt as a share of GDP. From their Probit models, unlike the findings of Kim et al. [2011] for low-income countries, the fixed exchange rate regime would insignificantly increase the likelihood of a sudden stop, given the same level of reserves.[4] One potential explanation for this is the Probit estimations also include the change in the real exchange rate, which may capture the explanation of the exchange rate regime. Their main results suggests there is not apparent over-accumulation of reserves in emerging economies, because only 10 out of 27 emerging economies hold the excess international reserves. Similar to the results of Calvo et al. [2008] and Kim et al. [2011],

[3] Calvo et al. [2012] presented the fragility of financial markets and institutions is increasing in the last three decades.

[4] Kim et al. [2011] found that the probability of a crisis tends to be significantly lower under flexible exchange rate regimes for low-income countries.

they also found that current account deficits are a critical factor taken into account by the central bank in holding the optimal amount[5] of international reserves.

Moore and Glean [2016] also provided a cost-benefit type approach to evaluating reserve adequacy for small island developing countries. They also followed the idea of Kim et al. [2011] to identify the exogenous shocks (external demand, terms-of-trade, FDI, aid, remittances, and climatic shocks) and crises, and took the policy maker's objective function of Calvo et al. [2012] to minimize the losses from a sudden stop against the cost of holding reserves. Their estimation took into account government policy and the inherent vulnerability of small countries. In the regression with a dummy variable fixed exchange rate regime, the variable was insignificant, and the results did not change appreciably[6], which was similar to the result of Calvo et al. [2012]. Using the cost-benefit methodology, they found the optimal holding of foreign exchange reserves is approximately 13 weeks higher than the international rule of thumb, depending on the economic characteristics of the country. Indeed, they also found that country with a prudent public expenditure (government policy) can hold a smaller stock of reserves without necessarily impacting on the expected growth for the country, and then the optimal holdings of reserves could fall to just 19 weeks.

The above papers with the cost-benefit method give this paper some critical information. First, the low-income countries, as Kim et al. [2011] mentioned, mainly face the current account shocks, such as external demand, terms-of-trade, FDI, aid, and climatic shocks. Second, exchange rate regimes could influence the level of reserves under the precautionary motive. Kim et al. [2011] presented that

[5]The optimal amount is quantified by the cost-benefit method.

[6]The fixed exchange rate would insignificantly increase the likelihood of a crisis.

low-income countries with fixed exchange rate regimes should hold more than the traditional rule of thumb under flexible exchange rate regimes. Unfortunately, Calvo et al. [2012] and Moore and Glean [2016] argued the fixed exchange rate regime would insignificantly increase the likelihood of crises (Probit model) in emerging economies and small island developing countries[7] respectively. Third, government policy would affect the holdings of reserves. Moore and Glean [2016] revealed that fiscal policy is an essential factor to quantify the optimal reserves. Fourth, the optimal level of international reserves is slightly higher than the rule of thumb - 3 months of imports.

1.2.2 SOE Method Approach to Determining Reserves

The small open economy model with a precautionary saving motive is another method to quantify the level of reserves. Fogli and Perri [2015] presented a standard open economy model with time varying macroeconomic uncertainty that can quantitatively account for the relationship between uncertainty and net foreign assets. The crucial mechanism is precautionary motive: more uncertainty induces households to save more, and higher savings are in part channeled into foreign assets. Ljungqvist and Sargent [2004] said self-insurance occurs when the household uses savings to insure himself against income fluctuations. On the one hand, the household could withdraw his savings and avoid large temporary drops in consumption in response to low income realizations. On the other hand, the household could partly save high income realizations in anticipation of bad outcomes in the future. Some papers focus on the precautionary demand for assets that arises from the sudden stop risk in emerging economies, such as Durdu et al.

[7]The data of small island developing countries includes low-income economies and emerging economies.

[2009], Alfaro and Kanczuk [2009], and Jeanne and Ranciere [2011]. Jeanne and Ranciere [2011] used a model of the optimal level of international reserves to smooth domestic absorption in response to sudden stops in capital flows (capital account) for a small open economy. However, the recent buildup of reserves in emerging market countries seems in excess of what would be implied by an insurance motive against sudden stops. Others focus on uncertainty, for little integration with capital market as low-income countries, stemming from the current account, such as Dhasmana and Drummond [2008], Barnichon [2008], and Valencia [2010]. Dhasmana and Drummond [2008] used a two-good endowment economy model facing terms of trade and aid shocks in the current account to derive the optimal level of reserves by comparing the cost of holding reserves with their benefits as an insurance against a shock. Their simulations suggested that a few sub-Saharan Africa countries (low-income countries) do not currently carry reserves consistent with the expected output costs associated with expected terms-of-trade or aid shocks. So, international reserve accumulation follows a precautionary motive to build buffers and shield domestic demand from balance of payments (current account and capital account) crises.

Valencia [2010] used the precautionary savings model to compute the level of reserves for Bolivia whose current account shocks are the primary balance of payments risk. In the baseline version of the model, households are assumed to consume only tradable goods and make consumption decisions to maximize the expected present discounted value of the utility derived from consumption. The sequence of events is as follows: at the beginning of the period, consumers have net foreign assets X_t , conditional on which they make consumption decisions C_t, in the middle of the period with the remainder $X_t - C_t$ invested in a risk-free security that yields R. At the end of the period - after decisions have been made - income is realized, which determines with how many assets the consumer arrives in period $t+1$. The budget constraint of households is

$$X_{t+1} = R(X_t - C_t) + \tau_{t+1} Y_{t+1} + A_t$$

, where Y reflects the level of permanent income, τ denotes transitory shocks to income, assumed to be mean-one, i.i.d., and distributed over a non-negative support, and finally A denotes all other non-export net current receipts. The key factor is τ which includes two i.i.d. components: export volumes and terms of trade shocks. Next, the extended model adds the investment variable. Because now income is endogenous, consumers save not only for precautionary purposes but also to finance the stock of capital. Therefore, the modified budget constraint is

$$x_{t+1} = R(x_t - c_t - k_t) + \tau_{t+1} k_t^{\alpha} + (1-\delta)k_t + a$$

, where k is the capital, and $\tau_{t+1} k_t^{\alpha}$ denotes income from exports. The differences between baseline and modified model are that the consumer now finds it profitable to cut consumption and finance the stock of capital, and savings need to fulfill the precautionary motive and the investment decision simultaneously. Author suggested the optimal level of reserves[8] from both models result in the range 29 and 37 percent of GDP, which is higher than the standard rule of thumb. These differ-

[8]The baseline model uses the standard Euler equation for consumption $u'(c_t) = R\beta E_t u'(c_{t+1})$ and the normalized budget constraint $x_{t+1} = R(x_t - c_t) + \tau_{t+1} + a$ to determine the optimal level of reserves x^* with the transitory shocks to income τ. The modified model uses the standard Euler equation for consumption $u'(c_t) = R\beta E_t u'(c_{t+1})$, the standard Euler equation for capital $u'(c_t) = \beta E_t u'(c_{t+1})(\alpha \tau_{t+1} k_t^{\alpha-1} + (1-\delta))$ and the normalized budget constraint $x_{t+1} = R(x_t - c_t - k_t) + \tau_{t+1} k_t^{\alpha} + (1-\delta)k_t + a$ to determine the optimal level of reserves x^* with the transitory shocks to income τ.

ent results illustrate it is important to appropriately account for country-specific risks in order to derive adequate measures of reserve buffers.

Valencia [2010] said this is not a critical issue of who holds these reserves (central bank or household), as long as the central bank's objectives are in line with households with regards to smoothing demand fluctuations. The policy function for reserve management predicted by the precautionary savings model is non-linear and, therefore, difficult to describe as a simple rule of thumb for the central bank. Jeanne and Sandri [2016] found a simple linear rule can capture most of the welfare gains from optimal reserve management when the central bank holds reserves instead of households. They characterized the optimal management of reserves using an open-economy model of precautionary savings with carrying costs in financially closed economies. They found results are consistent with the rule of thumb (reserves are close to three months of imports) under plausible calibrations for low-income countries, driven by exogenous stochastic processes for the value of exports, the output of nontradable goods, and the real rate of interest. Then, they considered a simple linear rule according to which reserves have to converge towards a target while buffering export shocks. Comparing with the reserves under household precautionary savings motive, they found that the linear rule approximates fairly well. In short, they pointed out that it is more important to properly adjust reserves in response to shocks than choosing a particular reserve target because the welfare gains from reserves management come from using the reserves rather than keeping them close to the target.

These papers, using the small open economy model for low-income countries, show the main idea that reserves play a straightforward and primary role of precautionary savings against current account shocks. In the closed economy, households with a precautionary savings motive, facing uncertainty of economy, can use assets to smooth the consumption. In the open economy, if the international asset market is accessible, households could also hold foreign assets against shocks. Also, Jeanne and Sandri [2016] provided a central bank policy rule which could capture the optimal reserves under precautionary savings motive. Except for the first reason of holding international reserves, other papers illustrate rest reasons. Korinek and Serven [2016] analyzed how reserve accumulation can serve to undervalue a country's real exchange rate and increase economic growth - reason (3) mercantilism. They argued the accumulation of international reserves as a second best policy in economies with learning-by-investing externalities. In the other direction, Benigno and Fornaro [2012] also found that the welfare gains when reserve policy is large by introducing credit shocks in the model. During periods of financial stress, the government uses foreign exchange reserves to provide liquidity to the tradable sector, which involves financial transactions with foreign investors. Espinoza and Winant [2014] still explored reason (4) with considering reason (6). In periods of sudden stops, governmentâĂŹs optimal investment levels, as well as the financing and central bank reserves decisions, are affected by the risk. His model solves a portfolio decision involving external debt, central bank reserves, and physical capital; and illustrates different functions of these assets.

1.2.3 Contributions to Literature

In general, the main objective of Dhasmana and Drummond [2008], Barnichon [2008], Valencia [2010], and Jeanne and Sandri [2016] is to explain the holding reserves under precautionary saving motive against current account shocks, similar to capital account shocks in the researches of Durdu et al. [2009], Alfaro and Kanczuk [2009], and Jeanne and Ranciere [2011]. However, the main idea of Benigno and Fornaro [2012] is that international reserves provide confidence for foreign investors, prevent a sudden flight to quality and loss of capital for the country. The shortcoming of these papers, which use the small open economy model, is that they quantify the optimal reserves only under each reason individually. In other words, they do not analyze the interactional effects of each reason on international reserves. The contribution of this paper will combine the first and the second reasons for holding international reserves to explore the amount under different exchange rate regimes. What is the level of reserves after considering a precautionary saving motive and stable exchange rate motive simultaneously? Are the results consistent with the cost-benefit method under low-income countries, as Kim et al. [2011]? Also, the foreign assets as reserves involve two purposes - precaution and investment in the standard models. This paper separates two purposes: liquidity (money) related reserve account for precautionary motive and foreign bonds for investment motive.

Last but not least, the model's structure in this paper is motivated by Einarsson et al. [2002]. He develops a simple two good small open economy model with domestic resource shock, which is the main driving force of the economy's business cycle. Households rent capital and provide labor to firms, and have access to an international bond market. Additionally, the central bank has different monetary policies under two alternative exchange rate regimes (floating exchange rate regime and monetary union). With a floating exchange rate, the central bank can implement an independent monetary policy. Under this regime, the exchange rate plays a vital role in absorbing macroeconomic shocks. However, under monetary union, the central bank could not take an independent monetary policy, since the money stock passively adjusts to any changes in the balance of payments. Under this regime, the domestic price plays a vital role in absorbing macroeconomic shocks. Klein and Shambaugh [2015] showed that a central bank could only achieve simultaneously two out of capital mobility, monetary autonomy, and pegged exchange rate objectives. If there is no constraint on capital mobility, the central bank could choose monetary autonomy or pegged exchange rate. That is the reason why the model of Einarsson et al. [2002] could choose an independent monetary policy under the floating exchange rate regime.

This paper combines Einarsson et al. [2002] - model's structure, Kim et al. [2011] - identified current account shocks, Valencia [2010] - precautionary savings, and Jeanne and Sandri [2016] - central bank policy rule. The main objective of this paper is to compare the reserves with a precautionary saving motive under the floating exchange rate regime with those under the pegged exchange rate regime for low-income countries. First, Einarsson et al. [2002] provided a suitable model's structure, including household, firm, central bank with two goods small open economy. The most important part of Einarsson et al. [2002] is that the central bank could implement different monetary policies under two alternative exchange rate regimes, so I can compare results between floating and pegged exchange rate regimes using this model's structure. Second, this paper will focus on low-income countries, which are mostly financially closed economies. Therefore, the current account shocks that were identified by Kim et al. [2011] mainly impact on these countries. Third, Valencia [2010] illustrated the mechanism of the precautionary saving - households would prefer to save more international reserves to smooth consumption facing the uncertainty. Furthermore, Jeanne and Sandri

[2016] found a linear policy rule could capture the optimal reserves under the precautionary savings motive of households. Now, this paper can obtain a central bank policy rule, which is in line with households with regards to smoothing demand fluctuations. This paper uses it for independent monetary policy under floating exchange rate regime, by which the model could get the baseline result for precautionary saving motive only as Dhasmana and Drummond [2008], Barnichon [2008], Valencia [2010], and Jeanne and Sandri [2016]. Whereas the central bank renunciates the monetary autonomy under a pegged exchange rate regime. Then, the model would get the level of reserves by considering a stable exchange rate. Finally, we can compare the reserves under different exchange rate regimes.

Facing current account shocks (including aid, terms-of-trade, external demand, foreign monetary policy, and productivity shocks), the infinitely lived representative household (with labor and capital income, and international aid) consumes imported and domestic goods by using cash (cash-in-advance). In addition to those uncertain income, the household directly holds money (reserves) for a precautionary saving motive under the central bank system. Because of the limited access to international financial markets for low-income countries, the current account shocks are the driving force of the economy's business cycle. Floating exchange rate and monetary autonomy: the central bank could pursue the independent rule which follows, as Jeanne and Sandri [2016] suggested, reserves on behalf of households under the floating exchange rate. Therefore, households could smooth the consumption in response to these shocks by "holding money (reserves)". The appropriate amount of international reserves is the household's optimal level of precautionary savings (money) in response to these shocks in the model. However, the pegged exchange rate and renunciation of monetary autonomy: the central bank should use the international reserves to stabilize the exchange rate (change money supply) and keep the balance of payments equal to zero under the pegged exchange rate. Then, this paper can analyze the behavior of households to quantify the level of money (reserves) under different exchange rate regimes.

1.3 The Theoretical Model

1.3.1 Sectors in Model

The model is a neoclassical dynamic general equilibrium model of a small economy that includes a representative household, a single aggregative firm, and a central bank. The economy receives international aid every period from the rest of the world. Additionally, the low-income countries treat aid, terms of trade, external demand, and foreign monetary policy as exogenous variables.

Firstly, the household consumes imported goods and domestic goods, also can buy foreign bonds and hold money for a precautionary savings motive, and does domestic capital investment. The amount of international reserves - assets of the central bank should be equal to money - the liabilities of the central bank. Therefore, the household's income comes from working, investment, international aid, and money holdings.

Furthermore, as Arellano et al. [2009] said, the firm in the tradable sector is labor-intensive industry, such as agriculture, mining, and manufacturing. However, the firm in the non-tradable sector is capital-intensive industry, such as water, electricity, and telecommunications. Also, Brock and Turnovsky [1994] and Goldstein and Lardy [2005] had a similar argument. Therefore, low-income countries typically specialize in low-skill labor-intensive industries and export these goods; and most non-tradable firms focus on highly capital-intensive infrastructure projects. To keep matters as simple as possible, the model assumes that a single aggregative firm would produce goods for domestic and foreign households.

Last, the central bank provides money to the household. Also, a central bank balance sheet is always balanced. The central bank can choose open economy policy between pegged exchange rate and monetary autonomy. Under the regime of a floating exchange rate, the central bank has the option of conducting an independent policy rule. The central bank is benevolent and manages money to help households fulfill the precautionary savings. However, under the regime of a pegged exchange rate, the stock of nominal balances evolves according to the balance of payments. For instance, if the current account is a deficit, the central bank would use international reserves corresponds to stabilize the foreign exchange rate.

1.3.2 Household Sector

Household maximizes expected lifetime utility, has preferences over a composite bundle of imported and domestic goods and includes disutility of labor, where γ is the coefficient of relative risk aversion, χ specifies the preference weight of hours in utility, and the Frisch elasticity for labor supply is $\frac{1}{\psi}$.

$$E_0 \sum_{t=0}^{\infty} \beta^t [\frac{c_t^{1-\gamma}}{1-\gamma} - \chi \frac{l_t^{1+\psi}}{1+\psi}]$$

The consumption - composite goods follow the constant elasticity of substitution (CES) form, where θ is the elasticity of substitution of consumption between imported and domestic goods, and ω is the weight household places on imported consumption.

$$c_t = [\omega^{\frac{1}{\theta}}(c_t^M)^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}}(c_t^N)^{\frac{\theta-1}{\theta}}]^{\frac{\theta}{\theta-1}}$$

The consumption price index P_t is CES form also, where P_t^M is the imported goods price, P_t^N is the domestic goods price, $p_t \equiv \frac{P_t}{P_t^N}$ and $p_t^M \equiv \frac{P_t^M}{P_t^N}$.

$$P_t = [\omega(P_t^M)^{1-\theta} + (1-\omega)(P_t^N)^{1-\theta}]^{\frac{1}{1-\theta}}$$
$$p_t = [\omega(p_t^M)^{1-\theta} + (1-\omega)]^{\frac{1}{1-\theta}}$$

The real exchange rate is defined as the nominal exchange rate multiplied by the ratio of the foreign CPI to the domestic CPI, where S_t denotes the nominal exchange rate (the price of one unit of foreign currency in terms of domestic currency), P_t^* denotes the nominal price of consumption in the foreign country in units of foreign currency, and P_t denotes the nominal price of consumption in the domestic country in the units of domestic currency.

$$e_t \equiv \frac{S_t P_t^*}{P_t}$$

Household has access to an international bond market, holds money for consumption and capital investment, receives labor income, and international aid, where aid D_t^* is exogenous stochastic processes. The household's budget constraint:

$$P_t c_t + S_t B_t^* + I_t + M_t = P_t^N(w_t l_t + r_t^K k_{t-1}) + S_t i_{t-1}^* B_{t-1}^* + S_t D_t^* + M_{t-1}$$

Household cash-in-advance constraint[9]:

$$P_t c_t + I_t \leq M_{t-1}$$

If $i_t^* \geq 1$, money is always dominated by foreign bond assets, and the cash-in-advance constraint would always hold with equality. The precautionary demand for liquidity leads to increased holding of liquid assets in response to income risk. The law of motion for domestic capital:

$$k_t = (1-\delta)k_{t-1} + \frac{I_t}{P_t^N}$$

In the real term:

[9] In particular the CIA constraint may not be bound under the timing assumption of Svensson [1985]. Similar to the household's borrowing constraint, the borrowing constraint is not a necessary condition to generate a precautionary motive. Carroll [2004] and Sandri [2014] argued that, only given a big negative shock, the borrowing constraint would be bound. The model assumes that the CIA constraint is bound.

$$
\begin{aligned}
&p_t c_t + p_t e_t b_t^* + k_t - (1-\delta)k_{t-1} + p_t m_t \\
&= w_t l_t + r_t^K k_{t-1} + p_t e_t b_{t-1}^* \frac{i_{t-1}^*}{\pi_t^*} + p_t e_t d_t^* + \frac{p_t m_{t-1}}{\pi_t} \\
&p_t c_t + k_t - (1-\delta)k_{t-1} = p_t \frac{m_{t-1}}{\pi_t}
\end{aligned}
$$

where $b_t^* \equiv \frac{B_t^*}{P_t^*}$, $m_t \equiv \frac{M_t}{P_t}$, $\pi_t^* = \frac{P_t^*}{P_{t-1}^*}$, $d_t^* \equiv \frac{D_t^*}{P_t^*}$, and $\pi_t = \frac{P_t}{P_{t-1}}$.

1.3.3 Firm Sector

The aggregative firm produces output with a Cobb-Douglas and constant returns to scale form, where A_t is an exogenous productivity shock. Also, the firm is competitive, choose labor and capital to maximize profit.

To keep matters as simple as possible, the model assumes that a single aggregative firm would produce goods for domestic and foreign households. Firm's production function:

$$y_t = A_t (l_t^d)^\alpha (k_t^d)^{1-\alpha}$$

The profit of the firm in a perfectly competitive industry:

$$\Pi_t = y_t - w_t l_t^d - r_t^K k_t^d$$

The productivity shock of the firm:

$$\ln A_t - \ln \bar{A} = \rho_A(\ln A_{t-1} - \ln \bar{A}) + \epsilon_t^A$$

1.3.4 Central Bank

In international macroeconomics: the central bank can only simultaneously achieve two out of the three objectives, which include capital mobility, monetary autonomy, and pegged exchange rate. Hence, the central bank can choose "floating exchange rate and monetary autonomy" or "pegged exchange rate and renunciation of monetary autonomy".

Under the floating exchange rate regime, the central bank could conduct an independent policy rule. Einarsson et al. [2002] presented the monetary authority has the option of conducting an independent policy rule, which may or may not be state dependent. The policy rule could be influenced by asset holdings, resources, productivity, terms of trade $\frac{P_t^X}{P_t^M}$, and external demand x_t^*, such as $M_t^s = F(A_t, d_t^*, \frac{P_t^X}{P_t^M}, x_t^*, M_{t-1}^s)$. The model assumes a simple ad hoc state dependent policy rule, as Jeanne and Sandri [2016], in which money growth partly accommodates output growth. This independent policy rule implies more price stability than a constant money growth. In this model, the liabilities of the central bank are money and assets are reserves. Therefore, the net change in money shows the net change in reserves in domestic currency ($V_t = M_t^s - M_{t-1}^s$).

$$M_t^s = \bar{\mu}(\frac{y_t}{y_{t-1}})^\zeta M_{t-1}^s$$

$$M_t^s = M_{t-1}^s + V_t$$

where $\bar{\mu}$ is the mean gross growth rate, and ζ measures the degree of money growth in response to output growth.
In the real term:

$$m_t^s = \bar{\mu}(\frac{y_t}{y_{t-1}})^{\zeta}\frac{m_{t-1}^s}{\pi_t}$$
$$m_t^s = \frac{m_{t-1}^s}{\pi_t} + v_t$$

Under the pegged exchange rate regime, the stock of money evolves according to the balance of payments, where V_t is the balance of payments residual (changed reserves). The balance of payments should be equal to the sum of the current account and capital account. The current account involves net export, net income from abroad, and net current transfers. The capital account shows the net change in foreign bond investments and reserves.

$$V_t = P_t^X x_t^* - P_t^M c_t^M + S_t D_t^* + S_t i_{t-1}^* B_{t-1}^* - S_t B_t^*$$
$$M_t^s = M_{t-1}^s + V_t$$

The pegged exchange rate regime needs

$$S_t = S_{t-1}$$

In the real term:

$$p_t v_t = p_t^X x_t^* - p_t^M c_t^M + p_t e_t d_t^* + p_t e_t \frac{i_{t-1}^*}{\pi_t^*} b_{t-1}^* - p_t e_t b_t^*$$

$$m_t^s = \frac{m_{t-1}^s}{\pi_t} + v_t$$

$$\frac{\pi_t^*}{\pi_t} = \frac{e_t}{e_{t-1}}$$

where $v_t \equiv \frac{V_t}{P_t}$.

1.3.5 Equilibrium

A competitive equilibrium of the model includes the following conditions.

Labor holds the factor market clearing.

$$l_t = l_t^d$$

Capital also holds the factor market clearing.

$$k_{t-1} = k_t^d$$

Output market equilibrium:

$$P_t^N y_t = P_t^X x_t^* + P_t^N c_t^N + I_t$$

In the real term:

$$y_t = p_t^X x_t^* + c_t^N + k_t - (1-\delta)k_{t-1}$$

Import price and terms of trade:

$$P_t^M = S_t P_t^*$$
$$tot_t = \frac{P_t^X}{P_t^M}$$

In the real term:

$$p_t^M = p_t e_t$$
$$tot_t = \frac{p_t^X}{p_t^M} = \frac{p_t^X}{p_t e_t}$$

Money market equilibrium:

$$M_t^s = M_t$$
$$M_t = M_{t-1} + V_t$$
$$M_t = \bar{\mu}(\frac{y_t}{y_{t-1}})^\zeta M_{t-1} \qquad \text{(floating)}$$
$$S_t = S_{t-1} \qquad \text{(pegged)}$$

Balance of payments equilibrium:

$$V_t = M_t - M_{t-1} = P_t^X x_t^* - P_t^M c_t^M + S_t D_t^* + S_t i_{t-1}^* B_{t-1}^* - S_t B_t^*$$

1.3.6 Model in Full

For the small open economy, the low-income countries face external shocks (stationary and Markov) each period, including d_t^* measures international aid shocks; tot_t measures terms of trade shocks; x_t^* measures external demand shocks; and i_t^* measures foreign monetary policy shocks. The formulas follow the same forms as productivity shocks.

After setting up the problem for low-income countries, the competitive equilibrium of this model should satisfy the following conditions, such as (i) household maximizes utility subject to the budget constraint and cash-in-advance constraint given prices, (ii) aggregative firm maximizes profit given prices, (iii) the central bank budget constraint is satisfied, and (iv) markets are clear.

The model in full: By normalizing the foreign price level P_t^* to unity, the model does not distinguish between real and nominal terms in the foreign sector. Endogenous state variables include k_t, b_t^*, m_t. Endogenous control variables include c_t, c_t^N, c_t^M, l_t, r_t^K, w_t, p_t, p_t^X, π_t, e_t. Exogenous variables include A_t, d_t^*, tot_t, x_t^*, i_t^*

$$p_t \frac{\chi l_t^{\psi}}{w_t} = \beta E_t \left(\frac{1}{\pi_{t+1}} c_{t+1}^{-\gamma} \right) \tag{1.1}$$

$$p_t \frac{\chi l_t^{\psi}}{w_t} e_t = \beta E_t (p_{t+1} \frac{\chi l_{t+1}^{\psi}}{w_{t+1}} e_{t+1} i_t^*) \tag{1.2}$$

$$\frac{c_t^{-\gamma}}{p_t} = \beta E_t [r_{t+1}^K \frac{\chi l_{t+1}^{\psi}}{w_{t+1}} + (1-\delta) \frac{c_{t+1}^{-\gamma}}{p_{t+1}}] \tag{1.3}$$

$$(p_t e_t)^{\theta} = \frac{\omega}{1-\omega} \frac{c_t^N}{c_t^M} \tag{1.4}$$

$$p_t c_t + k_t - (1-\delta) k_{t-1} = p_t \frac{m_{t-1}}{\pi_t} \tag{1.5}$$

$$c_t = [\omega^{\frac{1}{\theta}} (c_t^M)^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} (c_t^N)^{\frac{\theta-1}{\theta}}]^{\frac{\theta}{\theta-1}} \tag{1.6}$$

$$p_t = [\omega (e_t p_t)^{1-\theta} + (1-\omega)]^{\frac{1}{1-\theta}} \tag{1.7}$$

$$\alpha A_t (l_t)^{\alpha} (k_{t-1})^{1-\alpha} = w_t l_t \tag{1.8}$$

$$(1-\alpha) A_t (l_t)^{\alpha} (k_{t-1})^{1-\alpha} = r_t^K k_{t-1} \tag{1.9}$$

$$A_t (l_t)^{\alpha} (k_{t-1})^{1-\alpha} = p_t^X x_t^* + c_t^N + k_t - (1-\delta) k_{t-1} \tag{1.10}$$

$$p_t^X = p_t e_t tot_t \tag{1.11}$$

$$p_t(m_t - \frac{m_{t-1}}{\pi_t}) = p_t^X x_t^* - p_t e_t c_t^M + p_t e_t d_t^* + p_t e_t i_{t-1}^* b_{t-1}^* - p_t e_t b_t^* \quad (1.12)$$

$$m_t = \bar{\mu}(\frac{y_t}{y_{t-1}})^{\zeta} \frac{m_{t-1}}{\pi_t} \quad \text{(floating)}$$
$$\frac{1}{\pi_t} = \frac{e_t}{e_{t-1}} \quad \text{(pegged)}$$
$$(1.13)$$

$$\ln A_t - \ln \bar{A} = \rho_A(\ln A_{t-1} - \ln \bar{A}) + \epsilon_t^A \quad (1.14)$$

$$\ln d_t^* - \ln \bar{d}^* = \rho_d(\ln d_{t-1}^* - \ln \bar{d}^*) + \epsilon_t^d \quad (1.15)$$

$$\ln tot_t - \ln \bar{tot} = \rho_T(\ln tot_{t-1} - \ln \bar{tot}) + \epsilon_t^T \quad (1.16)$$

$$\ln x_t^* - \ln \bar{x}^* = \rho_x(\ln x_{t-1}^* - \ln \bar{x}^*) + \epsilon_t^x \quad (1.17)$$

$$\ln i_t^* - \ln \bar{i}^* = \rho_i(\ln i_{t-1}^* - \ln \bar{i}^*) + \epsilon_t^i \quad (1.18)$$

The sequence of decisions for low-income countries in this model is as follows. At time t, the household has the capability for consumption and capital investment only the cash carried over from the previous period $t-1$, so cash balances must be chosen before the household knows how much spending they will wish to undertake. Then, the household realizes exogenous shocks: the productivity, aid, terms of trade, external demand, and foreign monetary policy shocks. Domestic capital, foreign bonds, and money are predetermined. The household chooses consumption (given level of composite goods, minimize the cost of imported goods and domestic goods) and capital investment first subject to the cash-in-advance constraint, then makes foreign bonds decision. The firm chooses capital and labor to produce output. Central bank supplies money and also holds reserves ($M_t - M_{t-1} = V_t$). Therefore, money (as reserves) could measure lower bound precautionary saving motive from the household side. Prices and exchange rates are determined at this time.

In short, facing the uncertainty, the household under this model tries to balance the interrelationships of investment, money, and foreign bonds. Because the uncertainty is realized after money balances are chosen, a household may find that the holding money is too low to finance the desired consumption and capital investment level. Alternatively, the household maybe hold more money than needs, thereby giving up the interest income. For explaining these interrelationships, Valencia [2010] introduces two terms “prudence" (the agent saves international reserve in order to minimize the impact of future shocks on consumption) and “impatience" (the agent prefers to spend today rather than tomorrow). The optimal level of international reserves should satisfy the condition - these interrelationships are exactly balanced.

1.3.7 Precautionary Savings

Crucially, the agent's asset holding - reserves and foreign bonds ($a_t \equiv m_t + e_t b_t^*$) can smooth the consumption against the uncertainty. Comparing with the standard precautionary saving problem, we can simplify the above model to understand this motive clearly. However, the standard model involves two purposes - precaution and investment for the saving assets.

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t)$$

subject to[10]

$$p_t c_t + k_t - (1-\delta)k_{t-1} + p_t a_t$$
$$= w_t l_t + r_t^K k_{t-1} + p_t e_t d_t^* + p_t \frac{i_{t-1}}{\pi_t} a_{t-1} - p_t \frac{(i_{t-1}-1)}{\pi_t} m_{t-1}$$

rearrange budget constraint

$$a_t = (\frac{i_{t-1}}{\pi_t} a_{t-1} - c_t - \frac{k_t}{p_t}) + \frac{y_t}{p_t} + (1-\delta)\frac{k_{t-1}}{p_t} + e_t d_t^* - \frac{(i_{t-1}-1)}{\pi_t} m_{t-1}$$

The rearranged budget constraint is similar to the extended precautionary savings model of Valencia [2010] $x_{t+1} = R(x_t - c_t - k_t) + \tau_{t+1} k_t^{\alpha} + (1-\delta)k_t + a$, where x_t is net foreign assets, R is a risk-free security yield, c_t is consumption, k_t is the capital, $\tau_{t+1} k_t^{\alpha}$ is income from exports, and a is all other non-export net current receipts. However, the last term of rearranged budget constraint is a cost to holding money when the net nominal interest rate $(i_{t-1} - 1)$ is positive. Due to the carry cost of money, the overall asset holding could focus on precautionary purpose.

For the relation between the asset holdings and carry costs, the reduced form

[10] UIP is $i_{t-1} = \frac{S_t}{S_{t-1}} i_{t-1}^*$, in the real term $\frac{i_{t-1}}{\pi_t} = \frac{e_t}{e_{t-1}} \frac{i_{t-1}^*}{\pi_t^*}$.

model adds the carry cost of reserves, as shown by Jeanne and Sandri [2016]

$$\xi = \frac{G^{\gamma}}{\beta} - (1 + r^{*})$$

, where G is the growth rate of the economy. This is another way to decompose these two purposes. Therefore, $\frac{G^{\gamma}}{\beta}$ would be the interest rate under financial autarky. $1+r^{*}$ is the rate of return of holding reserves. Then, the difference between the two terms is the carry cost. If the carry cost ξ is positive, holding reserves should face an opportunity cost that ensures a finite level of reserves. The higher carry cost ξ would cause the reserves (money) to decrease.

In the low-income small open economy, the social planner is isolated from almost all asset markets and can only hold some amounts of international reserves (risk-free asset) to acquire "self-insurance" against the uncertain income. For instance, the social planner can draw international reserves, in response to low income realizations, and avoid large temporary drops in consumption. In contrast, the social planner can buy international reserves, when the income is high, in anticipation of poor outcomes in the future. Also, the social planner now finds it profitable to cut consumption and finance the stock of capital. In shorts, total savings could fulfill the precautionary motive and finance the capital stock. Plugging UIP into the constraint gets

$$a_t = (\frac{e_t}{e_{t-1}} \frac{i^{*}_{t-1}}{\pi^{*}_t} a_{t-1} - c_t - \frac{k_t}{p_t}) + \frac{y_t}{p_t} + (1-\delta)\frac{k_{t-1}}{p_t} + e_t d^{*}_t - (\frac{e_t}{e_{t-1}} \frac{i^{*}_{t-1}}{\pi^{*}_t} - \frac{1}{\pi_t}) m_{t-1}$$

The precautionary savings could be influenced by the real exchange rate and disposable income fluctuations under external shocks.

Due to the precautionary saving motive, a social planner can choose immediately to use his saving against the negative wealth effect to smooth consumption over time in low-income countries. After understanding the carry cost and precautionary motive, back to our original model, the central bank could help consumers to hold reserves indirectly and to get a similar allocation in the equilibrium to occupy most welfare level as a social planner's problem. Therefore, the original model under a floating exchange rate regime assumes the independent policy rule should care about the precautionary motive, such as money supply depends on output shocks while buffering income fluctuations. However, the original model under a pegged exchange rate regime assumes the central bank's objective is pegging the exchange rate. Then, we can explore external shocks under different exchange rate regimes with the precautionary saving motive.

1.4 Results

1.4.1 Data

This paper collects the panel data of 70 low-income countries[11] between 1966 and 2015 from the World Bank's World Development Indicators (WDI) database, Shambaugh exchange rate classification data set[12], and Emergency Events Database

[11] The countries include: Afghanistan; Bangladesh; Benin; Bhutan; Burkina Faso; Burundi; Cambodia; Cameroon; Cabo Verde; Central African Republic; Chad; Comoros; Congo, Dem. Rep.; Congo, Rep.; Cote d'Ivoire; Djibouti; Dominica; Eritrea; Ethiopia; Gambia, The; Ghana; Grenada; Guinea; Guinea-Bissau; Guyana; Haiti; Honduras; Kenya; Kiribati; Kyrgyz Republic; Lao PDR; Lesotho; Liberia; Madagascar; Malawi; Maldives; Mali; Marshall Islands; Mauritania; Micronesia, Fed. Sts.; Moldova; Mozambique; Myanmar; Nepal; Nicaragua; Niger; Papua New Guinea; Rwanda; Samoa; Sao Tome and Principe; Senegal; Sierra Leone; Solomon Islands; Somalia; South Sudan; St. Lucia; St. Vincent and the Grenadines; Sudan; Tajikistan; Tanzania; Timor-Leste; Togo; Tonga; Tuvalu; Uganda; Uzbekistan; Vanuatu; Yemen, Rep.; Zambia; Zimbabwe. See Figure 1.1.

[12] Shambaugh [2004], Klein and Shambaugh [2008], Obstfeld et al. [2010], and Klein and Shambaugh [2012] provided the classification of an exchange rate regime. Here, the paper would

(EM-DAT) published by the Center for Research on the Epidemiology of Disasters (CRED). Firstly, Figure 1.2 displays the reserves-to-imports ratio in months over time for different countries. There is an upward trend around the 3-months-of-imports rule of thumb. Figure 1.3 shows the distribution of reserves-to-imports ratio in months, which summarizes mean, median, and skewness to know the reserves of these low-income countries.

Then, the parameters in this model should be calibrated to replicate the key characteristics. Some parameters are taken from other papers and researches. For the relative risk aversion coefficient γ is set to 2 (Jeanne and Sandri [2016]); the elasticity of substitution between imported and domestic consumption θ is equal to 0.76 (Ostry and Reinhart [1992]); and the depreciation rate δ is 0.05, which is taken from Arellano et al. [2009]. Due to the standard values used in the RBC model, the preference weight of labor in utility χ is 1; Frisch elasticity for labor supply $\frac{1}{\psi}$ is 1/0.6; the world interest rate $\bar{i}^*$ is 1.02; the discount factor β is 1/1.02. Others base on the panel data: the labor share of production α is 0.79 by the production regression; the mean gross growth rate of money $\bar{\mu}$ is 1; buffering output shocks ζ is 0.26; weight of imported consumption in the gross consumption ω is 0.43 and mean levels of some external shocks are in the following table, which uses the similar methods as Arellano et al. [2009] and Jeanne and Sandri [2016]. The stochastic process for all the external shocks can get ρ and σ using detrended panel data[13]. Table 1.1 presents all the parameters used in the calibration.

use this measure of exchange rate regime based on the classification in Shambaugh [2004].

[13]This paper uses Hamilton [2018] method to detrend data.

Parameter	Symbol	Value
Discount factor	β	1/1.02
Relative risk aversion coefficient	γ	2
Depreciation rate	δ	0.05
Labor share of production	α	0.79
Mean gross growth rate of money	$\bar{\mu}$	1
Buffering output shocks	ζ	0.26
Preference weight of labor in utility	χ	1
Frisch elasticity for labor supply	$1/\psi$	1/0.6
Elasticity of substitution between imported and domestic consumption	θ	0.76
Weight of imported consumption in the gross consumption	ω	0.43
Productivity level	$\bar{A}$	1
Aid level	$\bar{d}^*$	0.202
Terms of trade level	$\bar{tot}$	1
External demand level	$\bar{x}^*$	0.318
World interest rate	$\bar{i}^*$	1.02
Autocorrelation coefficient of productivity shocks	ρ_A	0.43
Autocorrelation coefficient of aid shocks	ρ_d	0.43
Autocorrelation coefficient of terms of trade shocks	ρ_T	0.47
Autocorrelation coefficient of external demand shocks	ρ_x	0.47
Autocorrelation coefficient of foreign monetary policy shocks	ρ_i	0.50
Standard deviation of productivity shocks	σ_A	0.06
Standard deviation of aid shocks	σ_d	0.36
Standard deviation of terms of trade shocks	σ_T	0.16
Standard deviation of external demand shocks	σ_x	0.28
Standard deviation of foreign monetary policy shocks	σ_i	0.02
Correlation between terms of trade and external demand	$corr(\epsilon^T, \epsilon^x)$	-0.0939
Correlation between terms of trade and foreign monetary policy	$corr(\epsilon^T, \epsilon^i)$	0.0563
Correlation between external demand and foreign monetary policy	$corr(\epsilon^x, \epsilon^i)$	-0.0044

Table 1.1: Calibration for the benchmark model

1.4.2 Impulse Response Function

Figure 1.4 to Figure 1.7 shows the impulse response functions to the external shocks in productivity, aid, terms of trade, external demand, and foreign monetary policy under the floating exchange rate regime. The largest shock is terms of trade, and the smallest is foreign monetary policy (federal funds rate - FFR). When negative shock impacts on productivity with one standard deviation, it will decrease output and increase inflation. The substitute effect would cause households to consume more import and reduce investment with the CIA constraint.

It decreases a tiny amount of precautionary savings, which spend a long time going to the new steady state. Espinoza and Winant [2014] found that natural disasters (one component of productivity shocks) do not increase the probability of drawing down reserves. The effects of aid shocks are minimal for output and inflation, compared with others. The findings between consumption and investment are consistent with Arellano et al. [2009] who said a permanent flow of aid mainly finances consumption rather than investment, as the historical failure of aid inflows to translate into sustained growth. However, the effect causes more labor supply and less precautionary savings. Importantly, negative export shocks, including terms of trade and external demand, will decrease output and inflation. The decrease in terms of trade means export price relative to import price is cheaper, so domestic consumption rises and import falls. The negative shocks on external demand would cause the current account deficit, so the same results are as decrease in terms of trade. The real exchange rate depreciates, and the nominal exchange rate has a lagged effect. Under both shocks, there is a shift between the precautionary motive and investment motive. Facing uncertainty, the households save more money (reserves) for consumption smoothing and reduce foreign bond holdings. Then, the overall precautionary savings fall because of an increase in carry costs after this shift. Last but not least, the negative impact on foreign monetary policy would cause foreign output and inflation to increase. Therefore, the external demand and import price increases for the trade channel. What's more, the real and nominal exchange rates appreciate due to a decrease in the foreign interest rate. For the financial channel, households would decrease foreign bond holdings with less return. The domestic output and domestic consumption are a slight decrease after this shock. However, composite consumption and import increase a lot. Because this is a good scenario for the domestic economy, the precautionary savings are accumulated with the current account surplus.

Figure 1.8 to Figure 1.11 illustrates the effects of external shocks under the pegged exchange rate regime. The patterns are very similar to the effects under the floating exchange rate regime, except ones under the foreign monetary policy shock. Although the patterns are similar, the initial deviations are more significant with the pegged exchange rate regime. Figure 1.10 presents the impulse response functions of precautionary savings to the external shocks under the pegged exchange rate regime. The agents will use assets to stabilize the exchange rate and smooth consumption against the external shocks. So, the initial deviation of precautionary savings with foreign monetary policy shock is negative, instead of positive under the floating exchange rate. Under the floating exchange rate regime, agents cut the precautionary savings to smooth domestic absorption[14]. Compared with the floating exchange rate, the external shocks will consume much more reserves initially and similarly cause a permanent effect to lower the international reserves (except negative foreign monetary policy shock) under the pegged exchange rate. Figure 1.9 hints that households have more volatile composite consumption in order to satisfy the pegged exchange rate purpose. In other words, if the country wants to fulfill both pegged exchange rate and smoothing consumption purpose, the central bank will hold more reserves and choose softpegs[15].

[14]Agents would accumulate the precautionary savings, facing negative foreign monetary policy shock.

[15]Obstfeld et al. [2010] described 4 possibilities of softpeg: (1) maintains exchange rate within 5% up or down bands and has a maximum monthly change of less than 1%, but is not a peg; (2) maintains exchange rate within 5% bands against the base currency but outside of 2% bands and has some month where the change is greater than 1%; (3) has no month in which the exchange rate changes by more than 2% up or down, but violates the 5% band rule; (4) 0% change in 11 out of 12 months.

After analyzing the smoothing consumption and precautionary savings, the model also shows variables with adverse monetary policy shocks would be influenced differently under different exchange rate regimes. The Euler equation implies uncovered interest parity, so there is a strong relationship between the exchange rate and interest rate. Furthermore, higher interest rates increase the value of a country's currency. The different exchange rate regimes would cause different responses of variables with negative monetary policy shocks. Unlike the floating exchange rate regime, the increase in import price with pegged nominal exchange rate would cause an increase in low-income country CPI inflation. Additionally, the pegged nominal exchange rate triggers less volatile deviations in import and real exchange rate at the beginning. However, labor and output decrease a lot under the pegged exchange rate regime. Although the external demand increases, the decrease in terms of trade has a large negative impact on the domestic economy.

From Table 2.2, the real output[16] and real domestic consumption more volatile, but import for consumption is less volatile under pegged exchange rate regime. The pegged exchange rate could reduce the variance of import price in domestic currency, so it not only narrows volatility of import but also decreases the deviation of composite price and CPI inflation. As a result, the real exchange rate has a small variance under the pegged exchange rate regime. The real money (reserves) is less volatile with the floating exchange rate, whereas the real foreign bonds are more volatile. Under the floating exchange rate regime, the nominal exchange rate, including real exchange rate and CPI, can absorb the macroeconomic shocks. However, the inverse inflation is equal to the changed real exchange rate under the

[16]The empirical data - real GDP per capita also shows significant variance under the pegged exchange rate regime.

pegged exchange rate regime. The agents should use more precautionary savings to maintain the pegged exchange rate and smooth consumption. Also, a significant shift under terms of trade, external demand, and foreign monetary policy shocks from investment motive to precautionary motive for both regimes, when agents face uncertainty. Therefore, the welfare gains from precautionary savings come from using the reserves rather than keeping them close to the target.

Variable	Regime	Symbol	Variance
real output	[float]	y	0.008879
	[peg]		0.009295
real domestic consumption	[float]	c^N	0.000475
	[peg]		0.000503
real import	[float]	c^M	0.003530
	[peg]		0.003326
real money (reserves)	[float]	m	0.011521
	[peg]		0.014981
real foreign bonds	[float]	b^*	7.538162
	[peg]		6.983300
inflation	[float]	π	0.004120
	[peg]		0.003060
real exchange rate	[float]	e	0.008634
	[peg]		0.008307

Table 1.2: Moments of simulated variables

1.5 Conclusion

This work to date uses the theoretical model and simulation to illustrate how precautionary savings change in response to the current account shocks. For low-income countries, the main external shocks are from the current account. The model includes five shocks: productivity, international aid, terms of trade, external demand, and foreign monetary policy. Under the floating exchange rate regime, the results show the assets (money/reserves and foreign bonds) with the precautionary motive to smooth the consumption. However, the assets not only stabilize the exchange rate purpose, but also smooth consumption under the pegged exchange rate regime. Facing uncertainty, households put more weight on precautionary motive, instead of investment motive. The impulse response function from the benchmark model simulation reveals that the initial deviations are more significant with the pegged exchange rate regime. The floating exchange rate regime could reduce the variance of domestic consumption, while the pegged exchange rate regime would be better to stabilize imported consumption. Interestingly, the foreign monetary policy shocks show significant differences between the two regimes. Although the federal funds rate (world interest rate) shocks are the smallest among these five shocks, the effects on some variables are as large as the effects of productivity shocks. However, future research may develop other aspects.

First, this neoclassical dynamic general equilibrium model of a small economy ignores the vital role of sticky prices. The impulse response function shows the dynamic deviations of CPI/PPI gaps with different shocks under two regimes. The price channel is a significant and crucial part of transferring current account shocks of low-income countries. Therefore, the New Keynesian small open economy model is more suitable. Second, this model assumes a simple ad hoc state dependent policy rule, which may not be an excellent monetary policy rule to mimic real world behavior. Jeanne and Sandri [2016] implies that foreign bond holding partly accommodates the prior foreign bond level and exogenous shocks ($\frac{P_t^X}{P_t^M}$ is terms of trade, x_t is the external demand - export shocks). They found reserves have to converge towards a target level and buffer terms of trade and external demand shocks (export shocks). Based on their findings, central bank police rule is $M_t = M_{t-1} + \mu(M - M_{t-1}) + \tau(P_t^X x_t - P^X x)$. In this policy rule, parameter μ captures the speed of convergence to the target level, and the parameter τ is buffering the export shocks. If the central bank ignores the money (reserve) target ($\mu = 0$), the money will be more volatile following the external shocks as the original model. The CIA model could shed some light on the precautionary saving problem with the central bank strategy, but the results would be sensitive to the monetary policy rule equation. However, the New Keynesian model involves the interest rate as a tool under the Taylor rule instead of the money supply, which is a more popular assumption in the theoretical model. Third, this model finds that the economy is a different response to foreign monetary policy shocks under two regimes. The main transmission channels of federal funds rate shocks are the exchange rate, the international trade market, and the international financial market. In this model, the exogenous correlations of terms of trade, external demand, and foreign monetary policy shocks capture the mechanism of the international trade market channel. A negative shock of foreign monetary policy would cause foreign economy output and inflation to increase. Then, the domestic economy is more likely to face an increase in external demand. However, the exchange rate could fall with this negative shock, and import price in foreign currency would rise. So, the total effect on terms of trade depends on the net effect from both domestic and foreign economies. The missing part of this model is the foreign economy (the rest world), which would show the endogenous mechanism of the international trade market channel and reduce model assumptions. Also, this model does not include the government spending or transfer and domestic bonds, which would also influence precautionary savings. Moore and Glean [2016] found that the fiscal policy of government would influence reserves. If countries feel less need to hold precautionary reserves, macro-prudential policies may lead to less international reserves; or if policies help prevent outflows of international reserves, it could lead to more international reserves. Aizenman et al. [2015] found the negative impact of macro-prudential policies for developed countries and the positive one for developing countries.

This model reveals the precautionary savings of low-income countries against current account shocks. Are the findings also consistent with emerging market countries that are financially open economies? Now, we need to consider capital account shocks. Also, some emerging market countries are not small so that the countries would affect the price of tradable goods. China is a good case to quantify how much"mercantilist" and "precautionary" motives have contributed to the enormous reserves. Aizenman and Lee [2007] constructed a minimal model and a new empirical analysis to identify the contributions of precautionary and mercantilist motives to international reserves build-up. They found that trade openness and financial crises are essential in explaining the patterns of hoarding reserves, but the mercantilist motive is not. Also, Schröder [2017] undertook an empirical investigation and found precautionary motives are the dominant reason instead of mercantilist motives under two vastly differing approaches. Another avenue for future research is to test whether the findings from the model are consistent with empirical results. Using the data of low-income or emerging market countries, empirical research can estimate how the external shocks would affect the economy. Moreover, the empirical field could analyze the interaction effect of variables to solve the endogenous problem. Finally, monetary policy shocks would affect the economy through different channels. The empirical tests could reveal the result of each channel.

Overall, the objective is to develop a better theoretical and empirical understandings of the effects of external shocks. Currently, this paper focuses on the interactional effect between the precautionary motive and investment motive, and between consumption smoothing and exchange rate stabilization. Using a small open economy model for low-income countries, this paper shows that asset holdings (money/reserves and foreign bonds) smooth consumption under different exchange rate regimes and presents how agents shift motivations in response to the current account shocks. In the model, the precautionary savings include money and foreign bonds. The households choose money (reserves) for precautionary purposes and foreign bonds for investment motives. At the same time, the central bank supplies money to fulfill different exchange rate regimes. The next one will plan to extend the model to the New Keynesian model adding missing parts and find detailed empirical results of low-income or emerging market countries to supplement the theoretical model.

Appendix 1.A Graphs

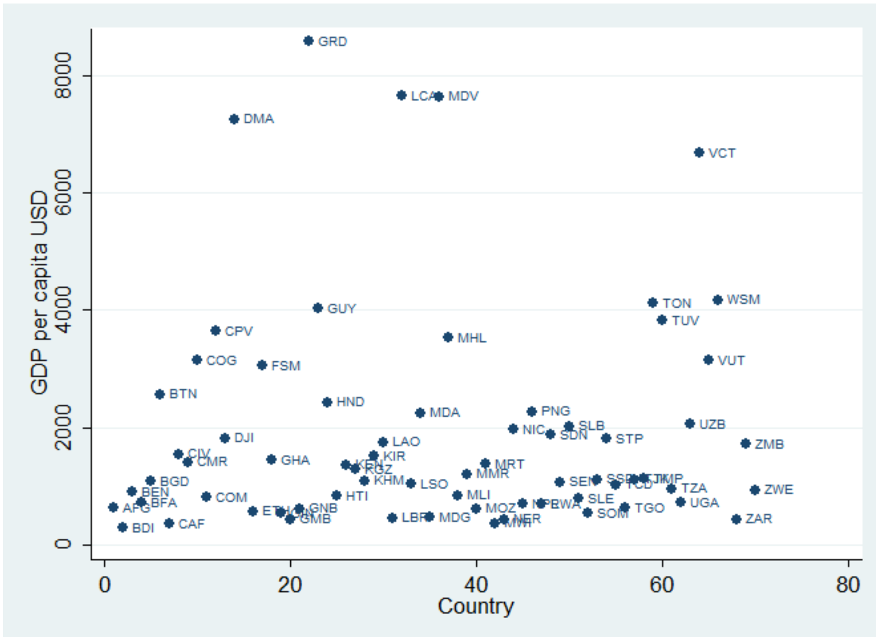

Figure 1.1: 70 low-income countries GDP per capita in 2014 (USD)

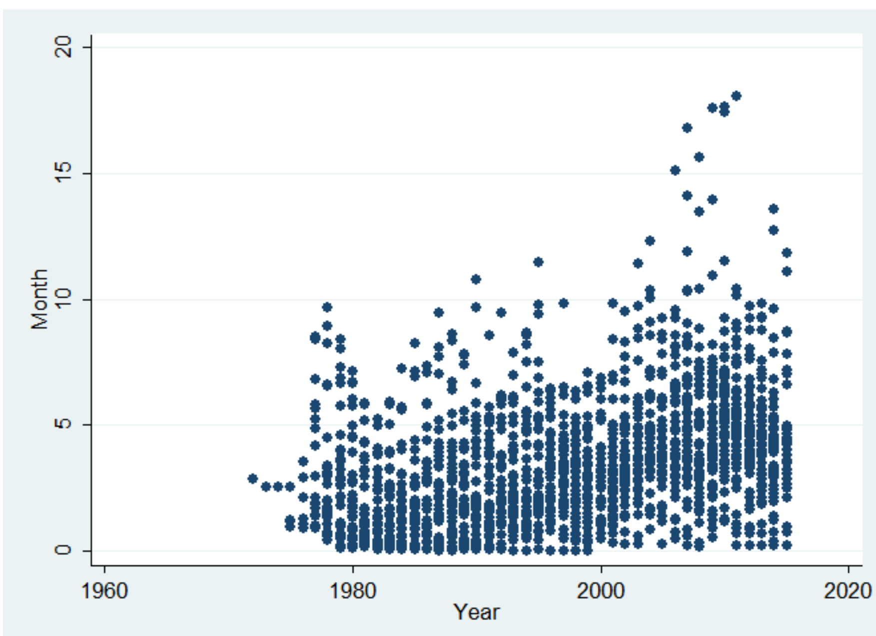

Figure 1.2: The reserves-to-imports ratio in months

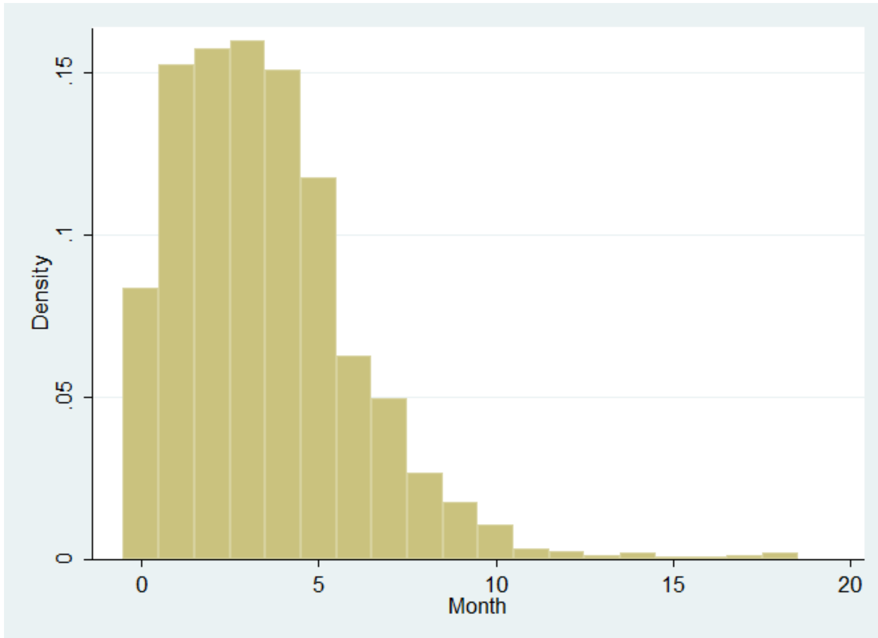

Figure 1.3: The distribution of reserves-to-imports ratio in months

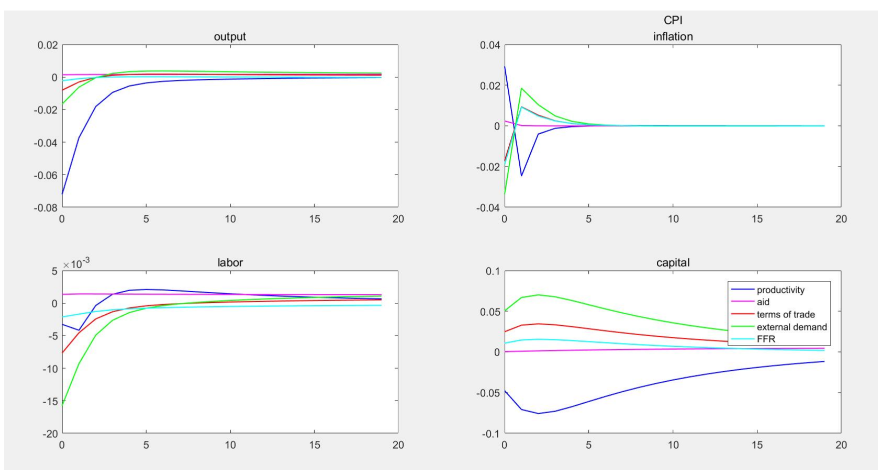

Figure 1.4: Floating regime - IR to external shocks

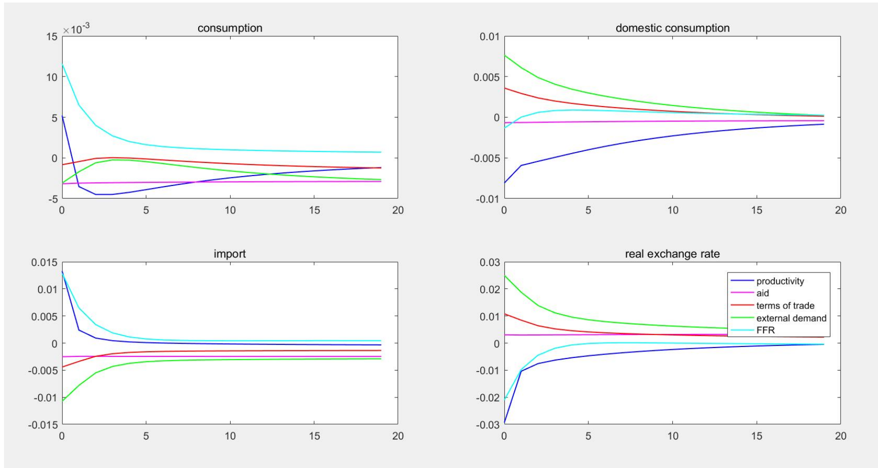

Figure 1.5: Floating regime - IR to external shocks

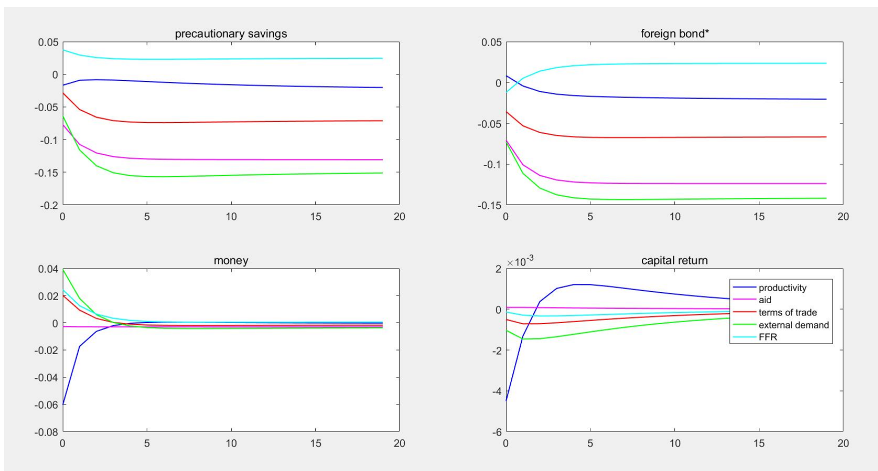

Figure 1.6: Floating regime - IR to external shocks

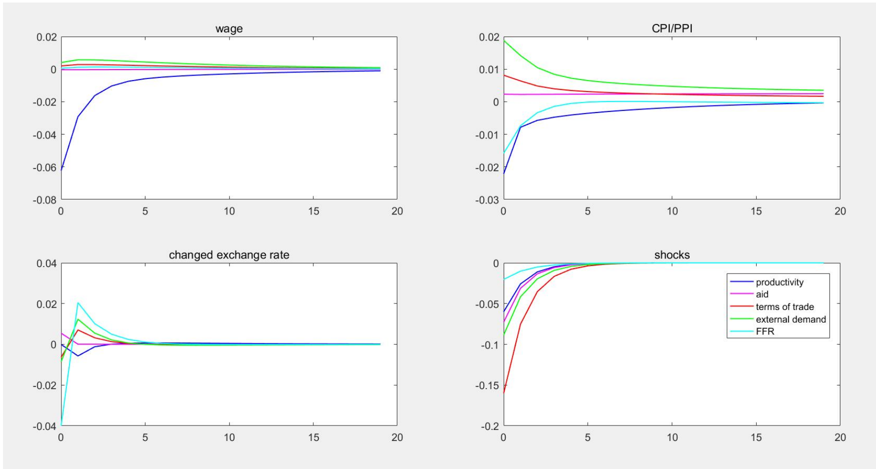

Figure 1.7: Floating regime - IR to external shocks

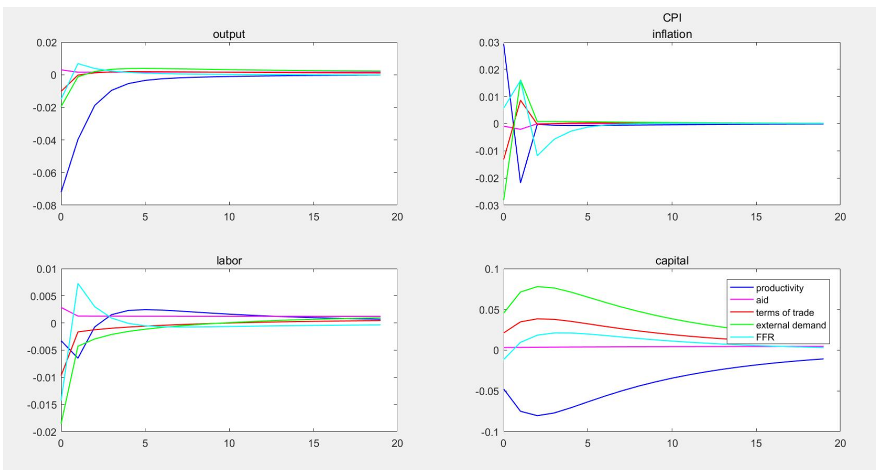

Figure 1.8: Pegged regime - IR to external shocks

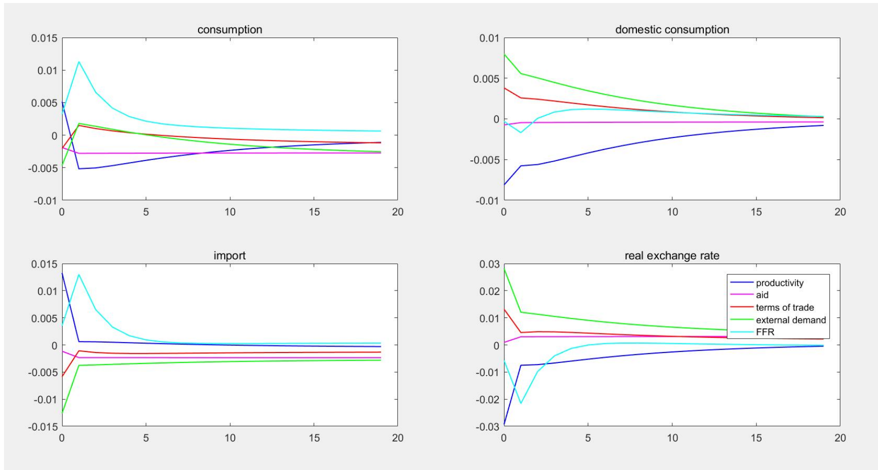

Figure 1.9: Pegged regime - IR to external shocks

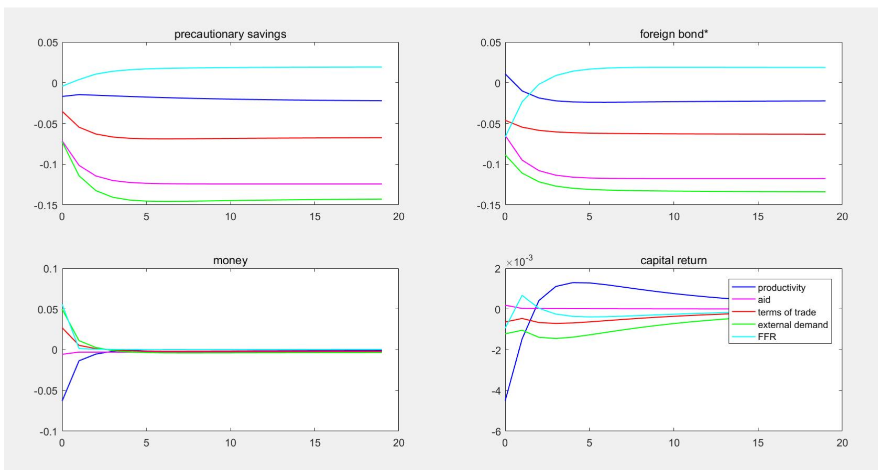

Figure 1.10: Pegged regime - IR to external shocks

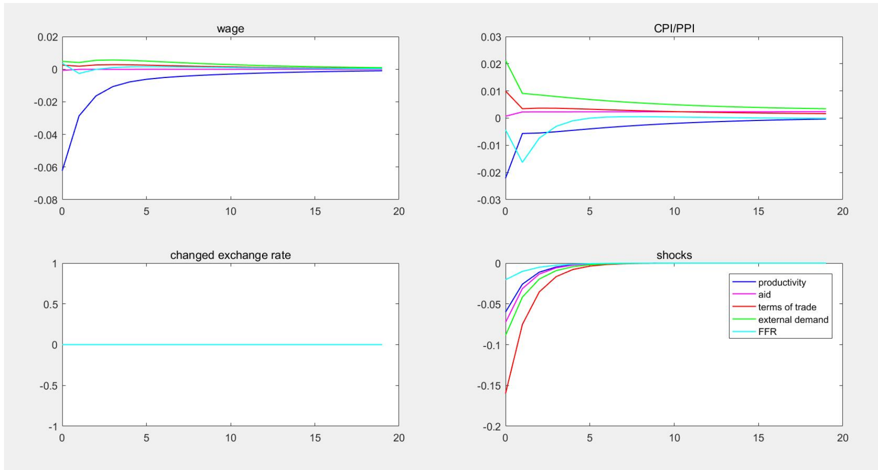

Figure 1.11: Pegged regime - IR to external shocks

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Chapter 2

The Impact of U.S. Interest Rate Changes on Emerging Market Countries under Cost-Push Shocks and Natural Rate Shocks

2.1 Introduction

During the 2008 financial crisis, the U.S. Federal Reserve used both conventional and unconventional monetary policies to set the federal funds rate at the zero lower bound, ensure market liquidity, and boost market confidence. Given the economic outlook, on December 16, 2015, the Federal Open Market Committee (FOMC) decided to raise the target range for the federal funds rate from a range of 0% to 0.25% to a range of 0.25% to 0.5%. The rate hike was a small one, while it would affect not only millions of Americans but also other economies. Since then, the FOMC has been gradually increasing its target range to fulfill the Federal Reserve's goals of maximum employment, low inflation, stable economic growth, and moderate long-term interest rates. However, the frequent changes in the Fed's monetary policy would have spillover effects on other economies.

In some previous episodes, the Fed raised rates to fight inflation, such as cost-push shocks. Due to the oil crisis in the 1970s, the inflation rate of the U.S. rose to a peak of 11% in early 1980. The Fed, after that, pursued tight monetary policy, rising interest rate, to lower inflation - Volcker disinflation. The Fed brought the inflation rate down to 4% by the end of 1983, but the disinflationary monetary policy also caused the U.S. 1981-1982 recession. The interest rate hike also increased debt cost (denominated in the U.S. currency), which made it harder for Latin Americans to pay back their debts. Because the petroleum-exporting countries earned much money and invested that money in international banks, during the oil price surge in 1973-1980, Latin American governments could easily borrow loans from international banks for their economic development. After the risky accumulation of foreign debts over a couple of years, the Latin American debt crisis happened in 1982. The spillover effect of U.S. interest rate hike under this cost-push shock impacted the Latin American economy, which triggered the purchasing power erosion by inflation, high unemployment rate, slumping imports and income, and stagnated economic growth[1].

What's more, the natural rate of interest also affects how the Fed steers interest rates, such as the natural rate shocks. The natural rate of interest, also called the neutral rate of interest or the long-run equilibrium interest rate, is the rate that would maintain the economy at full employment and stable inflation. The natural rate of interest is determined by structural features of the economy and is not observable. In addition, it may vary over time due to fluctuations in trends of productivity growth, changing demographics, and other structural shifts of the economy[2]. As a monetary policy guided by Taylor [1993] and Taylor [1999] - the Taylor Rule, the natural rate of interest could measure whether a change in the federal funds rate is low enough to stimulate or is high enough to dampen economic activities. For instance, the 2008 financial crisis shifted the structure of the U.S. economy. Facing the natural rate shocks, the Fed not only decreased the federal funds rate to the zero lower bound but also used unconventional policies that had put downward pressure on longer-term interest rates and helped make broader financial conditions more accommodative. Williams [2012] presented the Federal Reserve to use two types of unconventional monetary policies to stimulate the U.S. economy: forward policy guidance and large-scale asset purchases, after the 2008 financial crisis. Since households and investors make saving and

[1] Bernal and Cristina [1991] introduced economic history of Latin America.

[2] The Fed's Monetary Policy Report (July 2018) also emphasized academic studies have estimated the longer-run value of the natural rate of interest using statistical techniques to capture the variations among inflation, interest rates, real gross domestic product, unemployment, and other data series.

investment decisions depend on what they expect interest rates would be in the future, the Fed's views on the natural rate of interest have meaningful importance. The spillover effect of the lower U.S. interest rate under this natural rate shock impacted the world economy. Firstly, a depreciating dollar would enhance the competitiveness of U.S. goods at home and abroad. In other words, the non-U.S. exporters will suffer loss because their products will become more expensive. Secondly, an interest rate drop could also prompt a fresh flow of capital into high-yield but risky investments in the emerging markets and away from dollar-denominated bonds and instruments.

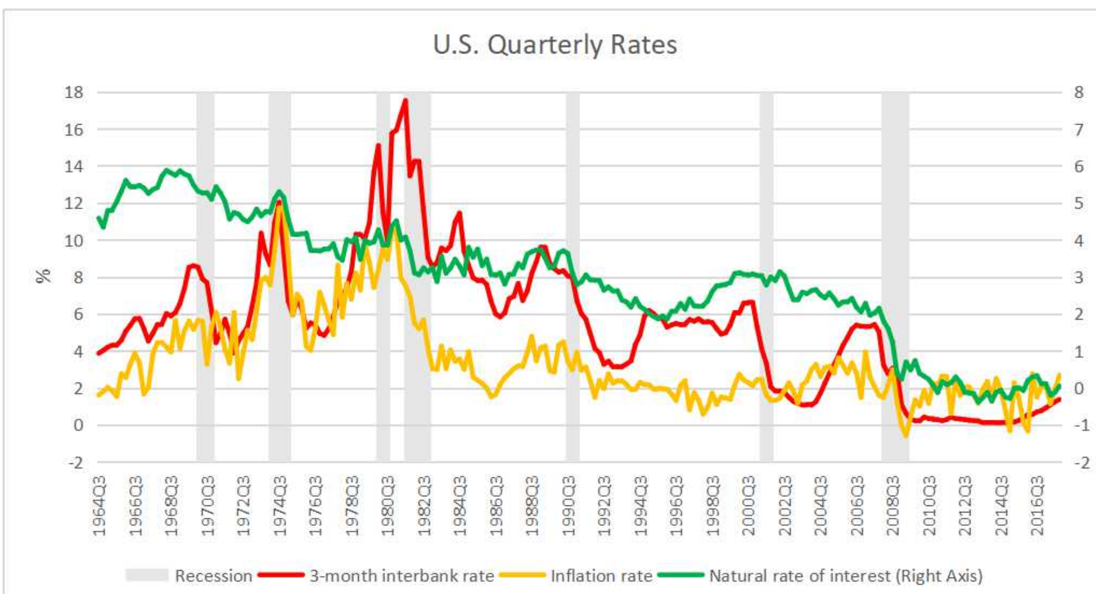

Figure 2.1: U.S. quarterly rates

Therefore, what is the impact of the U.S. interest rate changes under different shocks (cost-push shocks and natural rate shocks), as shown in Figure 2.1[3],

[3]All rates are quarterly data at the annual level from 1964Q3-2017Q4; Shaded areas indicate U.S. recessions from NBER recession data; 3-month interbank rate is from the OECD database; the inflation rate is calculated by GDP deflator from the OECD database; the natural rate of interest is estimated by Laubach and Williams [2003].

on emerging market countries' real output and inflation? What are the critical transmission channels of the impact? How could the emerging market countries deal with the impact? This paper, focusing on these issues, provides theoretical and empirical results to understand emerging market countries in response to the impact of U.S. interest rate changes. Table 2.1 briefly presents the different effects on other economies through various transmission channels. If the Fed follows the Taylor Rule, cost-push shocks will cause the price level to increase, then the federal funds rate hikes against high inflation and real output drops by the restrictive monetary policy. High inflation is more likely to have a significant adverse effect, rather than an apparent positive effect, on a U.S. currency's value and foreign exchange rate. For the financial market channel, the U.S. interest hikes would lead other economies to pay more for debts denominated in the U.S. currency and get less foreign capital inflow. Furthermore, if the expenditure-switching effect is more significant than the income absorption effect to the U.S., there would be more export for other economies. But if the exchange rate depreciation effect is more prominent than the price hike effect, the U.S. will reduce import that harms the benefits of other foreign exporters. Unlike cost-push shocks, natural rate shocks are determined by the structural shifts of the U.S. economy. If the Fed would not need to stimulate or slow the economy by monetary policy, the federal funds rate is the natural rate of interest. As Janet Yellen said, during an interview with The International Economy Magazine in 2005, monetary policy should be at neutral only when economic conditions are "just right". So, if the interest rate hikes by a positive natural rate shock, the real output would decrease to the new real potential output without significant effects on the price level. For the trade market channel, if the value of the U.S. currency is raised due to an increase in interest rate, one can expect the terms of trade to be improved with an appreciated exchange rate. As a result, even though exporters in the U.S. are enjoying a high price, they may be challenging to sell their goods in the international trade market. That means other economies face a higher import price and a more considerable export amount. Generally, the impact of U.S. interest rate changes on emerging market countries' real output and inflation is ambiguous because of the reaction of their central banks and governments, such as the inflation targeting policy or the pegged exchange rate regime. The above brief analysis is the motivation of this paper to study these issues.

Transmission	Cost-push shocks $\uparrow$	Natural rate shocks $\uparrow$
U.S. condition	$i^{us}\uparrow, Y^{us}\downarrow, P^{us}\uparrow$	$i^{us}\uparrow, Y^{us}\downarrow$
The exchange rate channel	$S^{o/us}\downarrow$	$S^{o/us}\uparrow$
The financial market channel	$B^{o}_{us}\downarrow$	$B^{o}_{us}\downarrow$
The trade market channel	$P^{m}_{o}\uparrow, X^{o}\uparrow$ or $P^{m}_{o}\downarrow, X^{o}\downarrow$	$P^{m}_{o}\uparrow\uparrow, X^{o}\uparrow\uparrow$

Table 2.1: How would U.S. interest rate hikes by different shocks affect other economies

2.2 Literature Review

Previous papers and researches focus on empirical and quantitative work for the impact of U.S. (or Euro area) monetary policy shocks on other countries. For developed countries, Kim [2001] revealed empirical evidence on the international transmission of U.S. monetary policy shocks for the G-6 countries (excluding the U.S.) with a flexible exchange rate regime using VAR models and found the world real interest rate is a crucial transmission instead of trade balance. Holman and Neumann [2002] emphasized the importance of the transmission of monetary shocks between the U.S. and Canada using time-series techniques and examined the impact of a monetary shock in one country on real activity in both countries, such as consumption, investment, employment, and the bilateral trade balance. Jannsen and Klein [2011] analyzed the international transmission effects of Euro area monetary policy shocks into other western European countries, using a structural VAR model and concluded a broadly similar change in the interest rate and GDP in these other western European countries, unlike insignificant effects on their exchange rates and trade balances. Their results suggested that the income absorption effect of being more critical than the expenditure switching effect in the international transmission of monetary policy and that exchange rate stabilization seems to be of some concern to monetary policymakers in small open economies. Rey [2016] presented evidence that U.S. monetary policy shocks are transmitted internationally and affect financial conditions even in inflation targeting economies with large financial markets, which means flexible exchange rates are not enough to guarantee monetary autonomy in a world of large capital flows.

For emerging economies, Mackowiak [2007] found that U.S. monetary policy shocks affect quickly and sharply interest rates and the exchange rate in a typical emerging market. The price level and real output in a typical emerging market respond to U.S. monetary policy shocks by more than the price level and real output in the U.S. itself. Employing the structural VAR, Xiao and Zhao [2012] showed that the effect of transmission of short-term international capital flows is stronger than the balance of trade and the world commodity prices index. Also, the exchange rate of RMB has the weakest transmission effect. Ramos-Francia and García-Verdú [2014] tested whether an EME has undergone a structural change in the policy rate, exchange rate, or long-term rate channels, facing U.S. monetary policy shocks. Although the evidence was not uniform across the various tests, they concluded an increase in the sensitivity of EMEs to U.S. monetary policy shocks could lead to higher dependence on U.S. economic developments and accordingly to a higher impact of U.S. policy on EMEs' policy cycles. Edwards [2015] analyzed whether local central banks' policy rates of three Latin American countries with flexible exchange rates, inflation targeting, and capital mobility - Chile, Colombia, and Mexico - are impacted by Federal Reserve actions, and found that these countries tend to "import" Fed policies.

In short, the U.S. monetary policy shocks could cause significant "policy contagion" to developed countries and emerging market economies. Miniane and Rogers [2003] tested the effect of U.S. monetary shocks on the exchange rate and foreign country (developed and developing) interest rates, and found countries with less open capital accounts do not exhibit systematically smaller responses. However, the exchange rate regime or degree of dollarization explains more of the cross-country differences in responses. Feldkircher and Huber [2016] illustrated international spillovers of expansionary U.S. aggregate demand and supply shocks, and a contractionary U.S. monetary policy shock to international output through the financial channel (i.e., interest rates) and the trade channel (i.e., the real effective exchange rate), using Bayesian global vector autoregressions. Also, they argued that the shocks emanating from abroad are less critical in advanced economies compared to domestic shocks. By contrast, external shocks play a vital role for economies in Latin America, Asia, and emerging Europe.

This paper uses a New Keynesian Small Open Economy Model and employs a Bayesian Local Projection (BLP) estimation to analyze the "policy contagion" by the U.S. Federal Reserve actions. First of all, this paper decomposes U.S. monetary policy rate changes from different sources: cost-push shocks and natural rate shocks, as mentioned in the introduction. Sometimes, the Fed rate rises by cost-push shocks: uncontrollably rising wages, the OPEC oil-price increases, and droughts or poor harvests. Alternatively, the Fed changes the monetary policy rate according to natural rate shocks. Bullard [2018] explained that it is vital for policymakers to know the natural rate of interest to determine whether the current policy rate setting is accommodative, neutral, or restrictive. He noted that the Fed could influence the real rate of interest but not the trend in the real rate of interest, which is viewed as driven by fundamental factors.

Furthermore, this paper involves three main transmission channels: the exchange rate, the international trade market, and the international financial market. As the above literature reviews, although each paper explored the impact of U.S. monetary policy shocks on other countries with different data sets and VAR methods to get mixed results, the effects significantly exist through transmission channels, which are the crucial part to link U.S. economy to other economies. Some theoretical papers use different models to explain these transmission effects. The primary and traditional Mundell-Fleming-Dornbusch (MFD) model focuses on international trade channels, as Dornbusch [1980], Obstfeld and Stockman [1985], and Obstfeld and Rogoff [1996]. The MFD model predicts that a positive U.S. monetary shock leads to other countries' terms of trade deterioration or exchange rate depreciation, which causes an improvement in other countries' trade balance and output (the expenditure-switching effect). However, a decrease in U.S. income following a federal funds rate hike reduces its import demand, which may worsen other countries' trade balance and output (the income-absorption effect). Despite that, Kim [2001] and Canova [2005] found strong evidence for the international financial channel and less for the international trade channel. Since the U.S. plays a pivotal role in global financial markets, an increase in the federal funds rate is likely to trigger movements in other countries' interest rates (international financial channel). Neumeyer and Perri [2005] decomposed the interest rate to an international rate and a country risk component with a neo-classical small open economy model. They found that in a sample of emerging economies, business cycles are more volatile than in developed ones, real interest rates are countercyclical and lead the cycle, consumption is more volatile than output, and net exports are strongly countercyclical. Their model generated business cycles consistent with Argentine data. Also, the intertemporal model (equipped with sticky price or/and sticky wage) emphasizes the forward-looking intertemporal decisions of economic agents, as Cardia [1991], Kollman [1997], Kollman [1999], Betts and Devereux [2000], and Betts and Devereux [2001]. A positive U.S. monetary policy shock triggers a temporary decrease in the world aggregate demand for current goods, so that the trade balance and output of other countries may worsen, also due to their consumption smoothing. However, the intertemporal model also comprises the expenditure-switching effect, so that the trade balance and output of other countries may improve. In brief, all three main transmission channels are essential to analyze the "policy contagion".

Last but not least, this paper considers that other countries' exchange rate regimes and international reserves may explain more of the cross-country differences in responses to the U.S. monetary policy changes. Miniane and Rogers [2003], Broda [2004], Shambaugh [2004], and Jannsen and Klein [2011] showed the exchange rate regime is significant in determining how the exchange rate and the interest rate respond to U.S. monetary policy shocks. Broda [2004] found the flexible exchange rate regimes could insulate the economy (the fluctuation of output, exchange rate, and price) more effectively against terms of trade disturbances than pegged regimes. Shambaugh [2004] observed significant differences between pegged regimes and flexible regimes in the way domestic interest rates respond to changes in foreign interest rates. Additionally, Arifovic and Masson [2004], Arifovic and Maschek [2012], and Kato et al. [2018] argued that international investors consider a shortage of the domestic economy's foreign currency reserves as a signal of increasing country risk. Policymakers in emerging economies have adopted accumulating international reserves strategy as an insurance policy against a sudden stop when there is no credible lender of last resort in the international monetary system. Concisely, the choice of exchange rate regime and precautionary saving (international reserves) is other countries' reaction in case of external shocks through international markets. The remainder of this paper is structured as follows: Section 2.3 describes the model setup and theoretical results; Section 2.4 is Bayesian Local Projection estimation and empirical results; The conclusions and policy recommendations are in Section 2.5.

2.3 New Keynesian Small Open Economy Model

2.3.1 Model Setup

This section describes the baseline model. The model is mostly based on a New Keynesian model of a small open economy that includes one representative household, one final goods firm, intermediate goods firms, foreign part, government, and central bank. The change of the U.S. interest rate goes through three channels - the exchange rate, the international trade market, and the international financial market to influence emerging market economies. Due to secure evidence for the international financial channel, as mentioned in the literature review, this paper adds working capital to the model. It means firms' inputs must be financed by short term loans, so changes in the interest rate affect the economy by changing firms' variable production costs and domestic price level to influence economy, as Fuerst [1992], Christiano et al. [2005] and Adolfson et al. [2007]. Final good firms use intermediate goods to produce homogeneous domestic goods, so this assumption makes working capital costs significant, as Basu [1995]. Because of the uncovered interest parity puzzle, this paper involves a risk premium for UIP to provide a connection between the U.S. interest rate and domestic interest rate. In the view of Arifovic and Masson [2004], Arifovic and Maschek [2012], and Kato et al. [2018], the risk premium depends on international reserves which provide confidence motive to foreign investors. This paper provides sterilization bonds to collect international reserves for the central bank. Alla et al. [2017] said sterilized intervention consists of the central bank purchasing or selling foreign currency-denominated assets (international reserves) with corresponding sales or purchases of domestic currency assets in order to leave the money supply unchanged. If foreign exchange intervention is not sterilized, then it does not constitute a separate instrument from monetary policy. Under foreign exchange sterilized intervention, the domestic central bank could simultaneously adopt other monetary policies[4] in response to U.S. interest rate changes. The shocks cause U.S. interest rate

[4] Galí and Monacelli [2005] evaluated the welfare losses under the central bank choosing different monetary policy rules (domestic inflation and CPI-based Taylor rules, and an exchange rate peg). They concluded a Taylor rule generally leads to excess volatility of nominal variables, and excess smoothness of real variables, but a pure exchange rate peg seems to have better stabilization properties than a Taylor rule. Also, Clarida et al. [1999] and Christiano et al. [2011] introduced some DSGE models for monetary policy analysis.

changes: cost-push shocks from the U.S. Phillips curve and natural rate shocks from the U.S. Taylor rule.

1. Household

Domestic household consumes domestic goods C_t^d and imported goods C_t^m, provides labor N_t to intermediate goods firms, and involves wage payment W_t, lump-sum tax T_t, and profit Π_t. Households can borrow and lend using domestic bonds D_t. The B_t^s are sterilization bonds sold by the central bank. However, we assume that domestic households can only use domestic bonds, contrary to foreign investors who can buy either domestic or foreign bonds. Here, χ specifies that the preference weight of labor in utility, and the Frisch elasticity for labor supply is $\frac{1}{\psi}$.

$$\max E_0 \sum_{t=0}^{\infty} \beta^t (\log C_t - \chi \frac{N_t^{1+\psi}}{1+\psi})$$
$$s.t. P_t C_t + D_t + B_t^s \leq i_{t-1}(D_{t-1} + B_{t-1}^s) + W_t N_t - T_t + \Pi_t$$

The consumption - composite goods C_t follows the constant elasticity of substitution (CES) form, where η is the elasticity of substitution of consumption between imported and domestic goods, and ω is the weight household places on imported consumption.

$$\min P_t^d C_t^d + P_t^m C_t^m$$
$$s.t. C_t = [(1-\omega)^{\frac{1}{\eta}} (C_t^d)^{\frac{\eta-1}{\eta}} + \omega^{\frac{1}{\eta}} (C_t^m)^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}}$$

P_t is the consumer price; P_t^m is the imported goods price; P_t^d is the domestic goods price, where $p_t \equiv \frac{P_t}{P_t^d}$, $p_t^m \equiv \frac{P_t^m}{P_t^d}$.

$$p_t = [(1-\omega) + \omega(p_t^m)^{1-\eta}]^{\frac{1}{1-\eta}}$$

2. Firms

The final goods firm uses intermediate goods with working capital costs to produce homogeneous domestic goods for domestic households and foreign countries. Final goods firm maximizes profits:

$$\max P_t^d Y_t - \int_0^1 P_{j,t}^d Y_{j,t} dj$$
$$s.t. Y_t = [\int_0^1 Y_{j,t}^{\frac{\epsilon-1}{\epsilon}} dj]^{\frac{\epsilon}{\epsilon-1}}$$

where Y_t is the final goods firm's output, and $Y_{j,t}$ is each intermediate goods firm's output as materials inputs of final goods firm with each intermediate goods price $P_{j,t}^d$.

Materials inputs:

$$Y_{j,t} = Y_t(\frac{P_t^d}{P_{j,t}^d})^{\epsilon}$$
$$P_t^d = [\int_0^1 (P_{j,t}^d)^{1-\epsilon} dj]^{\frac{1}{1-\epsilon}}$$

Intermediate goods firms use labor with working capital costs to produce intermediate goods, facing Calvo price setting frictions. Intermediate goods producers with productivity Z:

$$Y_{j,t} = ZN_{j,t}$$

Real marginal cost of production mc_t, where δ is a fraction of input costs that must be financed in advance:

$$\min \frac{(1-\delta+\delta i_t)W_t}{P_t^d} N_{j,t} + mc_t(Y_{j,t} - ZN_{j,t})$$

Therefore,

$$mc_t = \frac{(1-\delta+\delta i_t)W_t}{ZP_t^d}$$

Calvo price setting frictions

-Intermediate goods firms with probability θ cannot change price: $P_{j,t}^d = P_{j,t-1}^d$;

-Intermediate goods firms with probability $1-\theta$ set price optimally: $P_{j,t}^d = \tilde{P}_t^d$;

where stochastic discount factor $\Delta_{i,t+i} = \beta^i \frac{C_t}{C_{t+i}}$.

$$\max E_t \sum_{i=0}^{\infty} \theta^i \Delta_{i,t+i} [\frac{P_{j,t}^d}{P_{t+i}^d} Y_{j,t+i} - mc_{t+i} Y_{j,t+i}]$$

Therefore,

$$\tilde{p}_t^d \equiv \frac{\tilde{P}_t^d}{P_t^d} = \frac{K_t}{F_t}$$
$$K_t = \frac{\epsilon}{\epsilon-1}\frac{Y_t}{C_t} mc_t + \beta\theta E_t(\pi_{t+1}^d)^{\epsilon} K_{t+1}$$
$$F_t = \frac{Y_t}{C_t} + \beta\theta E_t(\pi_{t+1}^d)^{\epsilon-1} F_{t+1}$$

Aggregate price (domestic price):

$$P_t^d = [(1-\theta)(\tilde{P}_t^d)^{1-\epsilon} + \theta(P_{t-1}^d)^{1-\epsilon}]^{\frac{1}{1-\epsilon}}$$
$$\tilde{p}_t^d = \left[\frac{1-\theta(\pi_t^d)^{\epsilon-1}}{1-\theta}\right]^{\frac{1}{1-\epsilon}}$$

Aggregate output (final output):

$$Y_t^* \equiv \int_0^1 Y_{j,t}dj = \int_0^1 ZN_{j,t}dj = ZN_t$$
$$Y_t^* = \int_0^1 Y_t(\frac{P_t^d}{P_{j,t}^d})^\epsilon dj = Y_t(P_t^d)^\epsilon(P_t^{d*})^{-\epsilon}$$
$$P_t^{d*} \equiv [\int_0^1 (P_{j,t}^d)^{-\epsilon}dj]^{-\frac{1}{\epsilon}} = [(1-\theta)(\tilde{P}_t^d)^{-\epsilon} + \theta(P_{t-1}^{d*})^{-\epsilon}]^{-\frac{1}{\epsilon}}$$
$$p_t^{d*} \equiv (\frac{P_t^{d*}}{P_t^d})^\epsilon = \left[(1-\theta)\left(\frac{1-\theta(\pi_t^d)^{\epsilon-1}}{1-\theta}\right)^{-\frac{\epsilon}{1-\epsilon}} + \theta\frac{(\pi_t^d)^\epsilon}{p_{t-1}^{d*}}\right]^{-1}$$
$$Y_t = p_t^{d*}Y_t^* = p_t^{d*}ZN_t$$

where $(p_t^{d*})^{-1} \geq 1$, price dispersion means more has to be produced to achieve a given level of Y_t.

3. Foreign part

The foreign part sets imported goods price with working capital cost and needs exports from the final goods firm. Foreign investors hold domestic bonds from government and foreign bonds (UIP with risk premium). Assume C_t^m is produced by the foreign competitive firm, which sets price equal to marginal cost, where δ^f is a fraction of input costs that must be financed in advance, and P_t^f is the foreign currency price of foreign goods.

$$P_t^m = S_t P_t^f (1 - \delta^f + \delta^f i_t^f)$$

$$p_t^m = p_t q_t (1 - \delta^f + \delta^f i_t^f)$$

$$\frac{q_t}{q_{t-1}} = s_t \frac{\pi_t^f}{\pi_t}$$

where real exchange rate $q_t \equiv \frac{P_t^f S_t}{P_t}$, and changed nominal exchange rate $s_t \equiv \frac{S_t}{S_{t-1}}$. Foreign demand for exports, where Y_t^f is the foreign output, $\frac{P_t^x}{P_t^f} \equiv p_t^x$:

$$X_t = \left(\frac{P_t^x}{P_t^f}\right)^{-\eta_f} Y_t^f = (p_t^x)^{-\eta_f} Y_t^f$$

X_t is produced by the final goods firm, where δ^x is a fraction of intermediate goods costs that must be financed in advance.

$$S_t P_t^x = P_t^d (1 - \delta^x + \delta^x i_t)$$

$$q_t p_t p_t^x = 1 - \delta^x + \delta^x i_t$$

Foreign investors are sophisticated agents. The rate of return on domestic bonds, taking into account the risk premium ϕ_t, should be equal to the rate of return in foreign bonds.

$$\frac{i_t}{\phi_t} = \frac{S_{t+1}}{S_t} i_t^f$$

Assume the foreign country puts a negligible weight on the goods imported from (exported to) the small economy and market clearing condition $Y_t^f = C_t^f$, which would be as a standard closed economy model.

New Keynesian Phillips curve with cost-push shock:

$$\hat{\pi}_t^f = \beta^f E_t \hat{\pi}_{t+1}^f + \kappa^f (1 + \psi^f) \hat{y}_t^f + \hat{u}_t^f$$

where $\kappa^f \equiv \frac{(1-\theta^f)(1-\beta^f\theta^f)}{\theta^f}$, $\hat{y}_t^f \equiv \hat{Y}_t^f - \hat{Y}_t^{f,f} \equiv \hat{Y}_t^f - \hat{Z}_t^f$ is the foreign output gap and $\hat{u}_t^f$ is the cost-push shock.

Cost-push shock:

It is a shock that changes the output-inflation trade-off and drives a wedge between marginal cost and the output gap. Assume that it follows an AR(1).

$$\hat{u}_t^f = \rho_u^f \hat{u}_{t-1}^f + \epsilon_{u,t}^f$$

New Keynesian IS curve with natural rate of interest:

$$\hat{y}_t^f = E_t \hat{y}_{t+1}^f - (\hat{i}_t^f - E_t \hat{\pi}_{t+1}^f - \hat{r}_t^{f,f})$$

where $\hat{Y}_t^f = E_t \hat{Y}_{t+1}^f - (\hat{i}_t^f - E_t \hat{\pi}_{t+1}^f) \equiv E_t \hat{Y}_{t+1}^f - \hat{r}_t^f$ and $\hat{r}_t^{f,f}$ is the natural rate of interest that would be obtained if prices are fully flexible, so $\beta^f = \frac{1}{r^{f,f}}$.

Natural rate shock:

The flexible price level of output evolves exogenously in line with the level of technology $\hat{Y}_t^{f,f} = \hat{Z}_t^f$. If the technology obeys an AR(1), then the flexible price equilibrium level of output as following the same AR(1) $\hat{Y}_t^{f,f} = \rho_z^f \hat{Y}_{t-1}^{f,f} + \epsilon_{z,t}^f$.

$$\hat{r}_t^{f,f} = \rho_z^f \hat{r}_{t-1}^{f,f} + (\rho_z^f - 1)\epsilon_{z,t}^f$$

Policy with modified Taylor rule:

$$\hat{i}_t^f = \hat{r}_t^{f,f} + \rho_\pi \hat{\pi}_t^f + \rho_y \hat{y}_t^f$$

4. Government

Government sells bonds to domestic investors D_t and foreign investors D_t^f, where G_t is government spending.

$$\frac{i_{t-1}}{\phi_{t-1}} D_{t-1}^f + i_{t-1} D_{t-1} + P_t^d G_t = D_t^f + D_t + T_t$$

Foreign demand for domestic bonds $D_t^{f*} \equiv \frac{D_t^f}{P_t}$:

$$D_t^{f*} = \mu\left(\frac{i_t}{E_t \pi_{t+1}} \frac{E_t \pi_{t+1}^f}{i_t^f} \frac{1}{\phi_t}\right) = \mu\left(\frac{E_t q_{t+1}}{q_t}\right)$$

Risk premium:

$$\phi_t = \zeta\left(\frac{R^*}{R_{t-1}^*}\right)^\tau$$

where $R_t^* \equiv \frac{R_t}{P_t^f}$ is real international reserves, and τ implies the risk premium ϕ_t is responsive to changes in $\frac{R^*}{R_{t-1}^*}$

5. Central bank

Central bank chooses the interest rate and performs sterilized foreign exchange intervention, offsetting any increase in reserves by issuing sterilization bonds B_t^s.

Balance sheet:

$$S_tR_t - S_ti^f_{t-1}R_{t-1} = B^s_t - i_{t-1}B^s_{t-1}$$

Policy with Taylor rule ($\rho_i = 0$):

$$log(\frac{i_t}{i}) = \rho_i log(\frac{i_{t-1}}{i}) + (1-\rho_i)[\rho_\pi log(\frac{\pi_t}{\pi}) + \rho_y log(\frac{Y_t}{Y})]$$

6. Equilibrium

Balance of payment:

Cash outflow - Domestic country would buy foreign assets S_tR_t, import goods $P^m_tC^m_t = P^m_t\omega(\frac{p_t}{p^m_t})^\eta C_t$ and pay $\frac{i_{t-1}}{\phi_{t-1}}D^f_{t-1}$ to foreign investors who hold domestic bonds.

Cash inflow - Domestic country would sell export goods $S_tP^x_tX_t$, receive existing foreign assets return $S_ti^f_{t-1}R_{t-1}$ and sell domestic bonds D^f_t to foreign investors.

$$S_tR_t + P^m_tC^m_t + \frac{i_{t-1}}{\phi_{t-1}}D^f_{t-1} = S_tP^x_tX_t + S_ti^f_{t-1}R_{t-1} + D^f_t$$

$$q_tp_tR^*_t + p^m_t\omega(\frac{p_t}{p^m_t})^\eta C_t + \frac{i_{t-1}}{\phi_{t-1}\pi_t}p_tD^{f*}_{t-1}$$

$$= q_tp_tp^x_tX_t + \frac{i^f_{t-1}}{\pi^f_t}q_tp_tR^*_{t-1} + p_tD^{f*}_t$$

Final goods market clearing:

$$
\begin{aligned}
S_t R_t - S_t i^f_{t-1} R_{t-1} &= B^s_t - i_{t-1} B^s_{t-1} \\
\frac{i_{t-1}}{\phi_{t-1}} D^f_{t-1} + i_{t-1} D_{t-1} + P^d_t G_t &= D^f_t + D_t + T_t \\
P_t C_t + D_t + B^s_t &\leq i_{t-1}(D_{t-1} + B^s_{t-1}) + W_t N_t - T_t + \Pi_t
\end{aligned}
$$

Then,

$$
P_t C_t + S_t R_t - S_t i^f_{t-1} R_{t-1} + \frac{i_{t-1}}{\phi_{t-1}} D^f_{t-1} + P^d_t G_t = D^f_t + W_t N_t + \Pi_t
$$

Therefore,

$$
\begin{aligned}
Y_t = C^d_t + X_t + G_t &= (1-\omega) p^\eta_t C_t + X_t + G_t \\
p^{d*}_t Z N_t &= (1-\omega) p^\eta_t C_t + X_t + G_t
\end{aligned}
$$

2.3.2 Calibration

Parameter	Symbol	Value
Elasticity of substitution between imported and domestic consumption	η	0.76
Weight of imported consumption in the gross consumption	ω	0.36
Fraction of input costs that must be financed in advance (domestic)	δ	0.1
Fraction of intermediate goods costs that must be financed in advance	δ^x	0.1
Preference weight of labor in utility	χ	1
Frisch elasticity for labor supply	$1/\psi$	0.6
Probability cannot change price	θ	0.75
Elasticity of demand for domestic intermediate goods	ϵ	6
Fraction of government spending	η_g	0.16
Fraction of reserves over import	η_r	0.25
Monetary policy rule weight on historical interest rate	ρ_i	0
Monetary policy rule weight on inflation rate	ρ_π	1.5
Monetary policy rule weight on output	ρ_y	0.5
Responsiveness of foreign investors	τ	0.05
Risk premium	ζ	1.02
Productivity	Z	0.35
Discount factor	β	$1.02^{-1/4}/1.02$
Target inflation	π	1
Nominal interest rate	i	$(1.02)(1.02)^{1/4}$
Steady state output	Y	0.3485
Steady state reserves	R^*	0.1030
Steady state reserves in domestic currency	μ	0.0338
Fraction of input costs that must be financed in advance (foreign)	δ^f	0.1
Elasticity of demand for exports as function of relative price (foreign)	η_f	1.5
Elasticity of demand for domestic intermediate goods (foreign)	ϵ^f	10
Foreign Frisch elasticity for labor supply	$1/\psi^f$	2
Foreign probability cannot change price	θ^f	0.75
Foreign productivity	Z^f	1
Foreign output gap	y^f	1
Foreign natural rate of interest	$r^{f,f}$	$1.02^{1/4}$
Foreign target inflation	π^f	1
Foreign nominal interest rate	i^f	$1.02^{1/4}$
Autocorrelation coefficient of foreign cost-push shocks	ρ_π^f	0.16
Autocorrelation coefficient of foreign natural rate shocks	ρ_r^f	0.83
Standard deviation of foreign cost-push shocks	σ_π^f	0.01
Standard deviation of foreign natural rate shocks	σ_r^f	0.01

Table 2.2: Calibration for the baseline model

The parameters in the baseline model are calibrated to mimic the economy of developing countries or taken from other studies. The data set includes Argentina, Brazil, Korea, Mexico, and South Africa, as observed in 1978Q1-2017Q4. For the elasticity of substitution between imported and domestic consumption, Ostry and

Reinhart [1992] estimated η for a panel of 13 developing countries. Arellano et al. [2009] estimated the weight of imported consumption in the gross consumption ω for a small open economy. This paper assumes all working capital costs - the fractions of domestic input costs, intermediate goods costs, and foreign input cost that must be financed in advance - are 10%. The preference weight of labor in utility, sticky price probability of Calvo price setting frictions (domestic and foreign), target inflation (domestic and foreign), foreign Frisch elasticity for labor supply, foreign productivity (normalized to 1), foreign output gap, foreign natural rate of interest (quarterly), foreign nominal interest rate (quarterly) and elasticity of demand for domestic intermediate goods (foreign) are taken from standard model parameters. For the Frisch elasticity for labor supply, Boz et al. [2012] estimated it for emerging markets. Christiano et al. [2005] provided value to the elasticity of demand for domestic intermediate goods and elasticity of demand for exports as a function of relative price (foreign). The fraction of government spending is calculated by the average of real government spending over real GDP. The fraction of reserves over import follows the rule of thumb - reserves cover three-month import (1/4 of quarterly import)[5]. Monetary policy rule weight on the historical interest rate, inflation rate, and output are taken from Taylor [1993]. Following the related equations in the baseline model, the responsiveness of foreign investors τ, risk premium ζ, and productivity Z are estimated by panel data under a fixed effect. Discount factor, nominal interest rate, and steady state value (output, reserves, reserves in domestic currency) depend on steady state equations to be calculated. For detrended variables (data: energy commodity prices

[5] The developed countries' data set (Australia, Canada, Netherlands, New Zealand, and Sweden) shows the average fraction of reserves over import 0.22. However, the average fraction is 0.47 for developing countries. This paper treats the 1/4 of quarterly imports as a minimum requirement.

index and natural rate of interest from 1961Q1 to 2017Q4), this paper adopts the method from Hamilton [2018] instead of the Hodrick-Prescott filter. This paper uses the energy commodity prices index in the World Bank dataset[6] to calculate the related inflation. Then, the detrended energy inflation shows the autocorrelation and standard deviation of U.S. cost-push shocks ($\rho_\pi^f = 0.16$, $\sigma_\pi^f = 0.673$). Also, this paper detrends the natural rate of interest estimated by Laubach and Williams [2003] to find the autocorrelation and standard deviation of U.S. natural rate shocks ($\rho_r^f = 0.83$, $\sigma_r^f = 0.003$). However, this paper assumes that both shocks' standard deviations are 1%. Table 2.2 summarizes all the parameters used in the calibration.

2.3.3 Impulse Response Functions

The impulse responses for the different variables to a one percent innovation in U.S. cost-push or natural rate shock are displayed in Figure 2.2 to Figure 2.10 with different monetary policy rules. The U.S. interest rates (US FFR) increase by around 1% under two shocks, but natural rate shock causes a more persistent effect than the other. Under the CPI-based Taylor rule in Figure 2.2 to Figure 2.4, outputs and working hours (hours) under two shocks decrease on impact and then are followed by a hump-shaped pattern, but output and working hours under cost-push shock are more muted and less persistent. CPI inflation increases under natural rate shock and then start immediately to revert to steady state, unlike that under cost-push shock. However, PPI inflation rates under two shocks increase firstly and are followed by a hump-shaped pattern, because domestic sticky prices

[6] The energy commodity prices index includes coal (Australia, Colombia, South Africa), crude oil (U.K., Dubai or Saudi Arabian, U.S.), and natural gas (Europe, U.S., Japan).

need time to adjust external shocks. Why do they have different patterns and effects? The exchange rate channel shows that the changed exchange rate is negative under cost-push shock (positive under natural rate shock), which is consistent with the initial analysis of this paper. High inflation by cost-push shock is more likely to have a significant adverse effect on a U.S. currency's value and foreign exchange rate. The uncovered interest parity implies the transmission between the U.S. interest rate and the domestic interest rate. There are nominal interest rate hikes under two shocks. According to a negative change in the exchange rate, the impact on the nominal interest rate under cost-push shock is weak. For financial market channel, because the U.S. interest hikes would lead to other economies pay more for debt denominated in the U.S. currency and get less foreign capital inflow, domestic bonds by foreigners[7] decreases under two shocks. The less effect on domestic bonds under cost-push shock is due to negative changed exchange rates (U.S. currency's value depreciates). A similar intuition is for international reserves. Pina [2017] found global interest rate hikes increase reserve transfers, defined as the change in international reserves net of the interest earned on reserves, if the central bank manages international reserves to smooth inflation over time, as this paper's positive hump-shaped patterns in international reserves. The slight fall in initial international reserves under cost-push shock also because of U.S. dollar depreciation. The risk premium is negative correlation with international reserves. For the trade market channel, the terms of trade[8] get worse under natural rate shock than those under cost-push shock because of an appre-

[7]In figures, the title name with * means variables are the U.S. deflator adjusted real terms, instead of domestic deflator, such as R_t^* and $\frac{D_t^{f*}}{q_t}$.

[8]An improvement of domestic terms of trade benefits this country, which means it can buy more imports for any given level of exports. The nominal exchange rate could affect the terms of trade because an appreciation in the country's currency lowers its import prices but may not directly influence the export prices.

ciated U.S. currency. Therefore, import amounts decrease under two shocks with high import price and low income. However, export amounts increase under two shocks, because the expenditure-switching effect is larger than the income absorption effect for U.S. households. For the rest variables, facing the higher price and lower income or contractionary monetary policy (higher domestic interest rate), consumption decreases under two shocks. The government spending has similar patterns as outputs because of the passive assumption - fixed ratio between government spending and output for this model. In shorts, the different patterns and effects under two shocks are significantly amplified through the exchange rate channel.

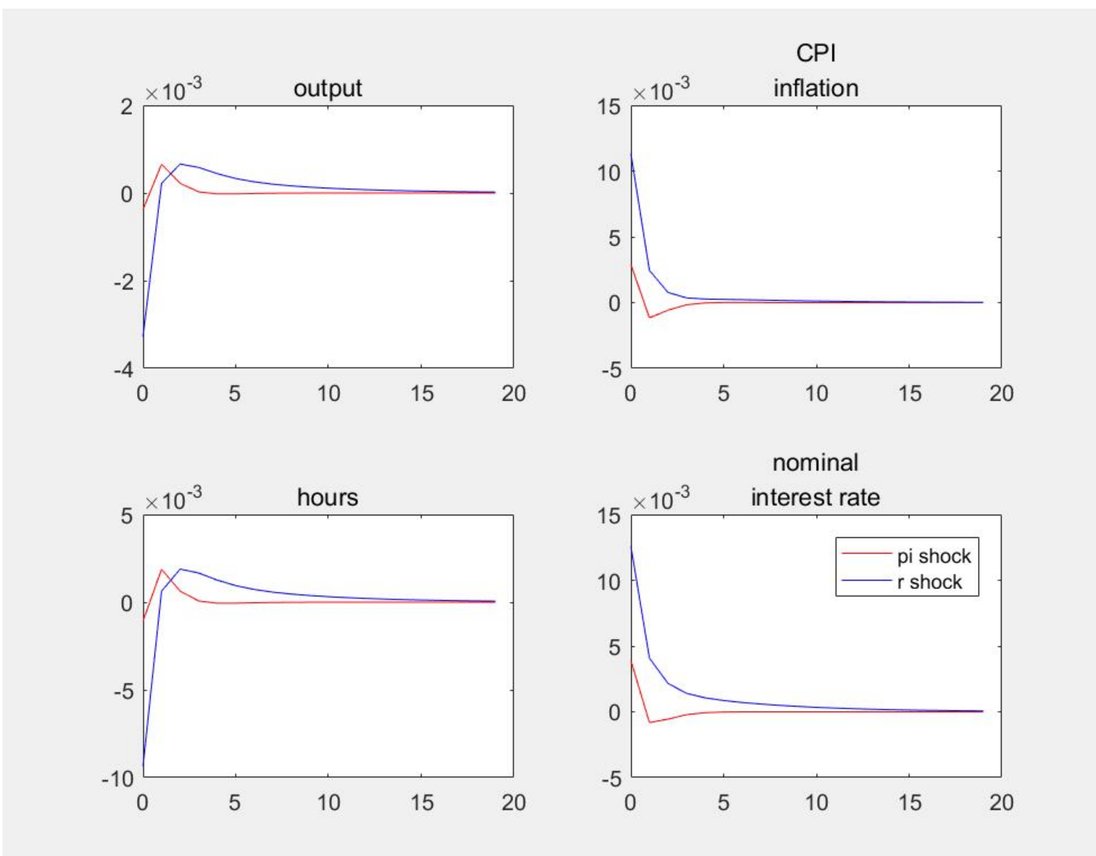

Figure 2.2: Cost-push shock v.s. Natural rate shock with CPI-based Taylor rule

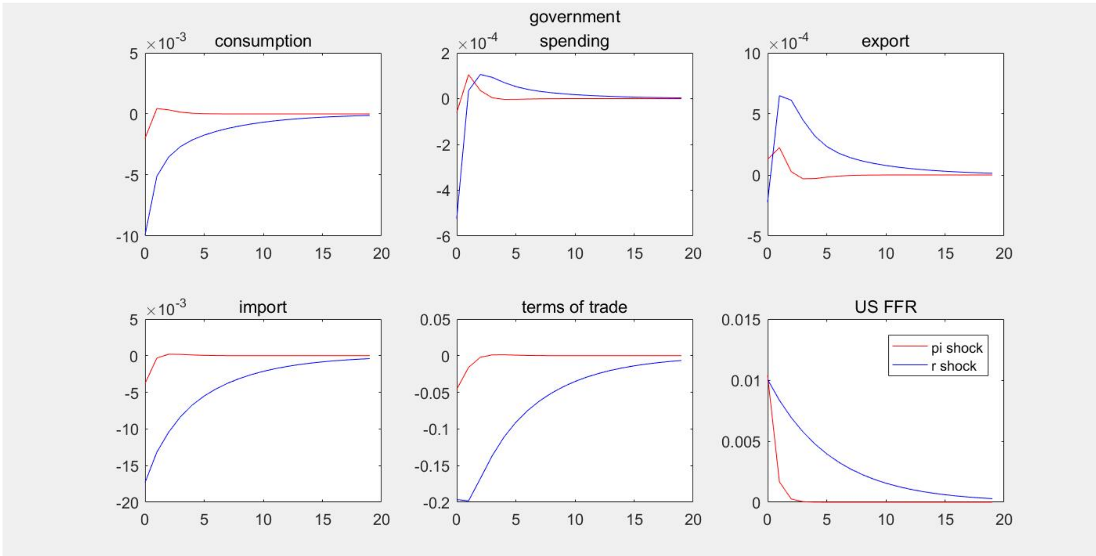

Figure 2.3: Cost-push shock v.s. Natural rate shock with CPI-based Taylor rule

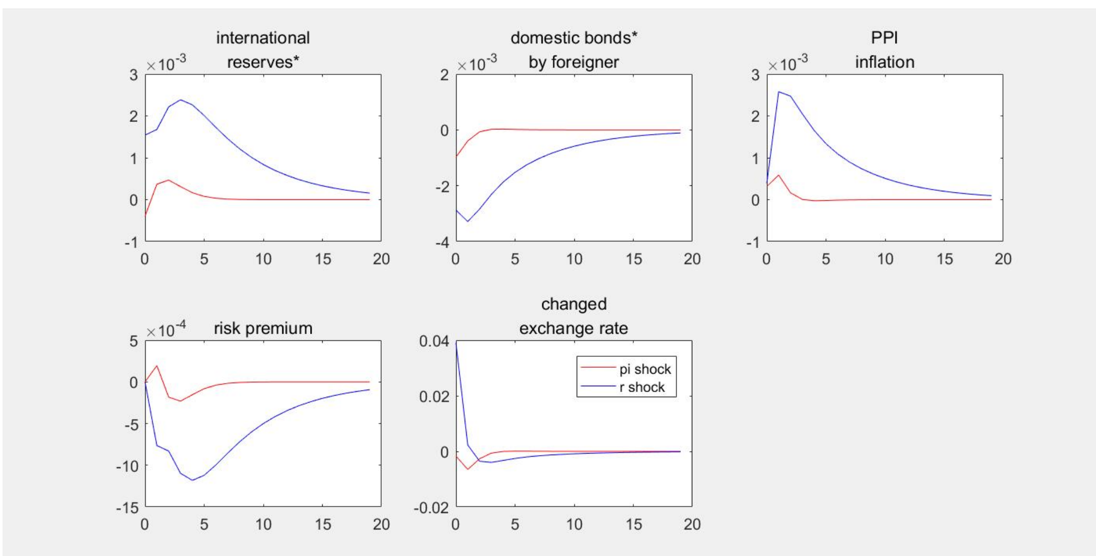

Figure 2.4: Cost-push shock v.s. Natural rate shock with CPI-based Taylor rule

In Figure 2.5 to Figure 2.7, the central bank chooses the pegged exchange rate regime, so two shocks do not affect the nominal exchange rate. However, the differences under two shocks go through the real exchange rate channel. For the financial market channel, facing two shocks, the central bank should use international reserves to keep the pegged exchange rate regime. This is the reason why international reserves decrease immediately under two shocks. The risk premium is negative correlation with international reserves. On the one hand, the increasing risk premium would cause a decrease in domestic bonds by foreigners. On the other hand, given uncovered interest parity with risk premium, U.S. interest rate hikes trigger that domestic nominal interest rate increases. For the trade market channel, import price (increase more) and export price rise under cost-push shock, but export price falls under natural rate shock. Hence, terms of trade get worse under natural rate shock than those under cost-push shock, although the nominal exchange rate does not change. Then, import amounts decrease under two shocks with low income. Because of lower domestic price, the effect on import amount is more significant under natural rate shock. Under cost-push shock, the expenditure-switching effect is more substantial than the income absorption effect for U.S. households, so the export amount increases. However, as a result of the expenditure-switching effect is less than the income absorption effect for U.S. households under natural rate shock, the export amount falls. Therefore, output, hours, consumption, and government spending decrease under natural rate shock and then start immediately to revert to steady state. Conversely, they slightly decrease and then are followed by a hump-shaped pattern under cost-push shock. The CPI inflation and PPI inflation rise initially under cost-push shock, unlike those under natural rate shock.

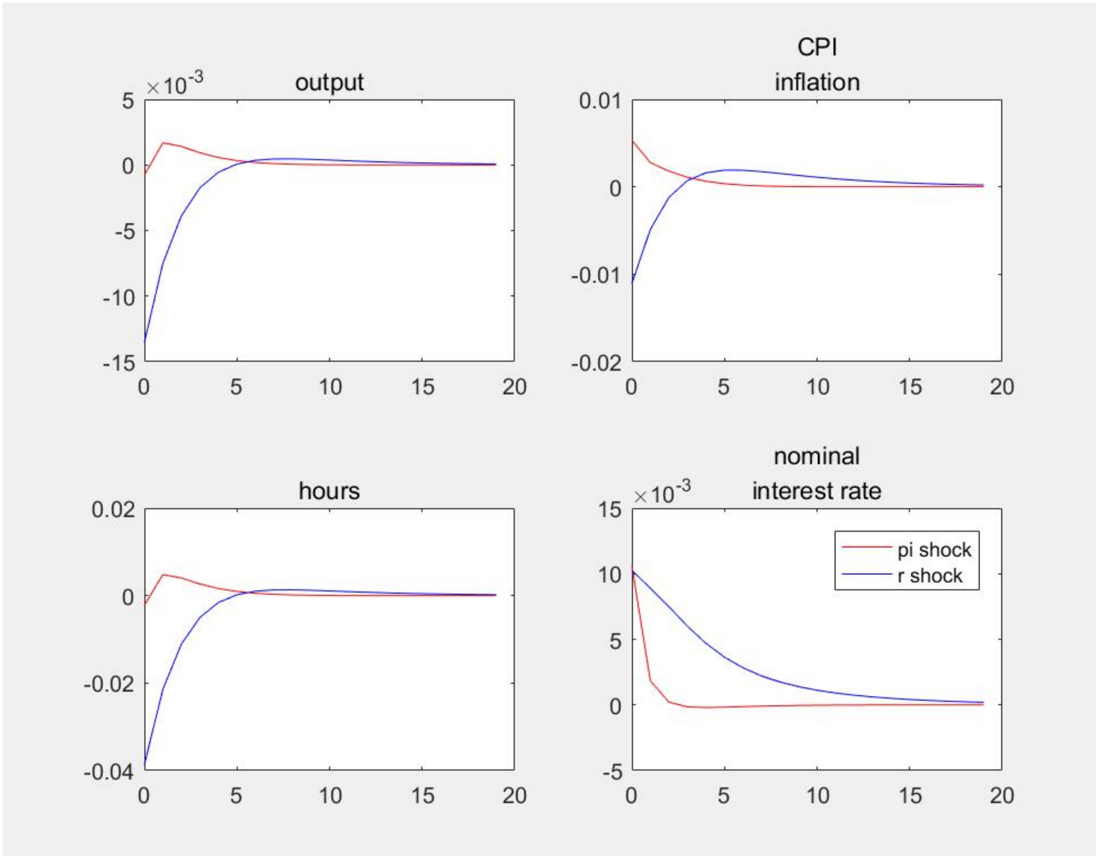

Figure 2.5: Cost-push shock v.s. Natural rate shock with Pegged exchange rate

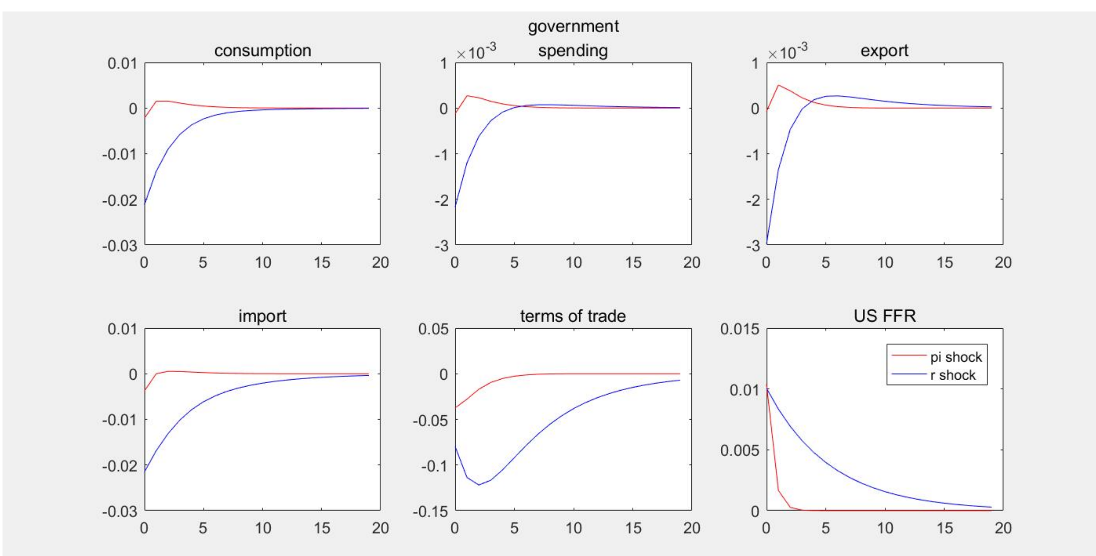

Figure 2.6: Cost-push shock v.s. Natural rate shock with Pegged exchange rate

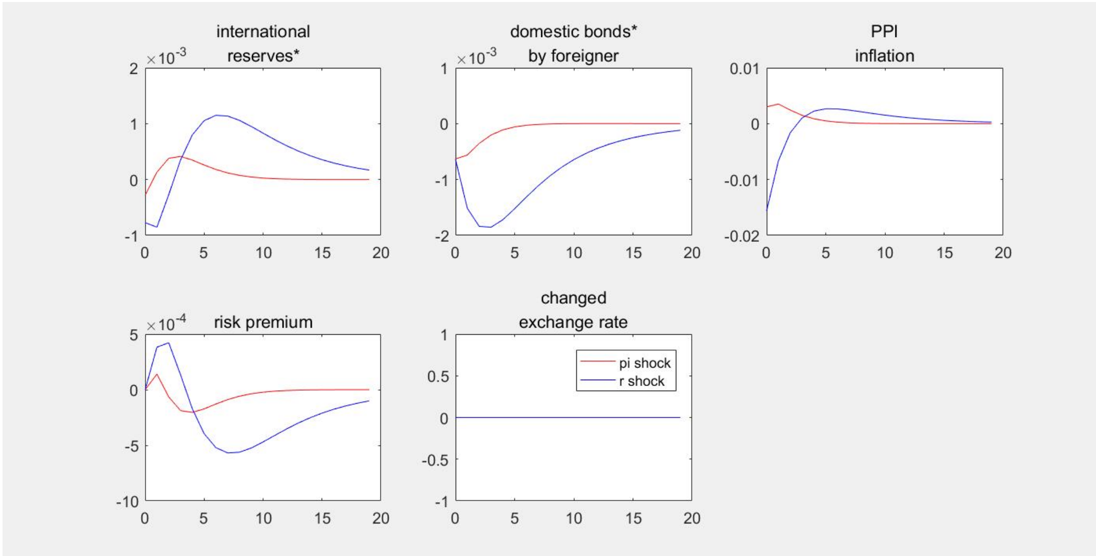

Figure 2.7: Cost-push shock v.s. Natural rate shock with Pegged exchange rate

If the central bank implements the PPI-based Taylor rule from Figure 2.8 to Figure 2.10, the exchange rate channel would be similar to one with the CPI-based Taylor rule. The variables, including international reserves, domestic bonds by foreigner, and risk premium, have the same pattern through the financial market channel, but the impacts on them are larger than those with the CPI-based Taylor rule, due to the less response of the central bank to external shocks. For the trade market channel, the intuition is the same as one under the CPI-based Taylor rule for terms of trade and import amount. Moreover, the expenditure-switching effect is significantly larger than the income absorption effect for U.S. households, so positive impact on export amount with larger magnitude under two shocks than those with the CPI-based Taylor rule. However, the output (also government spending) and hours are positive responses under two shocks, unlike the other two policies, although the magnitude is small. Because of PPI smoothness, the CPI inflation has a larger deviation than one with the CPI-based Taylor rule. Conversely, the PPI inflation has less deviation than one with the CPI-based

Taylor rule. Hence, two shocks less impact on the nominal interest rate hike with the PPI-based Taylor rule. In general, consumption under two shocks also decreases, because domestic households face increased price.

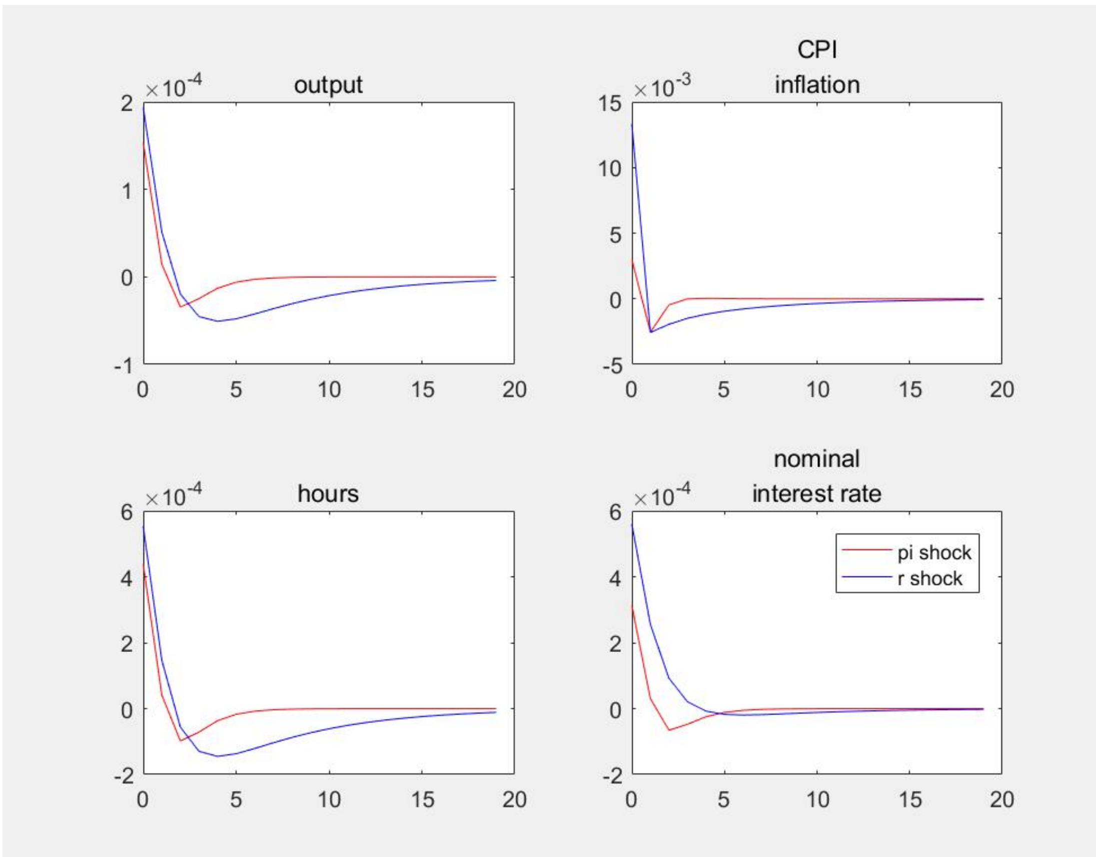

Figure 2.8: Cost-push shock v.s. Natural rate shock with PPI-based Taylor rule

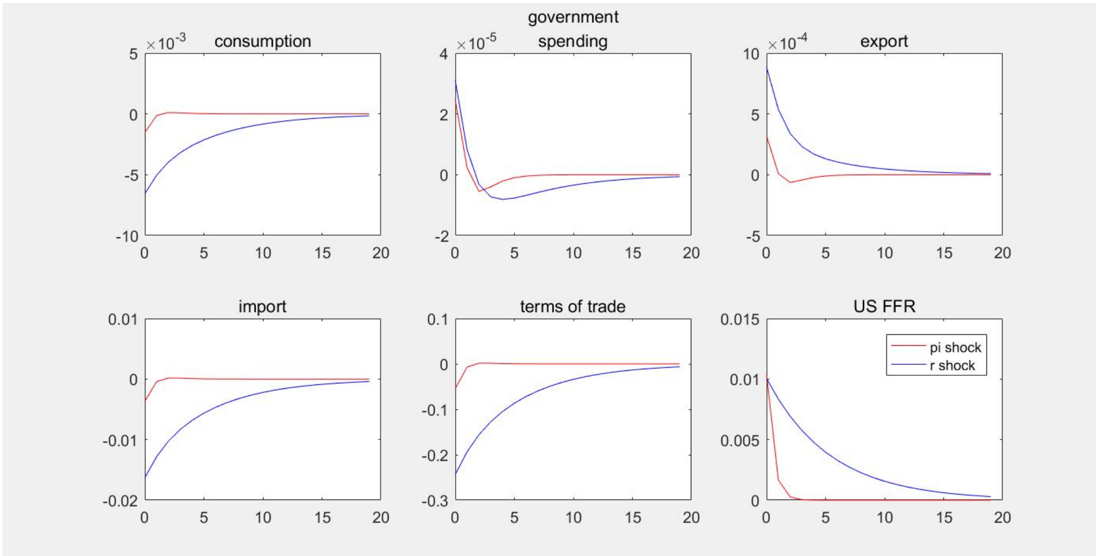

Figure 2.9: Cost-push shock v.s. Natural rate shock with PPI-based Taylor rule

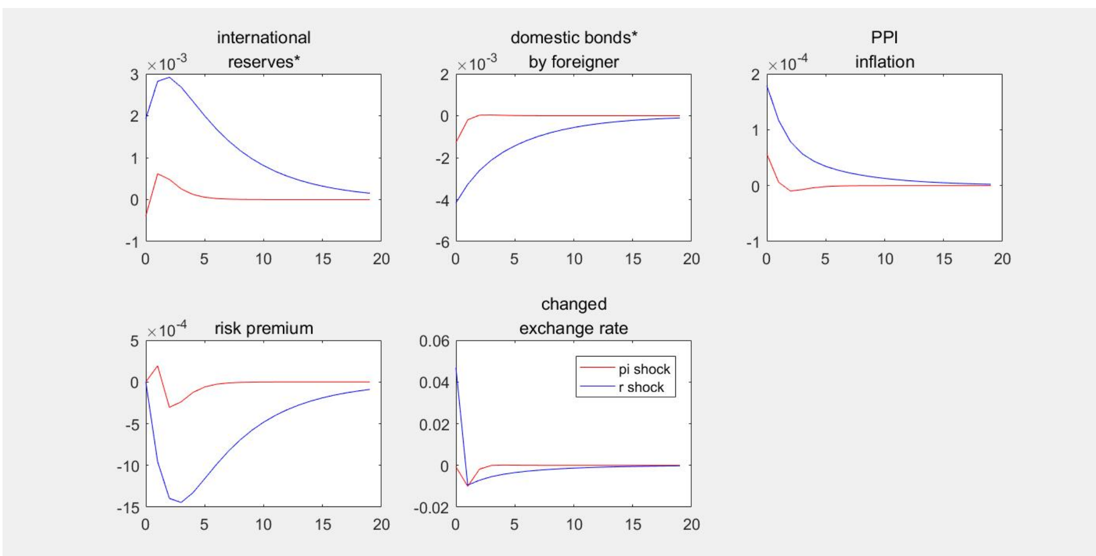

Figure 2.10: Cost-push shock v.s. Natural rate shock with PPI-based Taylor rule

After comparing results under two different shocks in each monetary policy regime, this paper also illustrates the differences in monetary policy regimes. Monetary policy analysis points to the presence of a trade-off between the stabilization of the nominal exchange rate (exchange rate channel), domestic bonds (financial market channel) and the terms of trade (trade market channel) on the one hand, and the stabilization of the output and the PPI inflation on the other. For instance, PPI-based Taylor rule, which achieves a simultaneous stabilization of both the output and the PPI inflation, causes a substantially larger volatility of the nominal exchange rate, domestic bonds, and the terms of trade through each channel relative to the CPI-based Taylor rules and the pegged exchange rate regime. Generally, a CPI-based Taylor rule delivers equilibrium dynamics that lie somewhere between the PPI-based Taylor rule and the pegged exchange rate regime.[9] Due to the excess smoothness of the nominal exchange rate, the pegged exchange rate regime generates significantly higher welfare losses (such as output and consumption) than two Taylor rules. On the contrary, the PPI-based Taylor rule delivers higher welfare than the similar CPI-based Taylor rule. In short, the impact of the U.S. interest rate changes under different shocks on emerging market countries' real output and inflation depends on the monetary policy that they would choose. In a pegged exchange rate regime, the central bank would give up the absorption capability of the nominal exchange rate to external shocks. However, a CPI-based Taylor rule stabilizes the composite price (imported and domestic goods price), so the monetary policy would put some weights on external terms. If the central bank focuses on internal goals with the PPI-based Taylor rule, three channels will bear the effect of external shocks.

[9] Galí and Monacelli [2005] presented the similar dynamic effects of a domestic productivity shock on a number of macroeconomic variables with different monetary policy rules.

2.4 Bayesian Local Projection Empirical Estimation

2.4.1 Data Description

The data are obtained from the Organization for Economic Co-operation and Development (OECD), International Monetary Fund (IMF), Federal Reserve Economic Data (FRED), World Bank, and local national accounts sources (see the Data appendix for more details). The data set includes emerging market countries - Argentina (ARG), Brazil (BRA), Korea (KOR), Mexico (MEX) and South Africa (ZAF), and developed countries - Australia (AUS), Canada (CAN), Netherlands (NLD), New Zealand (NZL) and Sweden (SWE) as observed in 1978Q1-2017Q4.[10] Due to the model's implication, data set collects real value variables - output, consumption, government spending, export, import. This paper uses working hours or the employed population to measure the labor market. The data set also has price index - GDP deflator, assets (denominated in the U.S. currency) - international reserves and debt securities, and nominal rates - exchange rates and interest rates. The cost-push and natural rate shocks are calculated in the model section.

The following results reported in Table 2.3 and Table 2.4 are based on time series detrended using the method from Hamilton [2018] instead of the Hodrick-Prescott filter. The unconditional correlation between each variable and cost-push shock or natural rate shock has shed some light on the problem. First of all, both shocks are positively correlated with FFR, but domestic interest rates of emerging economies show a negative correlation. Second, comparing with natural

[10] The data set is available for ARG between 1993Q1 and 2017Q4, for BRA between 1991Q1 and 2017Q4.

rate shock, cost-push shock is more likely to have a significant negative effect, rather than an obvious positive effect, on a U.S. currency's value and foreign exchange rate. Third, in contrast to developed economies, assets of emerging market economies in the financial market under natural rate shock are cyclical, due to lack of openness and a number of international aids. Fourth, export deviations of emerging economies are more sensitive to cost-push shock, while developed economies' are more responsive to natural rate shock, because of differences in export product attributes. Finally, the natural rate shock - the structural shock of the U.S. has a substantial effect on developed countries.

Country	Y	P	C	G	X	M	H	N	R	$\frac{D^f}{S}$	S	i	i^f
Argentina	0.0390	-0.0211	-0.0128	0.1072	0.1537	0.0264	-0.0042	-0.1509	0.0385	0.0377	-0.0077	-0.0753	0.0489
Brazil	0.0906	-0.0216	-0.0498	0.0597	0.0479	-0.0897	-0.0968	0.1203	-0.0209	0.0318	-0.0973	-0.0374	0.0638
Korea	0.0605	0.0174	0.0871	0.1389	0.0735	0.1586	-0.0307	-0.0401	0.1892	0.0697	-0.1885	-0.0136	0.0672
Mexico	-0.0038	0.0548	0.0708	-0.0310	0.0828	0.0354	-0.0392	-0.0137	-0.0783	0.0535	-0.0378	-0.0319	0.0672
South Africa	0.1369	0.0007	0.1711	-0.0015	-0.0535	0.0594	-0.1646	-0.1787	0.1488	0.0845	-0.2251	-0.0622	0.0672
Emerging Economies	0.0646	0.0060	0.0533	0.0547	0.0609	0.0380	-0.0671	-0.0526	0.0555	0.0554	-0.1113	-0.0441	0.0629
Australia	0.0669	0.0684	0.2861	0.0659	-0.1657	0.1985	0.0130	0.1433	0.0901	0.1787	-0.2580	0.0835	0.0672
Canada	0.0291	0.1218	0.0796	0.0699	-0.0005	0.0638	-0.0024	0.1019	0.0571	0.0788	-0.2387	0.0754	0.0672
Netherlands	0.0915	-0.0439	0.1003	0.0087	0.0872	0.0453	0.0079	-0.1409	-0.0696	0.2586	-0.1995	-0.0134	0.0672
New Zealand	0.0952	0.0304	0.1491	0.0202	0.0958	0.1061	0.0647	-0.0163	0.1414	-0.0291	-0.2118	-0.0856	0.0672
Sweden	0.1269	-0.1028	0.0535	0.0075	0.0445	0.0224	0.0464	0.0589	0.1492	-0.0191	-0.2086	0.0409	0.0672
Developed Economies	0.0819	0.0148	0.1337	0.0344	0.0123	0.0872	0.0259	0.0294	0.0736	0.0936	-0.2233	0.0202	0.0672

Table 2.3: Correlation with U.S. cost-push shocks

Country	Y	P	C	G	X	M	H	N	R	$\frac{D^f}{S}$	S	i	i^f
Argentina	-0.1133	-0.4083	-0.1174	-0.1907	-0.1430	-0.0634	-0.0958	0.2936	-0.0077	0.0871	-0.0495	0.0787	0.3998
Brazil	-0.5308	-0.2889	-0.5720	-0.5191	0.1981	-0.3839	-0.1321	-0.5165	-0.5088	-0.0922	-0.0863	-0.1144	0.4257
Korea	-0.0384	-0.0680	-0.0374	0.0743	0.0508	-0.0474	0.1695	-0.0928	0.3564	0.2659	-0.0973	0.2401	0.4898
Mexico	0.4076	0.1342	0.5155	-0.0626	0.1096	0.4508	-0.1238	0.1667	0.1537	-0.1299	-0.1460	-0.1355	0.4898
South Africa	0.2471	-0.1404	0.1582	-0.2060	0.3052	0.1676	-0.6958	-0.4360	0.0941	0.1735	0.1502	0.1997	0.4898
Emerging Economies	-0.0056	-0.1543	-0.0106	-0.1808	0.1041	0.0247	-0.1756	-0.1170	0.0175	0.0609	-0.0458	0.0537	0.4590
Australia	0.4887	-0.1905	0.2240	0.2367	0.1925	0.1792	0.3218	0.2569	0.0226	-0.1628	0.1759	0.1903	0.4898
Canada	0.6340	-0.0884	0.5334	0.1533	0.5143	0.5130	0.5136	0.5434	0.0701	-0.3629	0.2065	0.4159	0.4898
Netherlands	0.5720	-0.0568	0.3597	-0.1480	0.5883	0.4981	0.1111	0.4276	-0.3525	-0.3256	0.3400	0.3597	0.4898
New Zealand	0.2121	-0.2247	0.3056	0.0828	0.2426	0.2953	0.2003	0.0439	-0.2574	0.0750	0.2214	0.1402	0.4898
Sweden	0.5805	-0.2635	0.3339	0.1070	0.3405	0.5114	-0.0712	0.2846	-0.3261	-0.1428	0.1278	0.2096	0.4898
Developed Economies	0.4975	-0.1648	0.3513	0.0864	0.3756	0.3994	0.2151	0.3113	-0.1687	-0.1838	0.2143	0.2631	0.4898

Table 2.4: Correlation with U.S. natural rate shocks

Table 2.5 are also based on time series detrended using the method from Hamilton [2018]. Association rule learning finds interesting relations between variables in the data set. For emerging economies, if positive cost-push shocks, positive

FFR, and negative foreign exchange rate happen together, they are likely to also have the positive output, export, import, or reserves. However, there is only the positive export under natural rate shocks. In other words, emerging economies are more sensitive to cost-push shock, while developed economies are more responsive to natural rate shock. This method can show some interesting consequents with specific antecedents, but it ignores the magnitude effect and time influence.

Emerging Economies	Antecedents	Consequents	Support	Confidence	Lift
cost-push shocks					
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(Y \uparrow)$	0.135274	0.774510	1.417911
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(X \uparrow)$	0.133562	0.764706	1.435975
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(M \uparrow)$	0.142123	0.813725	1.361650
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(R \uparrow)$	0.130137	0.745098	1.287388
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(M \uparrow, Y \uparrow)$	0.128425	0.735294	1.544647
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(X \uparrow, M \uparrow)$	0.123288	0.705882	1.832157
natural rate shocks					
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(X \uparrow)$	0.07363	0.741379	1.392172
Developed Economies					
cost-push shocks					
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(Y \uparrow)$	0.123494	0.845361	1.435600
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(M \uparrow)$	0.112952	0.773196	1.372733
	$(u^f \uparrow, i^f \uparrow, S \downarrow)$	$(M \uparrow, Y \uparrow)$	0.103916	0.711340	1.543562
natural rate shocks					
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(Y \uparrow)$	0.128012	0.833333	1.415175
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(X \uparrow)$	0.126506	0.823529	1.498147
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(M \uparrow)$	0.125000	0.813725	1.444689
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(R \downarrow)$	0.109940	0.715686	1.499103
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(P \downarrow)$	0.108434	0.705882	1.403311
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(X \uparrow, Y \uparrow)$	0.114458	0.745098	1.818916
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(M \uparrow, Y \uparrow)$	0.117470	0.764706	1.659362
	$(r^{f,f} \uparrow, i^f \uparrow, S \uparrow)$	$(X \uparrow, M \uparrow)$	0.109940	0.715686	1.908497

Table 2.5: Association Rule Learning

2.4.2 Bayesian Local Projection Method

Miranda-Agrippino and Ricco [2017] provided a flexible econometric method -

Bayesian local projections robust to misspecifications that bridges between vector autoregressions (VARs) and local projections (LPs). The VARs produce IRFs by iterating up to the relevant horizon the coefficients of a one-step-ahead model. However, because of a small-size information set, underestimated lag order, and non-linearities, misspecified VARs can fail to capture all of the dynamic interactions. $y_{t+1} = C + B_1 y_t + .. + B_p y_{t-p+1} + \epsilon_{t+1}$ The LPs, Jordà [2005], estimate the IRFs from the coefficients of direct projections of variables onto their lags at the relevant horizon. However, due to the moving average structure of residuals, and the risk of over parametrization, LPs are likely to be less efficient, and hence subject to volatile and imprecise estimates. $y_{t+h} = C + B_1 y_t + .. + B_p y_{t-p+1} + \epsilon_{t+h}$ Therefore, choosing between iterated and direct methods involves a sharp trade-off between bias and estimation variance: the VAR produces more efficient parameter estimates than the LP, but it is prone to bias if the one-step-ahead model is misspecified.

Miranda-Agrippino and Ricco [2017] proposed a regularization for LP-based IRFs which builds on the prior that a VAR can provide, in first approximation, a decent description of the behavior of most variables. As the horizon grows, however, BLPs are allowed to optimally deviate from the restrictive shape of VAR-based IRFs, whenever these are poorly supported by the data. This, while the discipline imposed by the prior, allows to retain reasonable estimation uncertainty at all horizons. Hence, BLP can sensibly reduce the impact of compounded biases over the horizons, effectively dealing with model misspecifications.

2.4.3 Empirical Results

The main results of this section are that impulse response functions (IRFs) with the following VAR ($\epsilon_{i,t}^{f}$ includes two shocks) in these two groups of countries, facing cost-push and natural rate shocks, differ along some important dimensions. Figure 2.11 to Figure 2.15 show emerging market countries' IRFs under cost-push shocks (Figure 2.21 to Figure 2.25 for developed countries). Figure 2.16 to Figure 2.20 display emerging market countries' IRFs under natural rate shocks (Figure 2.26 to Figure 2.30 for developed countries).[11] In contrast to developed countries, the emerging market countries are more volatile, due to the lack of the well established market system and macro-control. Under natural rate shocks, consumption tends to be more volatile than output in emerging economies, while consumption is less volatile than output in developed economies. However, consumption is roughly as volatile as output under cost-push shocks in both emerging and developed economies. Furthermore, cost-push shocks cause larger volatility than natural rate shocks for each country, because of the characteristics of two shocks (cost-push shock $\rho_{\pi}^{f} = 0.16$, $\sigma_{\pi}^{f} = 0.673$ and natural rate shock $\rho_{r}^{f} = 0.83$, $\sigma_{r}^{f} = 0.003$).

[11] All IRFs have a 90% confidence interval. Variables and cointegrated variables pass the augmented DickeyâĂŞFuller test and conclude a stationary process. Akaike's information criterion (AIC), Schwarz's Bayesian information criterion (SBIC), and the Hannan and Quinn information criterion (HQIC) lag order selection statistics provide an optimal lag number 4. Please see the IRFs appendix for more details with other methods - VARs and LPs.

$$M_{12*12}\begin{bmatrix} Y_t \\ P_t \\ C_t \\ G_t \\ X_t \\ C_t^m \\ N_t \\ R_t^* \\ D_t^* \\ S_t \\ i_t \\ i_t^f \end{bmatrix} = B_0 + B_1\begin{bmatrix} Y_{t-1} \\ P_{t-1} \\ C_{t-1} \\ G_{t-1} \\ X_{t-1} \\ C_{t-1}^m \\ N_{t-1} \\ R_{t-1}^* \\ D_{t-1}^* \\ S_{t-1} \\ i_{t-1} \\ i_{t-1}^f \end{bmatrix} + \cdots + B_4\begin{bmatrix} Y_{t-4} \\ P_{t-4} \\ C_{t-4} \\ G_{t-4} \\ X_{t-4} \\ C_{t-4}^m \\ N_{t-4} \\ R_{t-4}^* \\ D_{t-4}^* \\ S_{t-4} \\ i_{t-4} \\ i_{t-4}^f \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \epsilon_{i,t}^f \end{bmatrix}$$

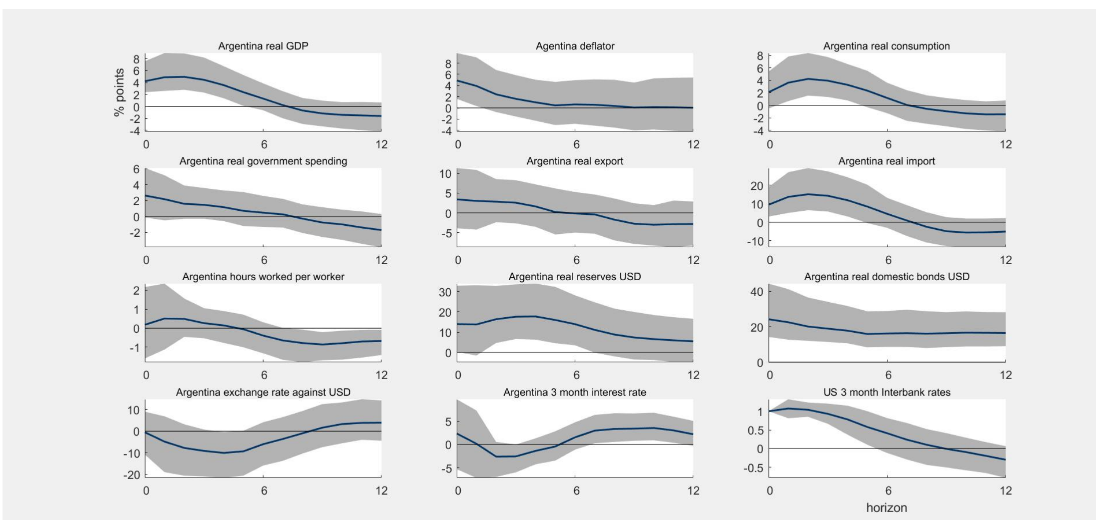

Figure 2.11: Cost-push shock with BLP method - ARG

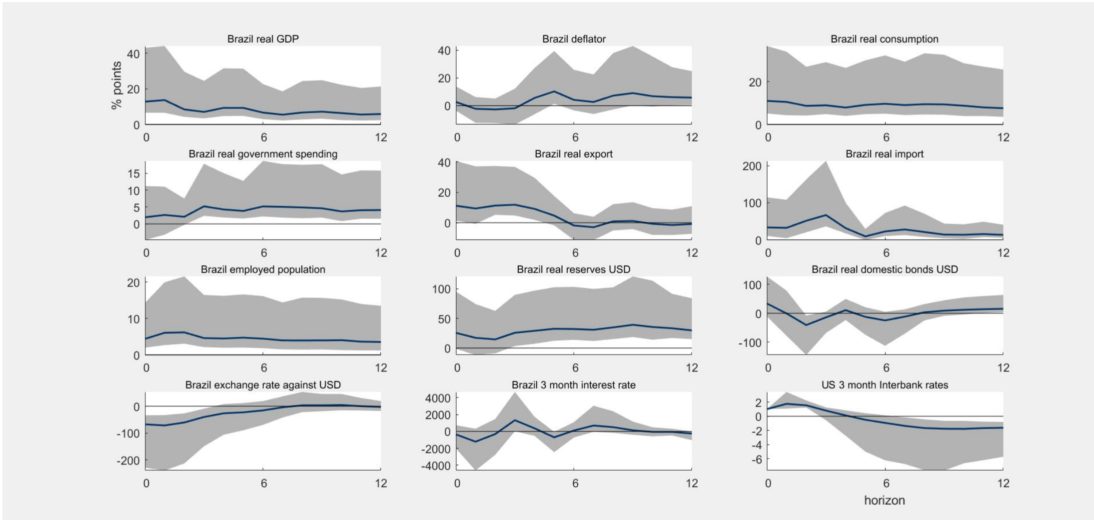

Figure 2.12: Cost-push shock with BLP method - BRA

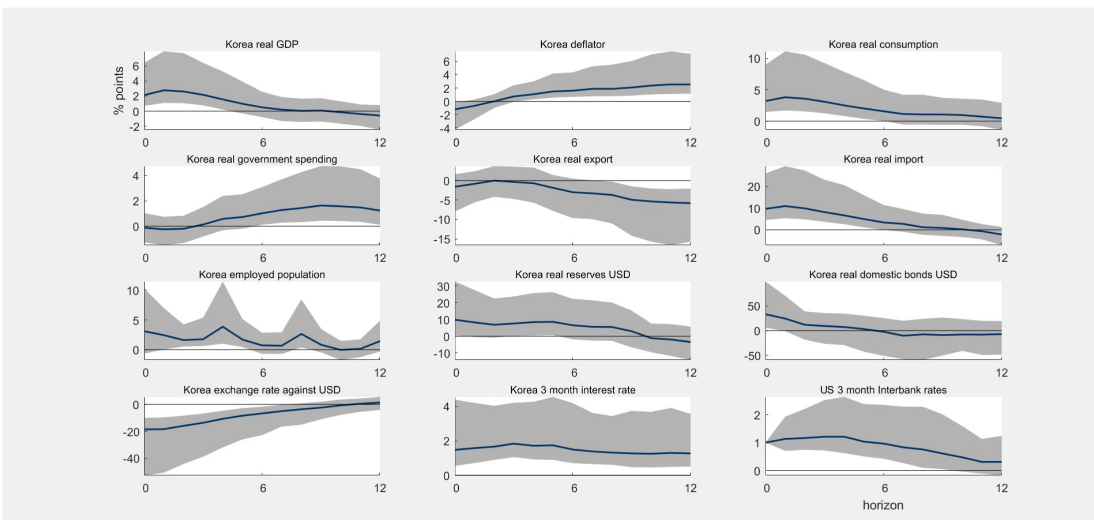

Figure 2.13: Cost-push shock with BLP method - KOR

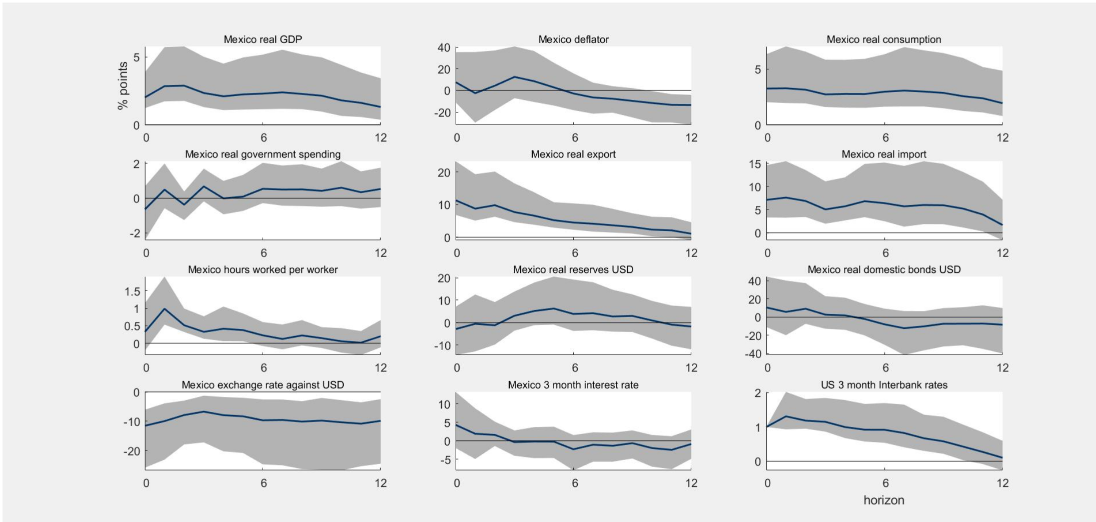

Figure 2.14: Cost-push shock with BLP method - MEX

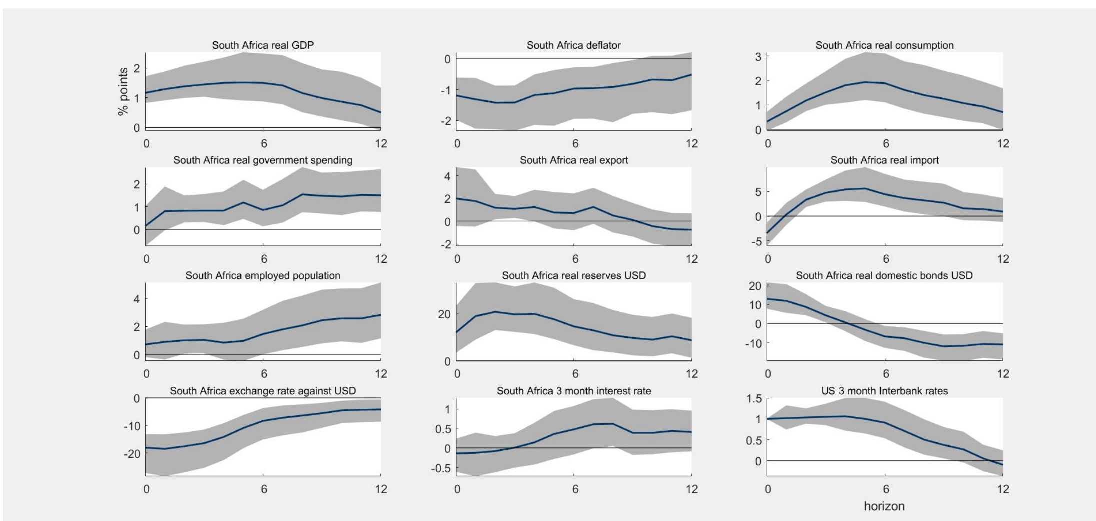

Figure 2.15: Cost-push shock with BLP method - ZAF

In either emerging market or developed countries, the exchange rate channel shows cost-push shocks would cause a negative effect on the exchange rate (USD depreciation), while natural rate shocks would trigger a positive effect on the exchange rate (USD appreciation), which are consistent with the predictions of the model (the CPI-based Taylor rule or the PPI-based Taylor rule). Also, domestic interest rate hikes are more significant and less volatile for developed countries under two shocks, due to well established foreign exchange markets.

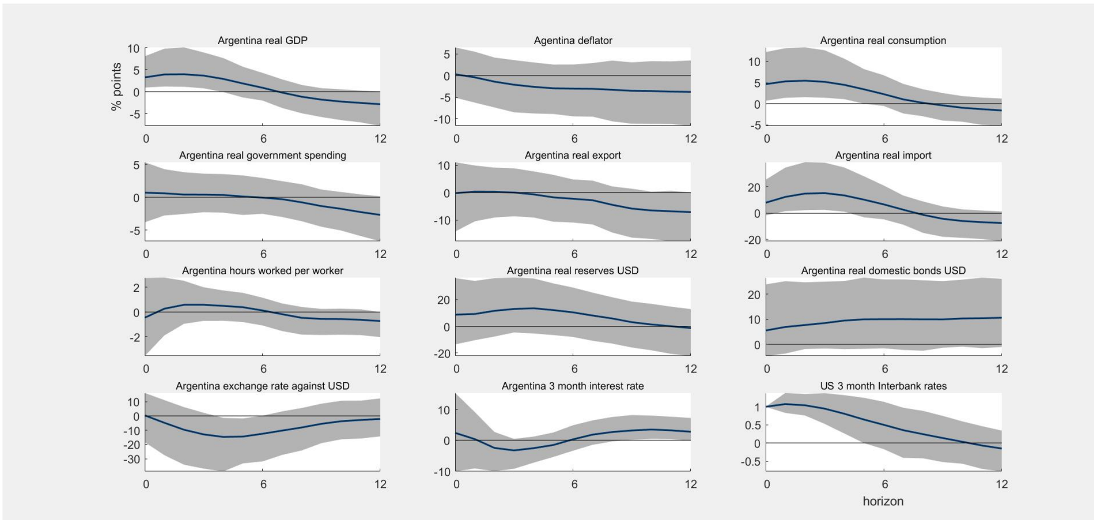

Figure 2.16: Natural rate shock with BLP method - ARG

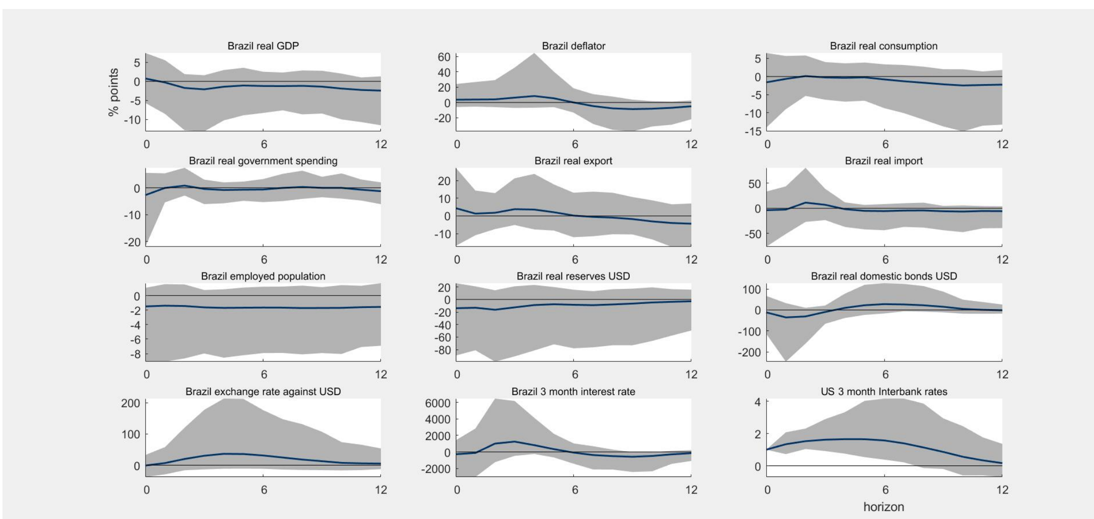

Figure 2.17: Natural rate shock with BLP method - BRA

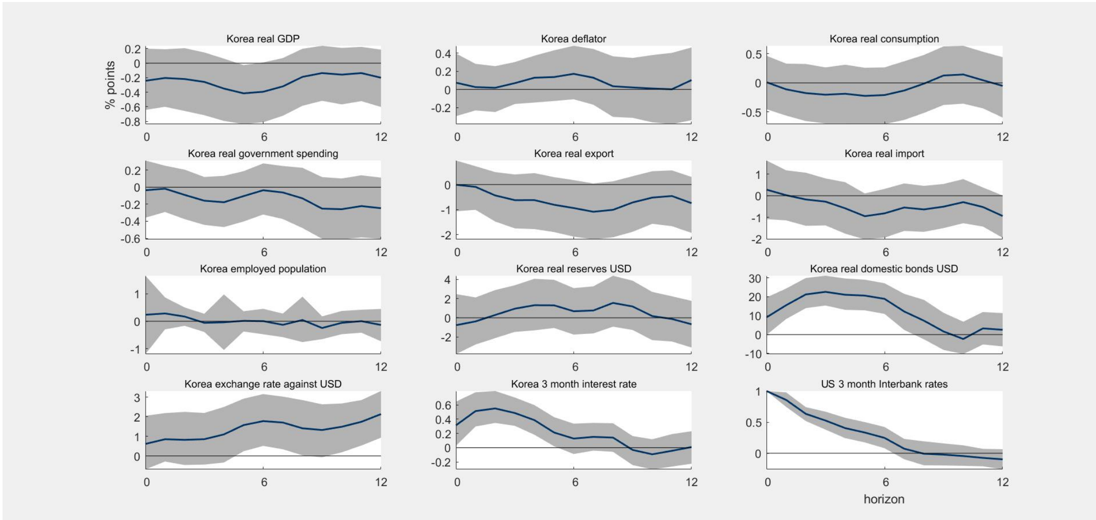

Figure 2.18: Natural rate shock with BLP method - KOR

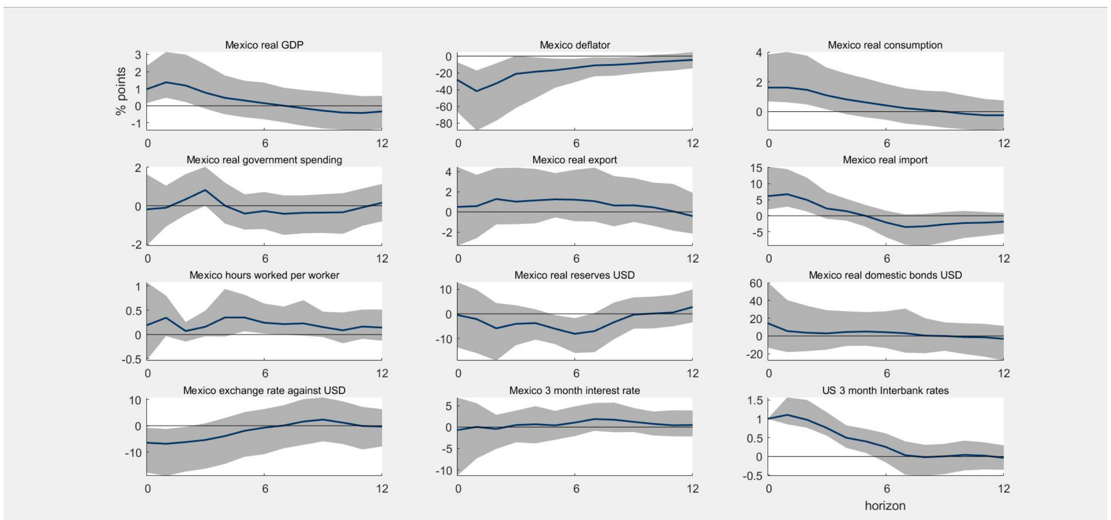

Figure 2.19: Natural rate shock with BLP method - MEX

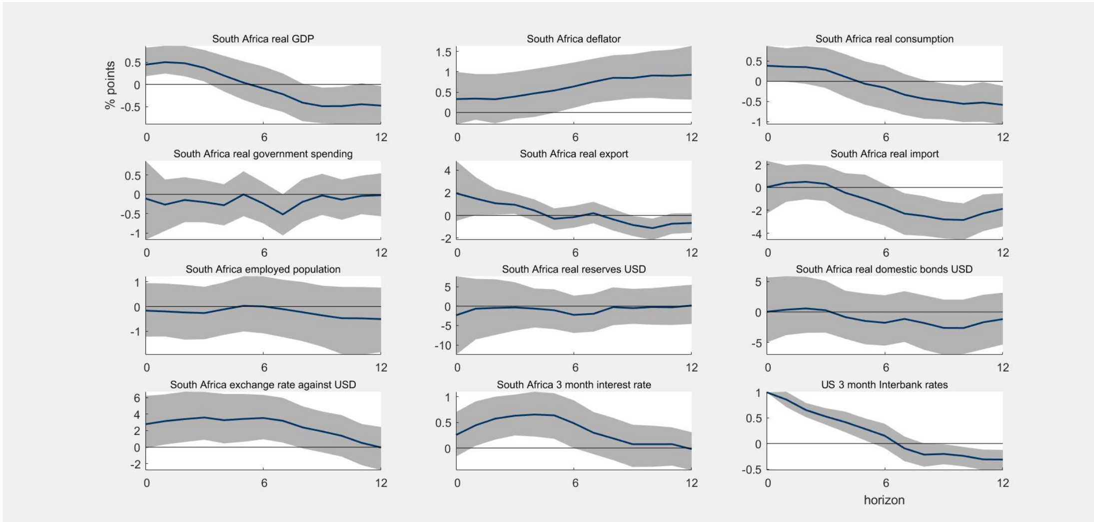

Figure 2.20: Natural rate shock with BLP method - ZAF

For financial market channel, one interesting finding is that the U.S. deflator adjusted international reserves of developed economies have significantly negative effects after natural rate shocks, unlike those after cost-push shocks, because international reserves as precautionary savings could smooth consumption with USD appreciation condition, which can explain that consumption is less volatile than output in developed economies (consumption is roughly as volatile as output under cost-push shocks). On the contrary, the U.S. deflator adjusted international reserves of emerging market economies have insignificant and ambiguous effects after natural rate shocks, due to the accumulation of reserves behavior. Under cost-push shocks, the predictions of the model and BLP IRFs show similar results. However, the patterns of U.S. deflator adjusted international debt securities for emerging market economies are not consistent with predictions of the model under both shocks. First, these variables measure the amount outstanding of international debt securities for issuers in the general government sector with all maturities, which are stock values instead of flow values. Second, emerging market countries tend to increase their public debts continuously. For instance, since 2014, Brazil's public debt as a share of GDP has jumped some 20% points to its present level of around 75%. Third, the model assumes the passive assumption - fixed ratio between government spending and output. Due to the above, the model does not capture the explosive path on public debts of emerging market economies. Unlike emerging market countries, most developed countries show significant negative patterns of international debt securities under two shocks.

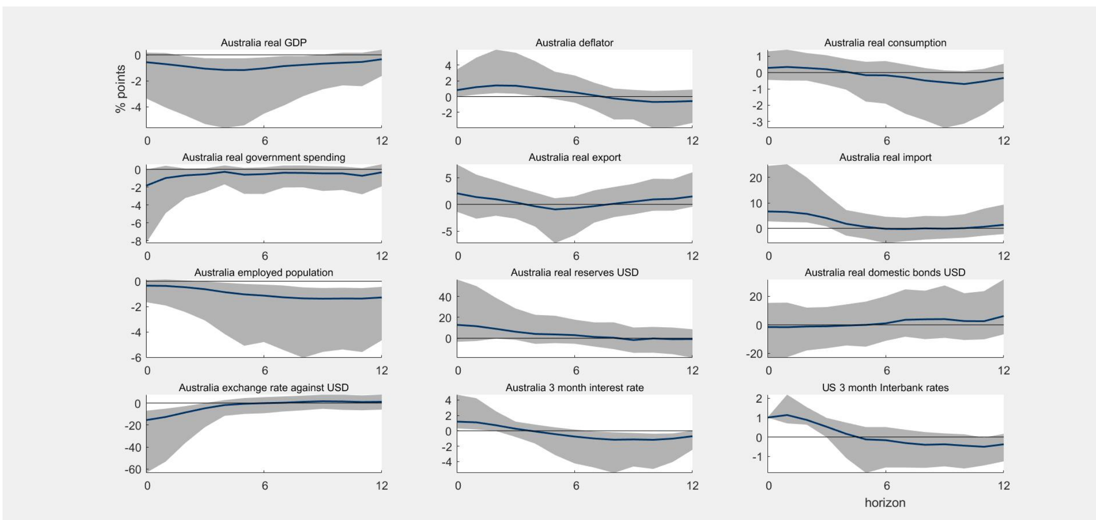

Figure 2.21: Cost-push shock with BLP method - AUS

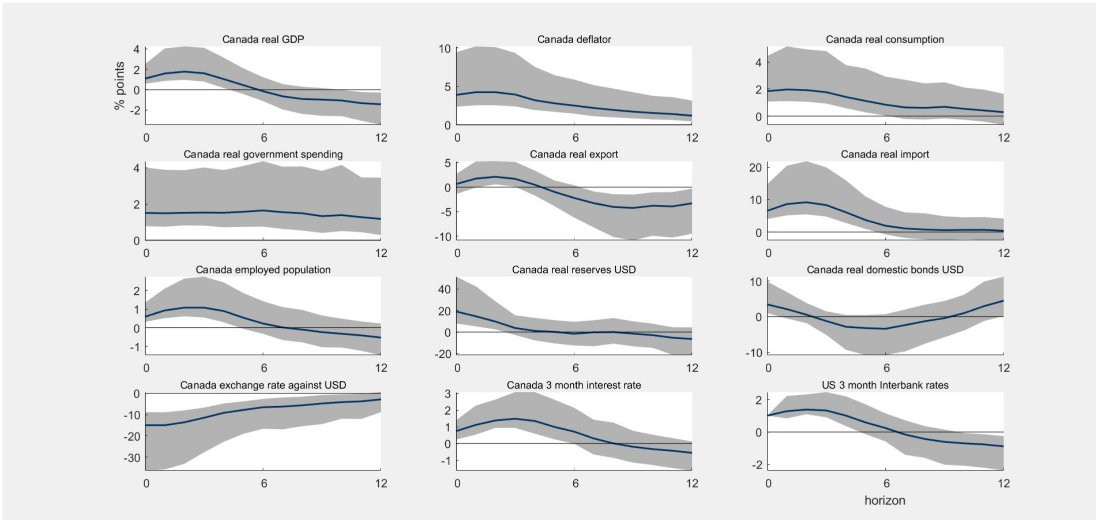

Figure 2.22: Cost-push shock with BLP method - CAN

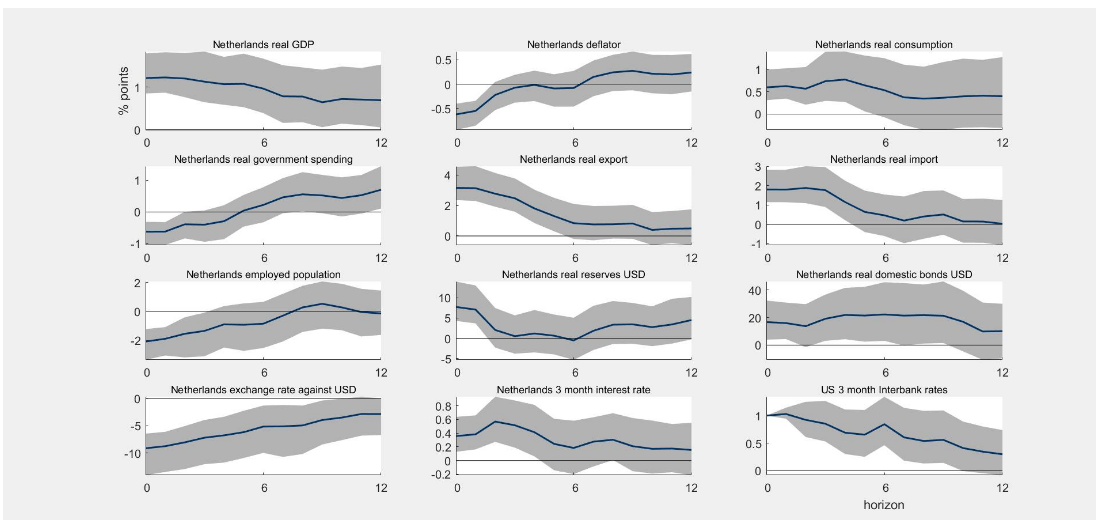

Figure 2.23: Cost-push shock with BLP method - NLD

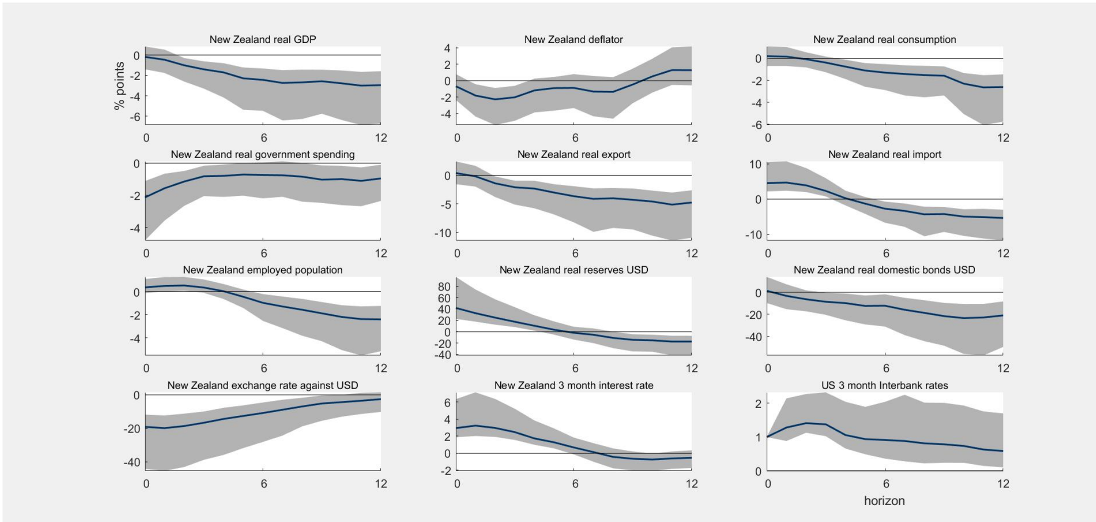

Figure 2.24: Cost-push shock with BLP method - NZL

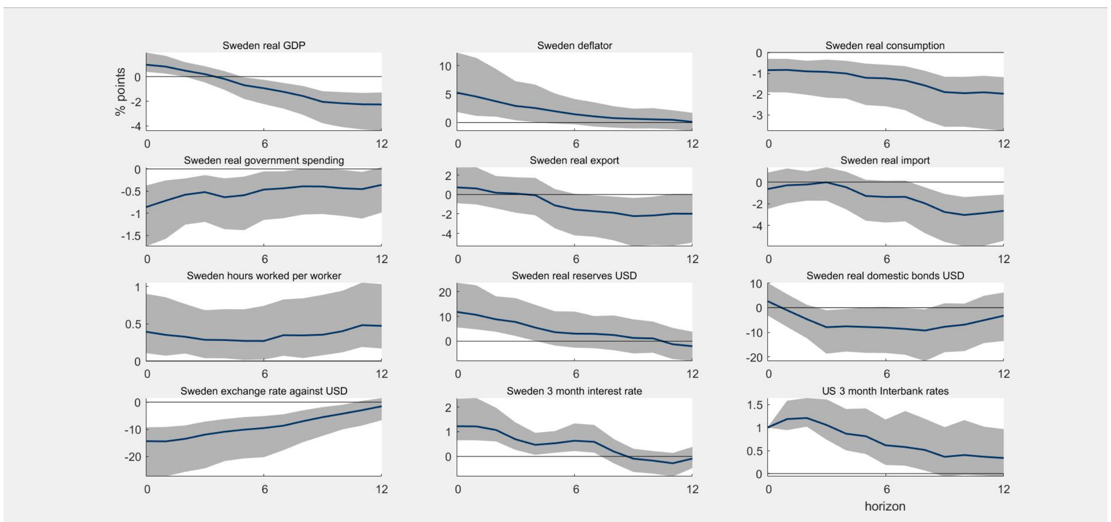

Figure 2.25: Cost-push shock with BLP method - SWE

For the trade market channel, the model predicts export amount increases and then decreases; while import amount decreases, and then increases under cost-push shocks with CPI or PPI-based Taylor rule. The empirical results show consistent patterns for real export, but only positive responses for real import (only South Africa shows consistent pattern as model) under cost-push shocks.

What's more, the natural rate shocks positively impact on the export amount and display negative effects on the import amount, according to the model. However, IRFs give insignificant positive responses for real exports (some significant ones, such as Canada, Netherlands, South Africa) and lagged negative responses for real imports. In addition, the model also presents a negative impact on terms of trade. In other words, export price decreases, and import price increases (or $\frac{P^x\downarrow\downarrow}{P^m\downarrow}$ or $\frac{P^x\uparrow}{P^m\uparrow\uparrow}$). The data of real export and import are measured by volume estimates with reference year 2010, which does not include any information about terms of trade. Finally, there are no significant differences between emerging and developed countries.

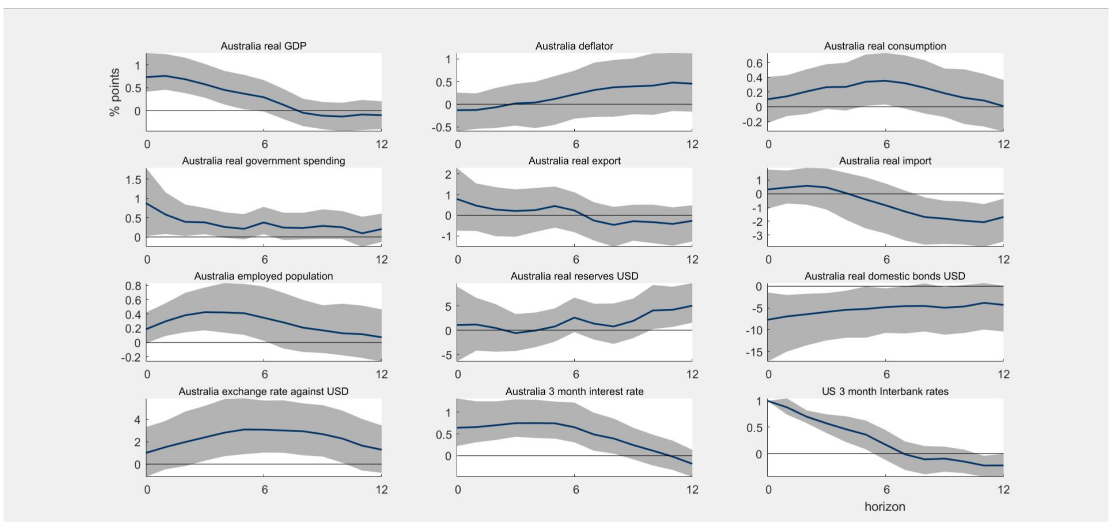

Figure 2.26: Natural rate shock with BLP method - AUS

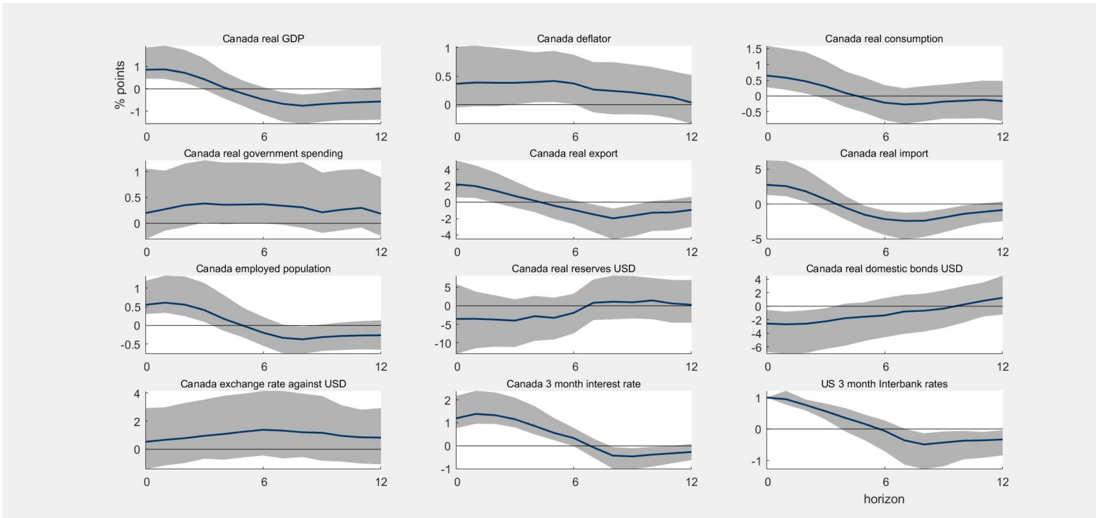

Figure 2.27: Natural rate shock with BLP method - CAN

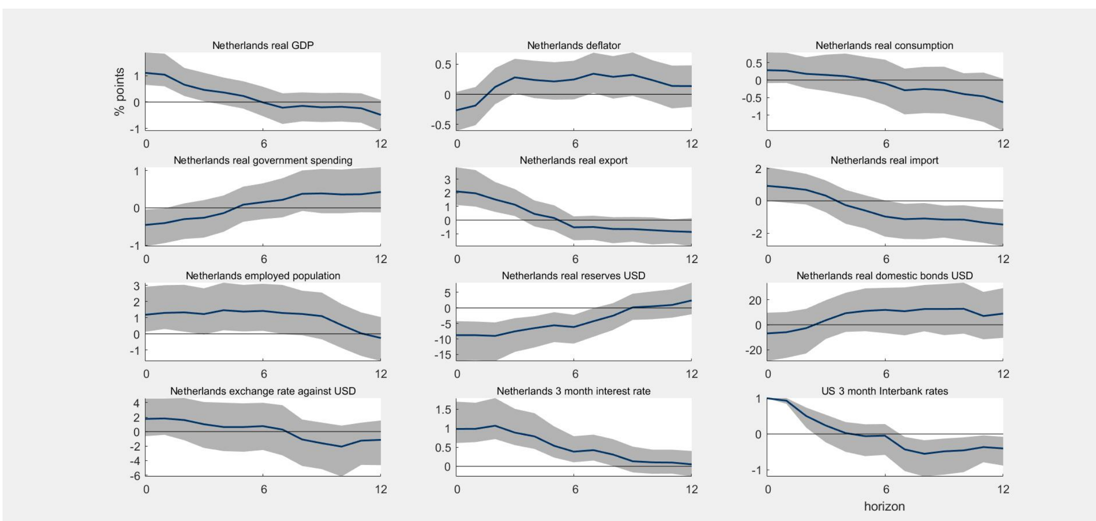

Figure 2.28: Natural rate shock with BLP method - NLD

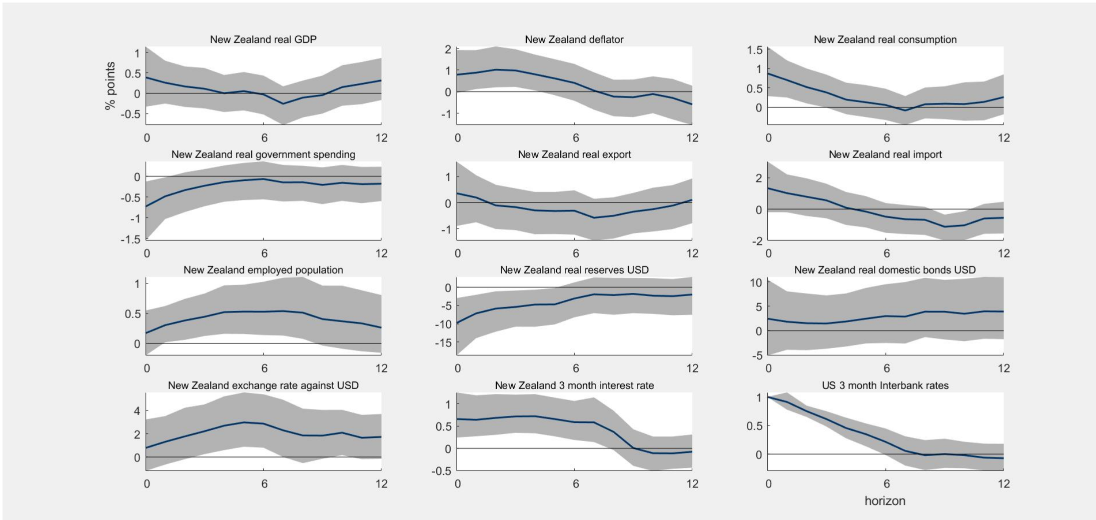

Figure 2.29: Natural rate shock with BLP method - NZL

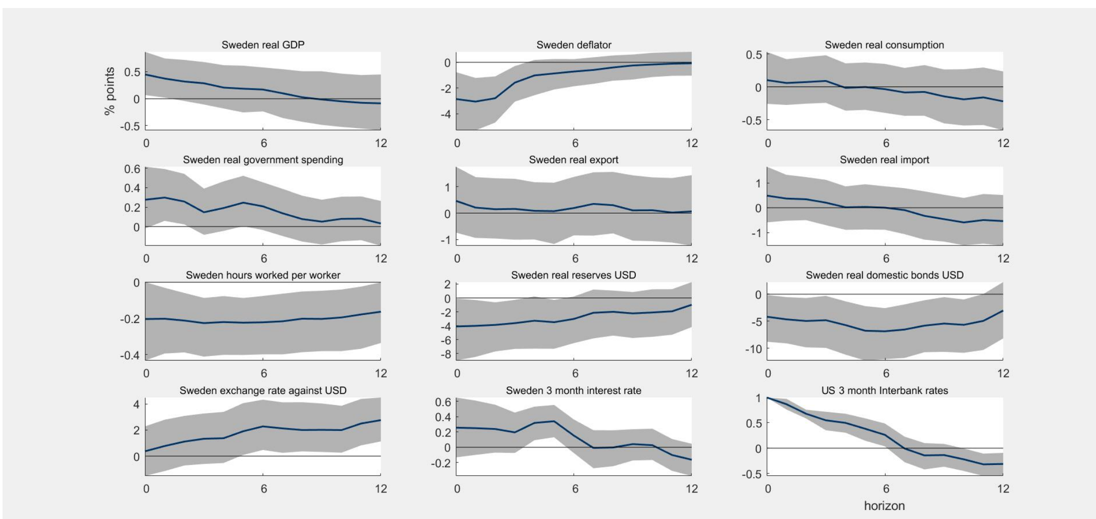

Figure 2.30: Natural rate shock with BLP method - SWE

Through three channels - exchange rate, financial market, and trade market channels, IRFs also reveal other economic indicators' responses. This paper uses either total working hours or the employed population to measure the labor market. The emerging market countries only have a significant and consistent up-down pattern under cost-push shocks as the model with the PPI-based Taylor rule, but an insignificant and unclear pattern under natural rate shocks. In contrast to emerging market countries, developed countries have a significant and unclear pattern under cost-push shocks, but a significant and consistent up-down pattern under natural rate shocks. The model assumes a fixed ratio between government spending and output, but the empirical test treats government spending as an endogenous variable. A positive response is showed under cost-push shocks for the emerging market economy and negative response for the developed economy. The price index - GDP deflator most likely involves a positive response under both shocks. For real output, Argentina, Mexico, South Africa, Australia, Canada, Netherlands, and Sweden have significant and consistent up-down patterns under both shocks as the prediction of model with the PPI-based Taylor rule. However, IRFs of real consumption under different countries and shocks present inconsistent results, comparing with the prediction of the model.

The monetary policy can affect the impact of the U.S. interest rate changes under different shocks on emerging market countries' real output and inflation. Different countries choose different monetary policy frameworks to achieve the objectives of the economy. It is tough to know what specific monetary policy framework will be used by a central bank when the authority to chase multiple goals. In other words, we don't know whether the emerging economies follow the Taylor rule or not. However, the model's prediction shed some light on the monetary policy. If the central bank focuses on internal goals with the PPI-based Taylor rule, three channels will bear the effect of external shocks. Indeed, it is common for CPI to include comprehensive sets of goods and services (the degree of openness will increase the complexity of CPI), while PPI includes mainly domestically produced goods. Based on the data, the average trade openness

(Trade-to-GDP ratio) of Argentina is 0.28; Brazil is 0.19; Korea is 0.63; Mexico is 0.41; South Africa is 0.50. Also, according to the Chinn-Ito Index (normalized to range between zero and one), the average financial openness of Argentina is 0.35; Brazil is 0.18; Korea is 0.43; Mexico is 0.59; South Africa is 0.13. The reports or reviews of emerging economies' central banks give some information about the stabilization of price. First, the Central Bank of Argentina emphasized the importance of inflation targeting regime in its monetary policy report in October 2017. Second, the Extended National Consumer Price Index (IPCA) is the reference for the Brazilian inflation-targeting system. Keeping inflation around the target is a fundamental objective of the Central Bank of Brazil. Third, inflation targeting is the monetary policy regime adopted by the Bank of Korea. It is the monetary policy framework focusing on inflation as the ultimate goal and aiming to achieve its objective over the mid-term horizon. Also, the Bank of Korea is making policy efforts to maintain financial stability while pursuing price stability through implementing its monetary policy. Fourth, the main objective of the Bank of Mexico is to keep low and stable inflation. The central bank uses a group of nominal variables that include short-term interest rates and balances in the current accounts of commercial banks at the central bank to influence the determinants of inflation. Fifth, the primary mandate of the South African Reserve Bank is to achieve and maintain price stability in the interest of balanced and sustainable economic growth. Also, the central bank has a complementary mandate to oversee and maintain financial stability. Overall, inflation targeting is one of the essential objectives for emerging economies and contributes towards more stable economic growth. The central banks do not need to overreact and smooth the external shocks, which could cause large deviations of output and inflation.

2.5 Conclusion

This paper analyzes the impact of U.S. interest rate changes under cost-push shocks and natural rate shocks as well as these shocks' transmission to emerging market countries. The results are two-fold: First, the theoretical model of a New Keynesian small open economy finds that changed exchange rate (exchange rate channel) is negative - USD depreciation under cost-push shock, while positive - USD appreciation under natural rate shock. The differences under the two shocks are amplified through domestic bonds (financial market channel) and terms of trade (trade market channel). Then, the real output of the emerging economy with the PPI-based Taylor rule is positive under both shocks and less volatile under cost-push shock, given the same magnitude of shocks. The model also illustrates the differences in monetary policy regimes. Monetary policy analysis presents the trade-off between the stabilization of the nominal exchange rate (exchange rate channel), domestic bonds (financial market channel) and the terms of trade (trade market channel) on the one hand, and the stabilization of the output and the PPI inflation on the other. As a result, the PPI-based Taylor rule, which achieves a simultaneous stabilization of both the output and the PPI inflation, causes a substantially larger volatility of the nominal exchange rate, domestic bonds and the terms of trade through each channel relative to the CPI-based Taylor rules and the pegged exchange rate regime. Generally, the CPI-based Taylor rule delivers equilibrium dynamics that lie somewhere between the PPI-based Taylor rule and the pegged exchange rate regime.

Second, the empirical test uses Bayesian local projections to analyze the sample that consists of five emerging and five developed countries. As the prediction of the model, the exchange rate channel has significant and different effects under both shocks. A country with a lower inflation rate than others would see an appreciation in the value of its currency. The empirical results reveal that cost-push shocks cause larger volatility than natural rate shocks for each country, due to their characteristics - significant deviation and less persistence. Under natural rate shocks, consumption tends to be more volatile than output in emerging economies, while consumption is less volatile than output in developed economies. However, consumption is roughly as volatile as output under cost-push shocks in both emerging and developed economies. Other interesting findings include domestic interest rate hikes are more significant and less volatile for developed countries under two shocks, due to well established foreign exchange and financial markets; the U.S. deflator adjusted international reserves of developed economies have significantly negative effects after natural rate shocks, but the result doesn't hold for emerging economies in the financial market; there are no significant differences between emerging and developed countries in the trade market under two shocks. The central banks do not need to implement monetary policy to overreact and smooth the external shocks. Putting more weight on the stabilization of external shocks could slow down economic growth or even worse. Understanding the above mechanisms could be the fundamental basis to design monetary policies or promote financial market reforms, which help central banks or governments stabilize emerging economies.

Appendix 2.A Model

The model in full: Endogenous control variables include p_t, p_t^m, q_t, π_t, π_t^d, p_t^x, s_t, p_t^{d*}, N_t, C_t, X_t, R_t^*, D_t^{f*}, ϕ_t, K_t, F_t, i_t, G_t, i_t^f, π_t^f, y_t^f, Z_t^f, $\hat{u}_t^f$, $r_t^{f,f}$. Exogenous variables includes $\epsilon_{u,t}^f$, $\epsilon_{z,t}^f$.

Price setting equations

$$p_t^{d*} = \left[(1-\theta)\left(\frac{1-\theta(\pi_t^d)^{\epsilon-1}}{1-\theta}\right)^{-\frac{\epsilon}{1-\epsilon}} + \theta\frac{(\pi_t^d)^{\epsilon}}{p_{t-1}^{d*}}\right]^{-1} \tag{2.1}$$

$$\left[\frac{1-\theta(\pi_t^d)^{\epsilon-1}}{1-\theta}\right]^{\frac{1}{1-\epsilon}} = \frac{K_t}{F_t} \tag{2.2}$$

$$K_t = \frac{\epsilon}{\epsilon-1}(1-\delta+\delta i_t)\chi N_t^{\psi+1} p_t^{d*} p_t + \beta\theta E_t(\pi_{t+1}^d)^{\epsilon} K_{t+1} \tag{2.3}$$

$$F_t = \frac{p_t^{d*} Z N_t}{C_t} + \beta\theta E_t(\pi_{t+1}^d)^{\epsilon-1} F_{t+1} \tag{2.4}$$

Household intertemporal Euler equation

$$\frac{1}{C_t} = \beta E_t \frac{1}{C_{t+1}} \frac{i_t}{\pi_{t+1}} \tag{2.5}$$

Relative price equations

$$p_t = [(1-\omega) + \omega(p_t^m)^{1-\eta}]^{\frac{1}{1-\eta}} \tag{2.6}$$

$$p_t^m = p_t q_t (1 - \delta^f + \delta^f i_t^f) \tag{2.7}$$

$$\pi_t \equiv \frac{P_t}{P_{t-1}} = \frac{P_t^d p_t}{P_{t-1}^d p_{t-1}} = \pi_t^d \left[\frac{(1-\omega) + \omega(p_t^m)^{1-\eta}}{(1-\omega) + \omega(p_{t-1}^m)^{1-\eta}} \right]^{\frac{1}{1-\eta}} \tag{2.8}$$

$$q_t p_t p_t^x = 1 - \delta^x + \delta^x i_t \tag{2.9}$$

$$\frac{q_t}{q_{t-1}} = s_t \frac{\pi_t^f}{\pi_t} \tag{2.10}$$

UIP equation

$$\frac{i_t}{\phi_t} = s_{t+1} i_t^f \tag{2.11}$$

Aggregate resource condition

$$p_t^{d*} Z N_t = (1-\omega) p_t^\eta C_t + X_t + G_t \tag{2.12}$$

Balance of payment

$$q_t R_t^* + \omega(\frac{p_t}{p_t^m})^{\eta-1} C_t + \frac{i_{t-1}}{\phi_{t-1}\pi_t} D_{t-1}^{f*} = q_t p_t^x X_t + \frac{i_{t-1}^f}{\pi_t^f} q_t R_{t-1}^* + D_t^{f*} \tag{2.13}$$

Government spending

$$G_t = \eta_g p_t^{d*} Z N_t \tag{2.14}$$

Central bank policy

$$log(\frac{i_t}{i}) = \rho_i log(\frac{i_{t-1}}{i}) + (1-\rho_i)[\rho_\pi log(\frac{\pi_t}{\pi}) + \rho_y log(\frac{Y_t}{Y})] \tag{2.15}$$

Risk premium

$$\phi_t = \zeta(\frac{R^*}{R^*_{t-1}})^\tau \tag{2.16}$$

Foreign demand for exports

$$X_t = (p_t^x)^{-\eta_f}(\frac{\epsilon^f - 1}{\epsilon^f})^{\frac{1}{1+\psi^f}} Z_t^f y_t^f \tag{2.17}$$

Foreign demand for domestic bonds

$$D_t^{f*} = \mu(\frac{E_t q_{t+1}}{q_t}) \tag{2.18}$$

Foreign New Keynesian Phillips curve

$$log(\frac{\pi_t^f}{\pi^f}) = \beta^f E_t log(\frac{\pi_{t+1}^f}{\pi^f}) + \kappa^f(1+\psi^f) log(\frac{y_t^f}{y^f}) + \hat{u}_t^f \tag{2.19}$$

where $\kappa^f \equiv \frac{(1-\theta^f)(1-\beta^f\theta^f)}{\theta^f}$ and $\beta^f = \frac{1}{r^{f,f}}$.

Foreign New Keynesian IS curve

$$log(\frac{y_t^f}{y^f}) = E_t log(\frac{y_{t+1}^f}{y^f}) - log(\frac{i_t^f}{i^f}) + E_t log(\frac{\pi_{t+1}^f}{\pi^f}) + log(\frac{r_t^{f,f}}{r^{f,f}}) \tag{2.20}$$

Foreign policy with Taylor rule

$$log(\frac{i_t^f}{i^f}) = \rho_\pi log(\frac{\pi_t^f}{\pi^f}) + \rho_y log(\frac{y_t^f}{y^f}) + log(\frac{r_t^{f,f}}{r^{f,f}}) \tag{2.21}$$

Foreign cost-push shocks

$$\hat{u}_t^f = \rho_u^f \hat{u}_{t-1}^f + \epsilon_{u,t}^f \tag{2.22}$$

Foreign natural rate of interest shocks

$$log(\frac{r_t^{f,f}}{r^{f,f}}) = \rho_z^f log(\frac{r_{t-1}^{f,f}}{r^{f,f}}) + (\rho_z^f - 1)\epsilon_{z,t}^f \tag{2.23}$$

Foreign technology shocks

$$log(\frac{Z_t^f}{Z^f}) = \rho_z^f log(\frac{Z_{t-1}^f}{Z^f}) + \epsilon_{z,t}^f \tag{2.24}$$

Appendix 2.B Data

Variable	Source	Detail	Period
Gross domestic product	OECD	National currency (Millions), volume estimates, reference year 2010, annual levels, seasonally adjusted	1978Q1-2017Q4
Private final consumption expenditure	OECD	National currency (Millions), volume estimates, reference year 2010, annual levels, seasonally adjusted	1978Q1-2017Q4
General government final consumption expenditure	OECD	National currency (Millions), volume estimates, reference year 2010, annual levels, seasonally adjusted	1978Q1-2017Q4
Exports of goods and services	OECD	National currency (Millions), volume estimates, reference year 2010, annual levels, seasonally adjusted	1978Q1-2017Q4
Imports of goods and services	OECD	National currency (Millions), volume estimates, reference year 2010, annual levels, seasonally adjusted	1978Q1-2017Q4
Hours worked per worker	OECD	(Hours), annual levels (not available for ARG, BRA, ZAF)	1978Q1-2017Q4
Employed population	OECD	(Thousands), aged 15 and over, seasonally adjusted (not available for ARG, ZAF)	1978Q1-2017Q4
GDP deflator	OECD	Index, reference year 2010, seasonally adjusted	1978Q1-2017Q4
International reserves	IMF	US Dollar (Millions), official reserve assets, official gold price	1978Q1-2017Q4
Exchange rates	OECD	National currency:USD, average of daily rates	1978Q1-2017Q4
International debt securities	FRED	US Dollar (Millions), issuers in general government sector, all maturities	1978Q1-2017Q4
Interest rates	OECD	3-month interbank rates, annual levels (available for AUS, CAN, NLD, NZL, SWE, ZAF, USA)	1978Q1-2017Q4
Interest rates	IMF	3-month deposit rates, annual levels (available for ARG, BRA)	1978Q1-2017Q4
Interest rates	FRED	3-month government securities rates, annual levels (available for KOR)	1978Q1-2017Q4
Interest rates	OECD	3-month treasury securities rates, annual levels (available for MEX)	1978Q1-2017Q4
Natural rate of Interest	Laubach & Williams	Estimates of the baseline LW model, one-sided estimates, annual levels	1961Q1-2017Q4
Energy commodity price indices	World Bank	Monthly indices based on nominal US dollars, reference year 2010	1961M1-2017M12

Table 2.6: Data Sources

Argentina's consumption, government spending, export, import data is available from 1993Q1 to 2003Q4 in local national accounts sources and from 2004Q1 to 2017Q4 in the OECD data set. Brazil's output, consumption, government spending, export, import data is available from 1991Q1 to 1995Q4 in local national accounts sources and from 1996Q1 to 2017Q4 in the OECD data set. For hours worked per worker (adjusted to annual level), Argentina has semester data from 1986S2 to 2002S2 and quarter data from 2003Q3 to 2017Q4 in local national accounts sources (ILOSTAT). Brazil has quarter data from 1992Q1 to 2001Q4 and month data from 2002M1 to 2017M12 in local national accounts sources. South Africa has semester data from 2000S1 to 2007S2 and quarter data from 2008Q1 to 2017Q4 in local national accounts sources (ILOSTAT). Also, for the employed population (aged 15 and over), Argentina has semester data from 1980S1 to 2002S1 and quarter data from 2003Q3 to 2017Q4 in local national accounts sources (ILOSTAT). South Africa has semester data from 2000S1 to 2007S2 and quarter data from 2008Q1 to 2017Q4 in local national accounts sources (ILOSTAT). GDP deflator of Argentina has some missing data from 1993Q1 to 2003Q4, collected from IMF data sources for supplement. International reserves and international debt securities are adjusted by U.S. GDP deflator to change nominal terms to real terms. For interest rates, Brazil's 3-month deposit rates are more volatile due to the high variability of local inflation. The quarterly energy commodity price indices are the average of monthly indices.

Appendix 2.C IRFs

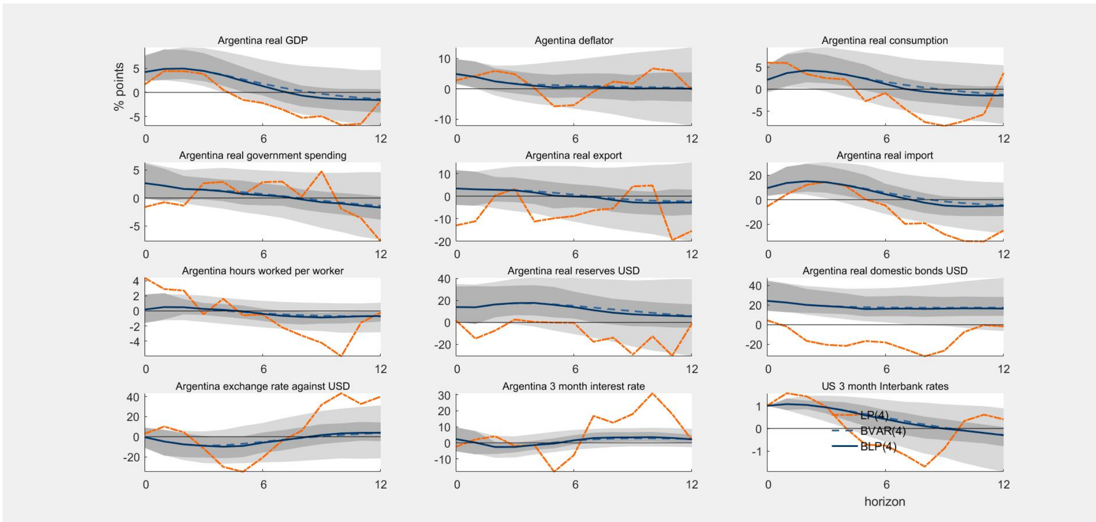

Figure 2.31: Cost-push shock with all methods - ARG

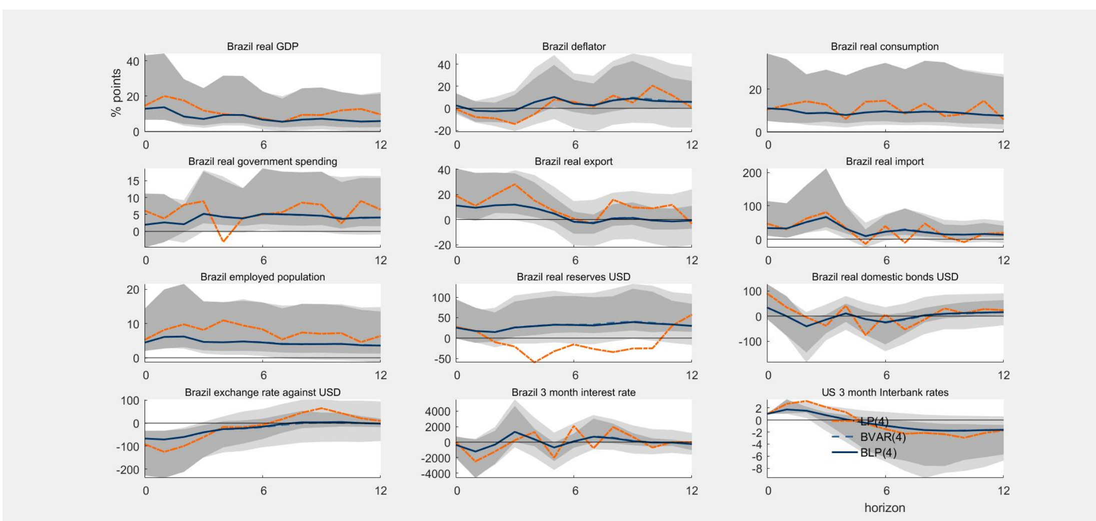

Figure 2.32: Cost-push shock with all methods - BRA

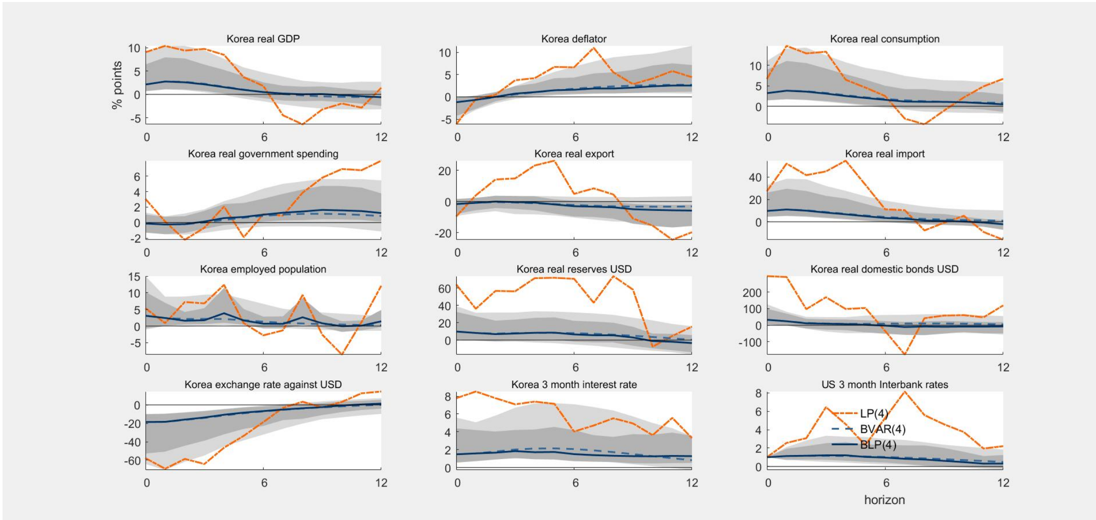

Figure 2.33: Cost-push shock with all methods - KOR

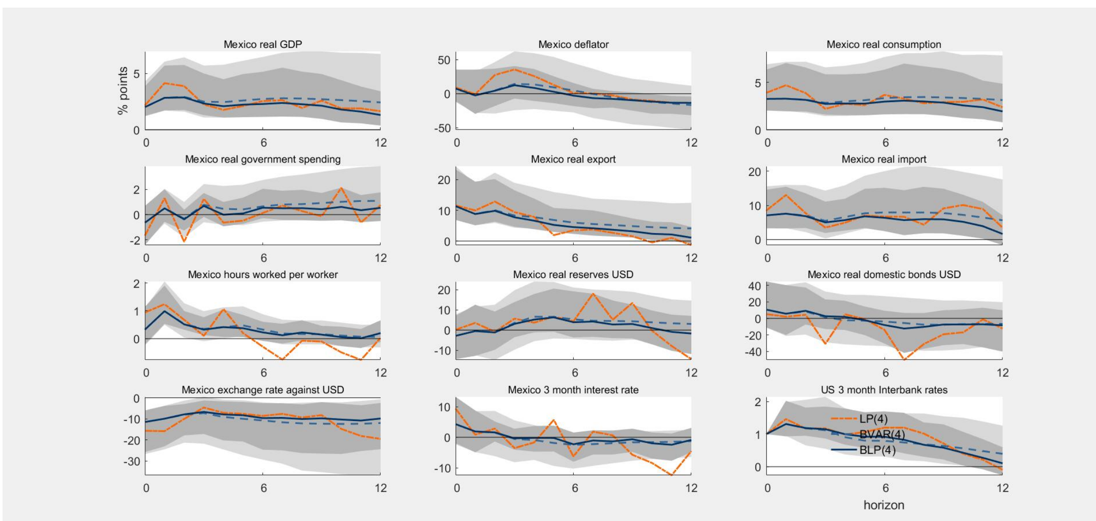

Figure 2.34: Cost-push shock with all methods - MEX

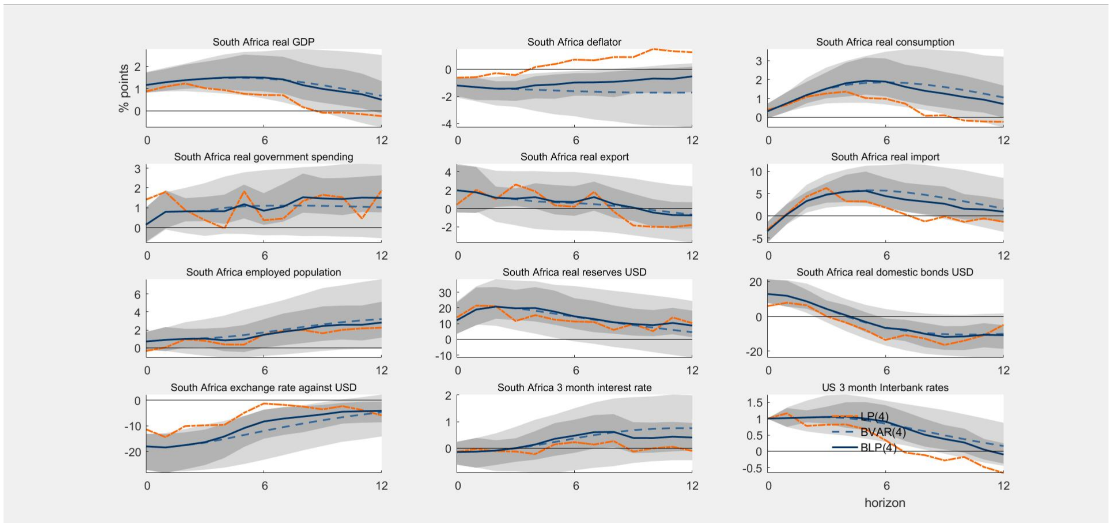

Figure 2.35: Cost-push shock with all methods - ZAF

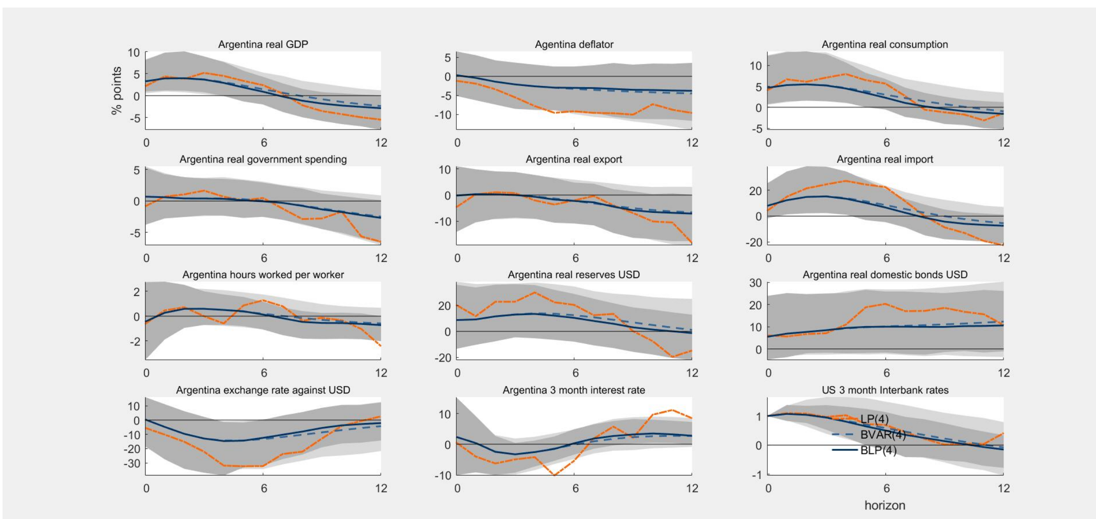

Figure 2.36: Natural rate shock with all methods - ARG

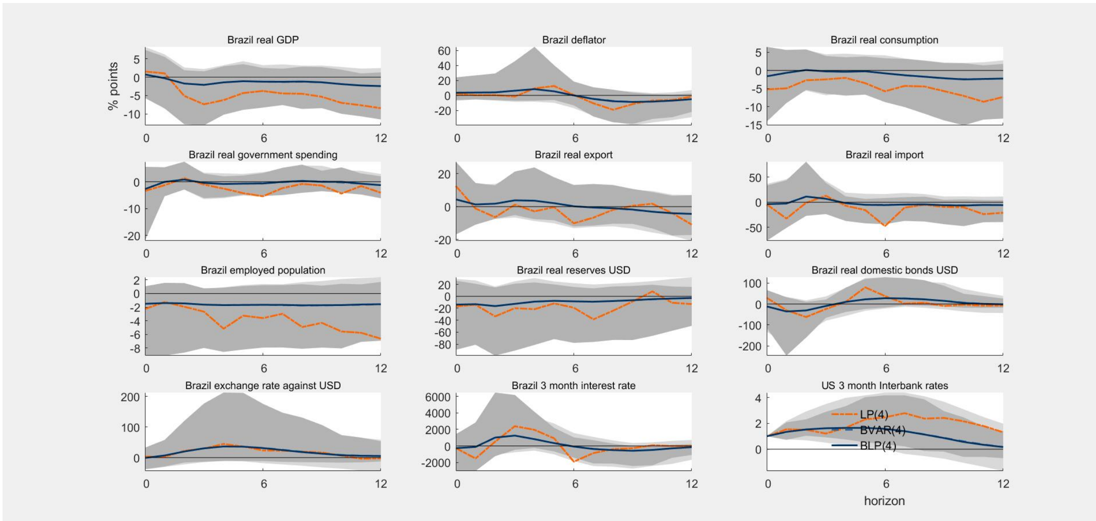

Figure 2.37: Natural rate shock with all methods - BRA

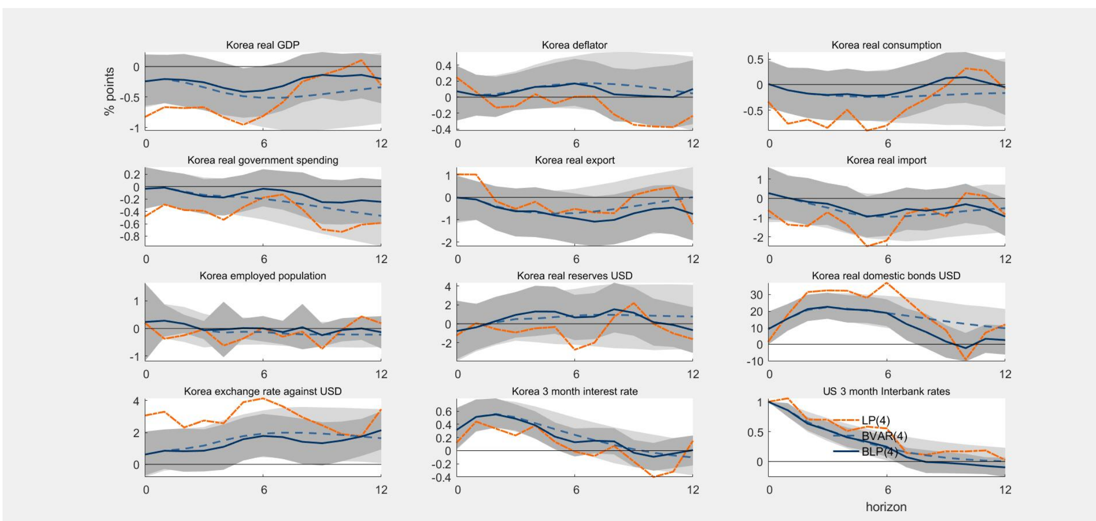

Figure 2.38: Natural rate shock with all methods - KOR

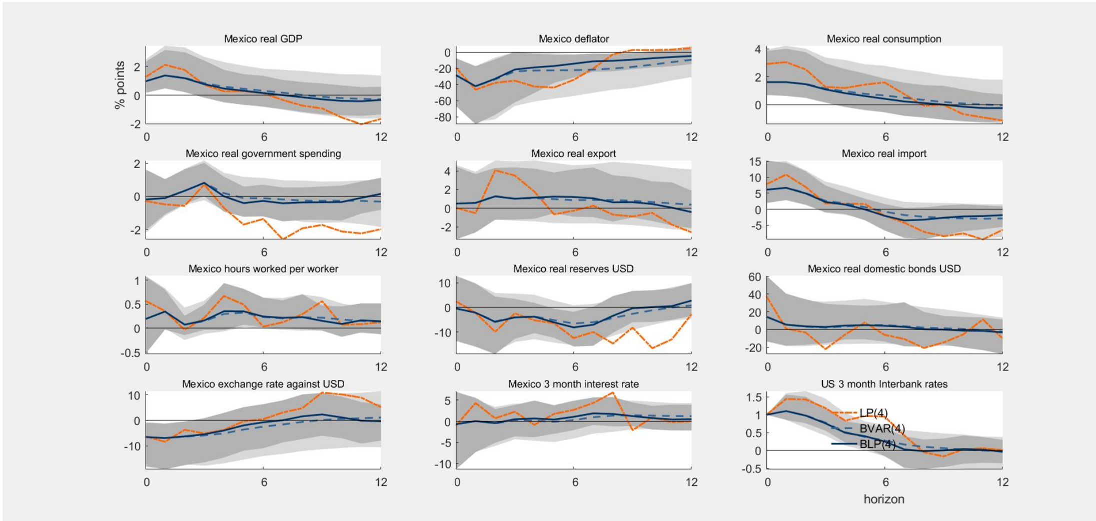

Figure 2.39: Natural rate shock with all methods - MEX

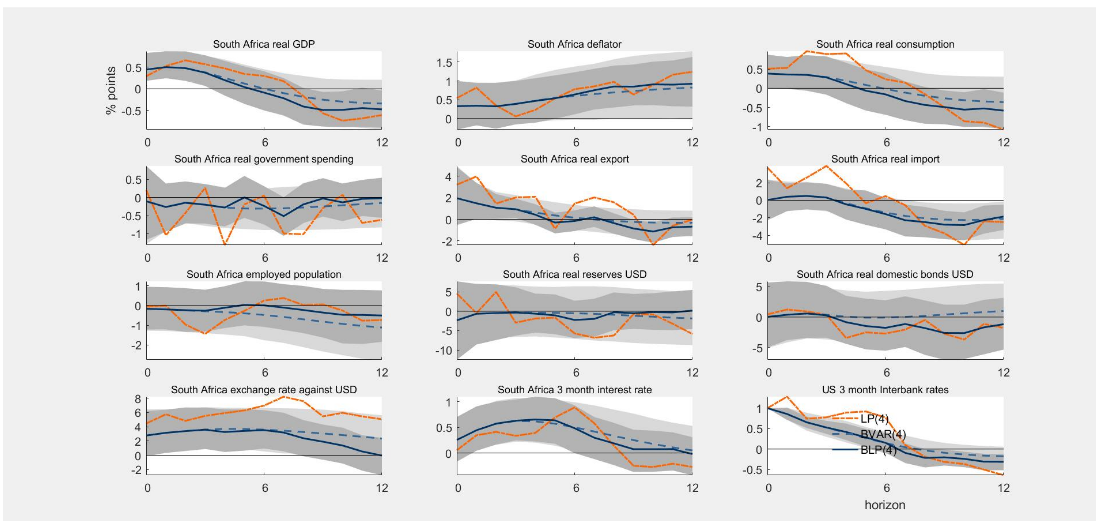

Figure 2.40: Natural rate shock with all methods - ZAF

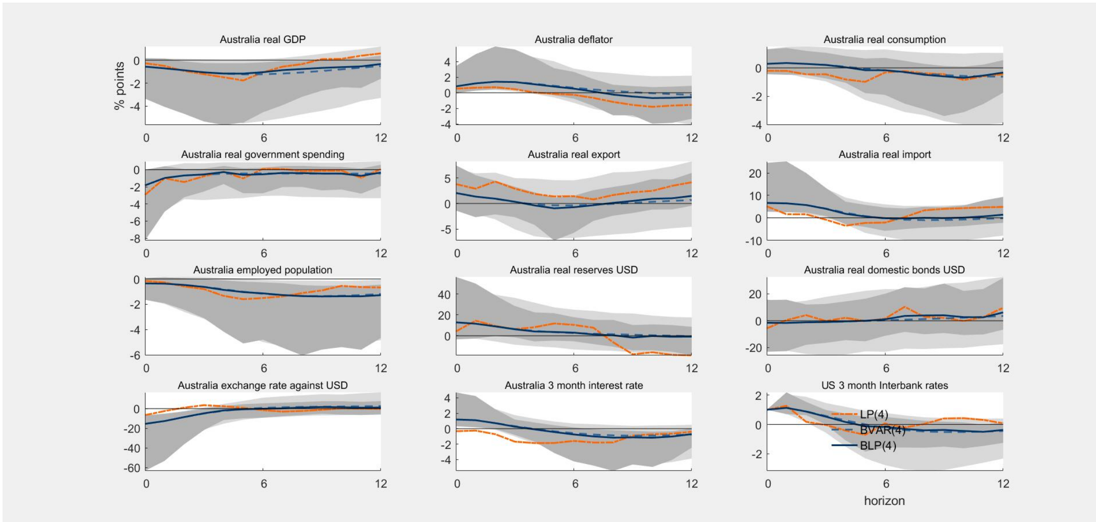

Figure 2.41: Cost-push shock with all methods - AUS

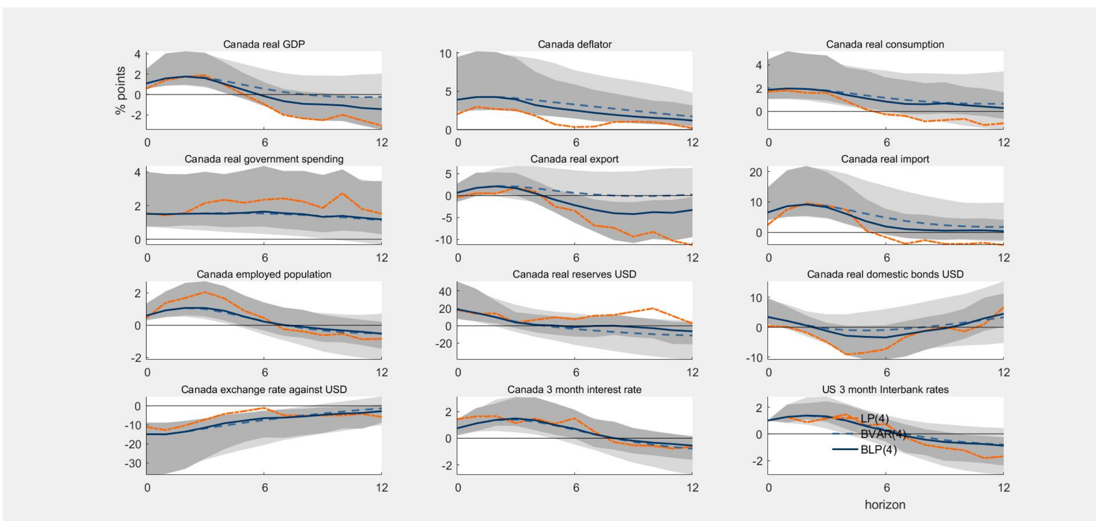

Figure 2.42: Cost-push shock with all methods - CAN

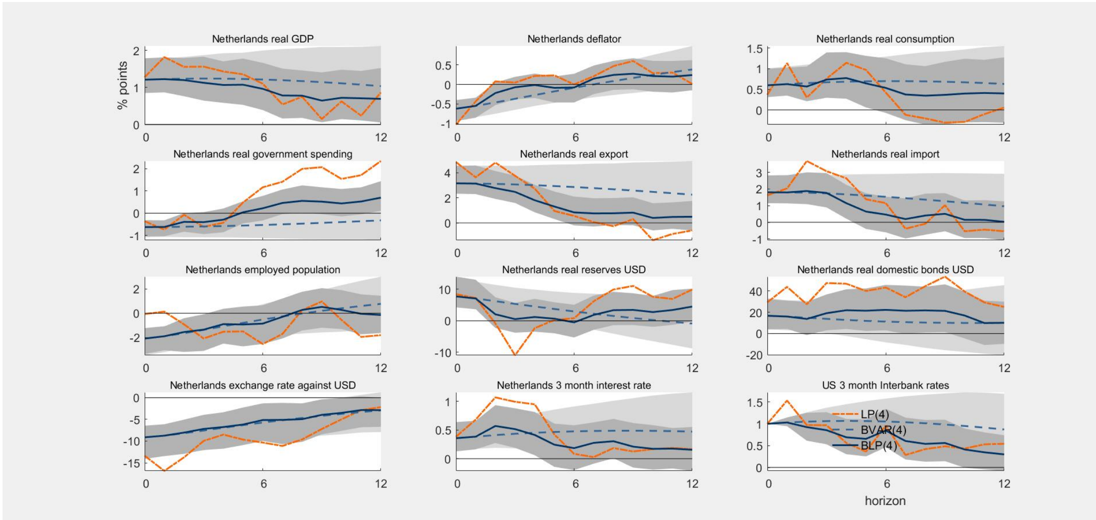

Figure 2.43: Cost-push shock with all methods- NLD

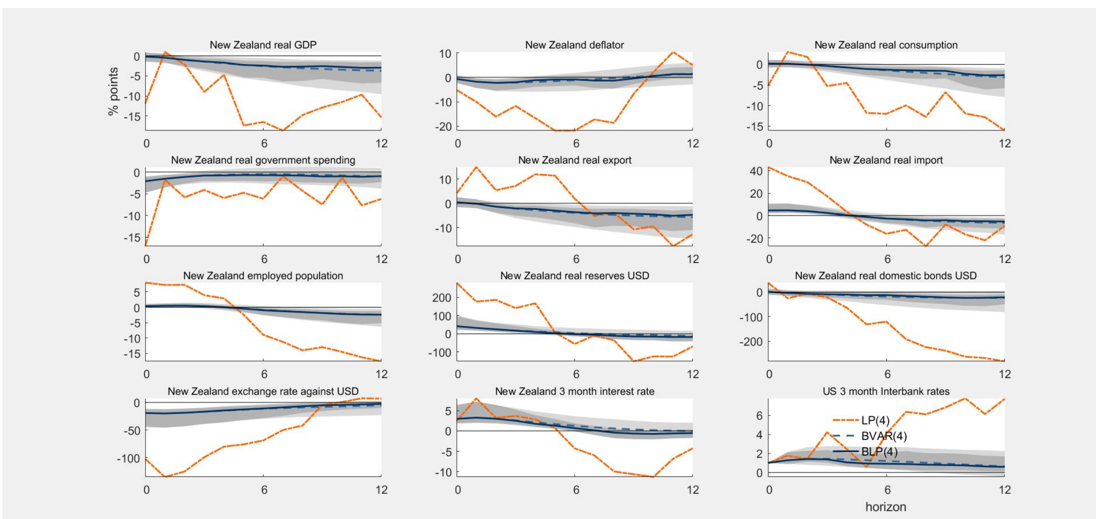

Figure 2.44: Cost-push shock with all methods - NZL

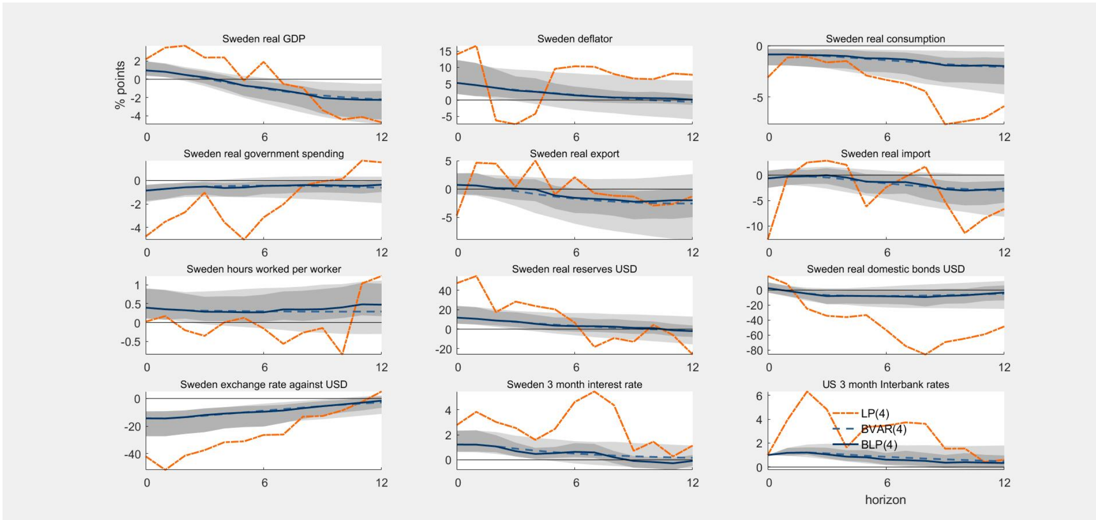

Figure 2.45: Cost-push shock with all methods - SWE

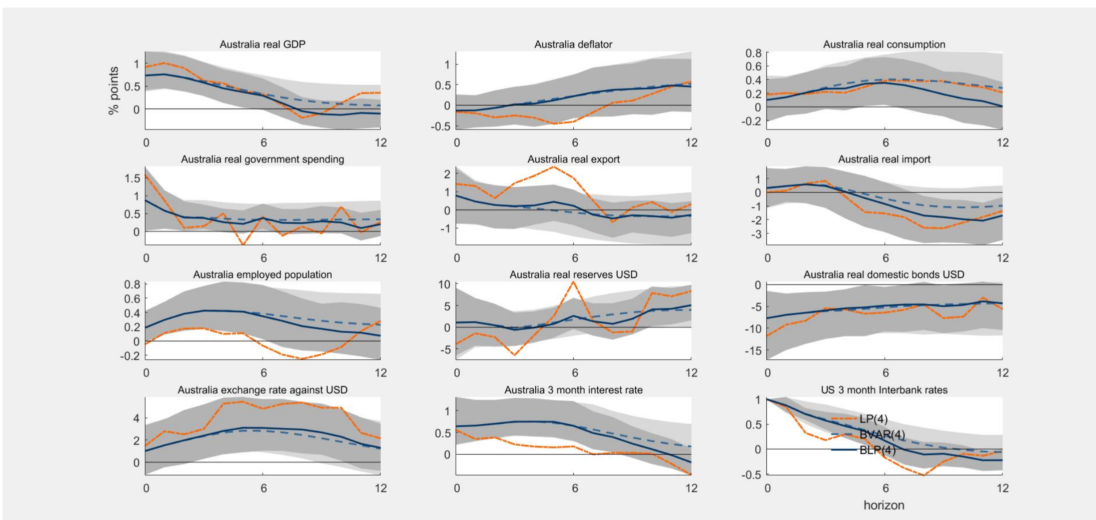

Figure 2.46: Natural rate shock with all methods - AUS

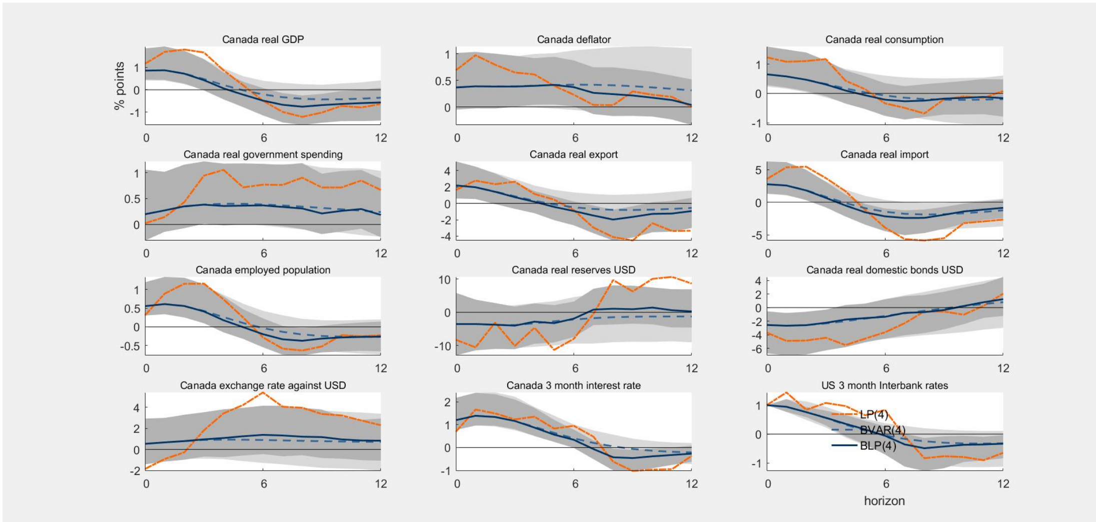

Figure 2.47: Natural rate shock with all methods - CAN

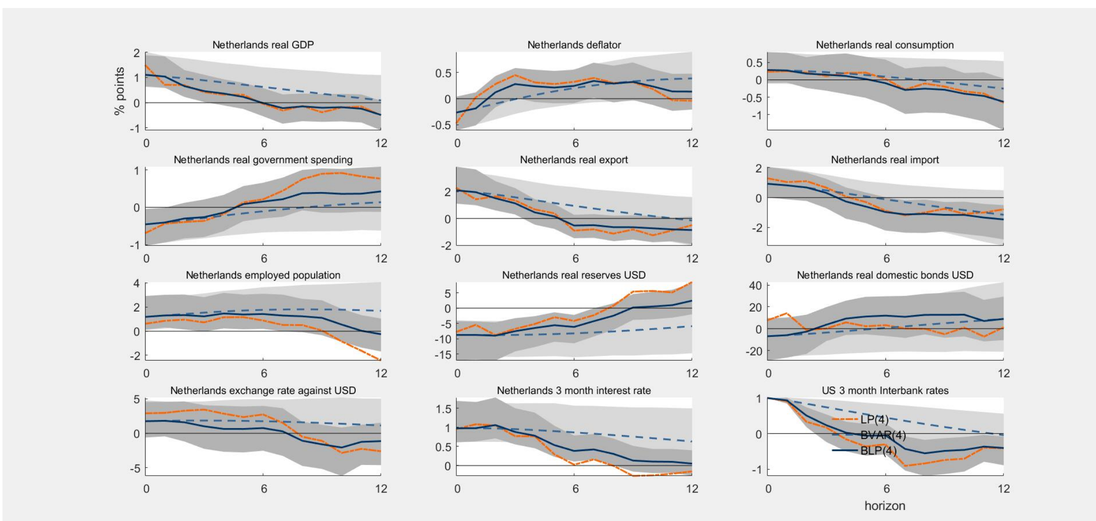

Figure 2.48: Natural rate shock with all methods - NLD

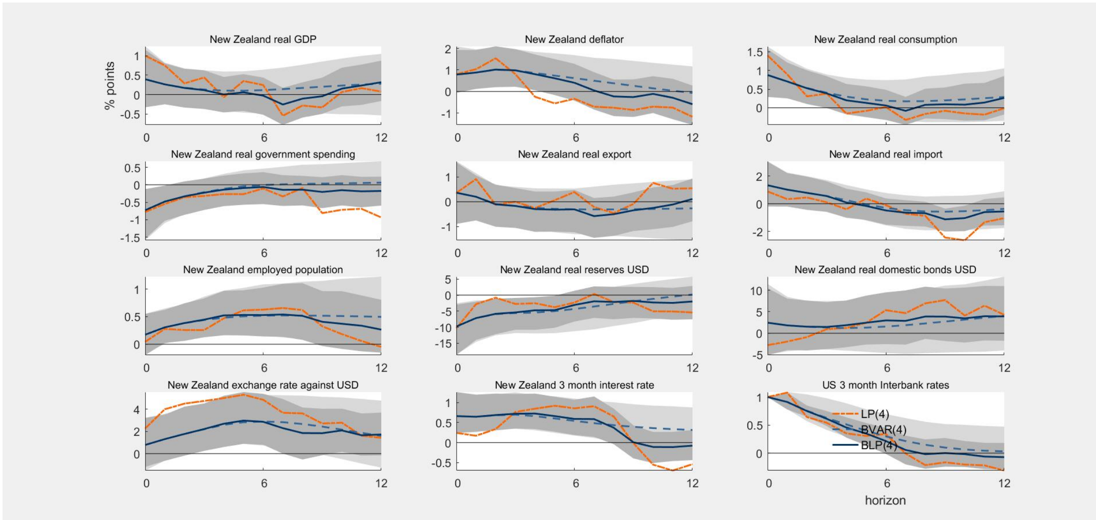

Figure 2.49: Natural rate shock with all methods - NZL

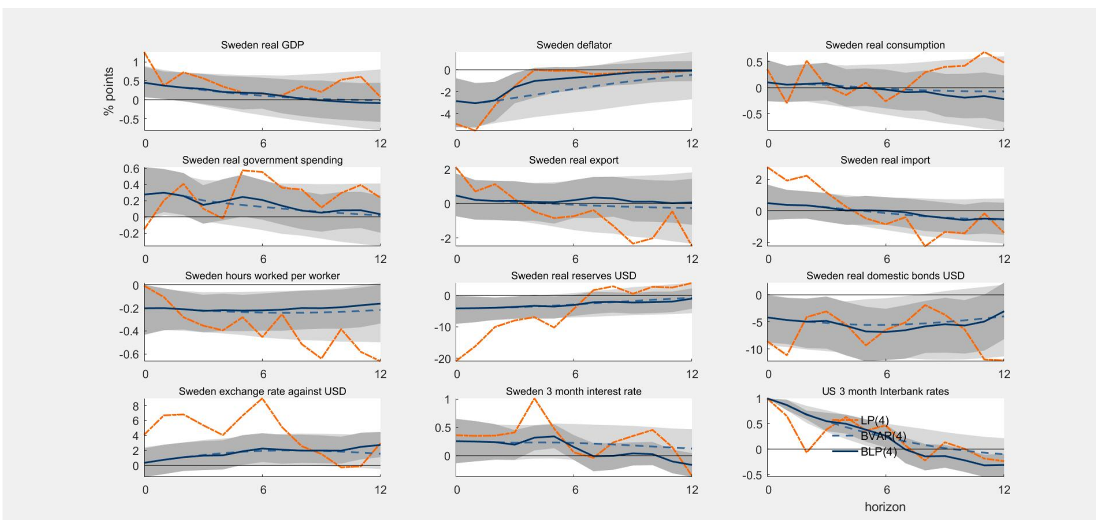

Figure 2.50: Natural rate shock with all methods - SWE

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Chapter 3

CNY-CNH Term Spread and Covered Interest Parity Deviations

3.1 Introduction

The influence of RMB has been growing in recent years as the Chinese economy expanding after the financial crisis. According to the latest Bank of International Settlements Triennial Central Bank Survey on the foreign exchange market, RMB now ranks as the world's sixth most traded currency. For several years Chinese authorities have argued for the desirability of an alternative to the U.S. dollar as the key reserve currency so that they are now moving in the direction of reducing their dependence on the U.S. dollar by internationalizing RMB. The internationalization of RMB may gain benefits such as decreasing exchange risks of international trade and investment, thereby reducing transaction costs, the People's Bank of China (PBoC), the central bank of China, founded offshore markets as a trial of RMB internationalization and a harbinger for domestic financial system liberalization in Hong Kong since 2010 which is known as the CNH market. Unlike the onshore foreign exchange market (CNY market), the offshore market (CNH market) is a relatively efficient market without restrictions in the onshore market.

This study is motivated to examine China's consistent onshore-offshore CIP deviations by particular shocks. Liao [2016] decomposed the CIP deviations to money market deviations and currency market deviations. In his model, the firm could choose issue bonds in one market, either in the Euro market or the U.S. market, to minimize the borrowing cost. Furthermore, the money market shocks or currency market shocks would affect the decision of this firm. However, this paper adds the financing time cost of banks to fit the scenario of China onshore and offshore markets, which means banks would issue bonds in both the onshore and offshore markets. Following Liao [2016], this paper modifies his model to explain Chinese onshore and offshore financial markets and fill the gap of the term spread differential and CIP violation spillover effects. This static model includes three agents - a bank, investors in the money market, and traders in the currency forward market. Onshore and offshore specialized investors actively allocate assets in the money market, and forward arbitrage trader makes a profit through CIP deviations in the currency forward market. Further, a representative bank connects these two markets by engaging FX hedge debt allocation. When the onshore relative to offshore credit spread (term spread) is high, the bank allocates a greater share of RMB debt in the offshore market. An increase in the offshore CNH, however, generates CNH exposure, which the bank hedges through currency forwards. Alternatively, when CIP deviations (transaction cost) are large, the bank chooses to minimize borrowing costs (credit spread cost and transaction cost) and financing time cost simultaneously and then decides on the optimal share. The two violations of money and currency markets are the primary consideration of the representative bank for debt issuance.

This paper estimates two types of exogenous shocks that affect this system. First, bond demand shocks in the money market are caused by monetary policy, investor preference, and money market regulatory. Second, non-issuance-related use of currency forward contracts shocks in the currency forward market includes central bank policy - FX intervention, trader expectation driven hedging and arbitraging demands, and currency market regulatory - capital control. Other literature on China's foreign exchange rate has not covered the capital control policy using a daily index to measure the level effect of the deviation from covered interest parity. This paper aims to fill that critical void. These two shocks have spillover effects from the RMB spot market (money market) to the forward market (currency market), and the other way around.

In the money market, this paper uses offshore-onshore term spread deviations $c = (r^a_{off} - r^{o/n}_{off}) - (r^a_{on} - r^{o/n}_{on})$[1] to measure money market gaps. Figure 3.1[2] shows the RMB and USD exchange rate in onshore and offshore currency markets. There were persistent discrepancies in the pricing of currency exchange forward between F_{on} and F_{off} before 8/10/2015. After that, but before 7/5/2017, spot exchange rates S_{on} and S_{off} existed significant gaps during some periods. Currently, the converging power shows in both onshore and offshore, and spot and forward exchange rate. In the currency market, this paper calculates onshore-offshore CIP deviations $b = r^{o/n}_{on} + s - f - r^{o/n}_{off}$ to estimate currency market gaps, where the spot exchange rate between onshore CNY and offshore CNH is $1 + s \equiv \frac{S_{on}}{S_{off}}$, and the forward exchange rate is $1 + f \equiv \frac{F_{on}}{F_{off}}$. The money market offshore-onshore term spread deviations and currency market onshore-offshore CIP deviations are displayed in Figure 3.2[3].

[1]If $c = (r^a_{off} - r^a_{on}) - (r^{o/n}_{off} - r^{o/n}_{on})$, this equation can be interpreted to overtime offshore-onshore credit spread deviation

[2]S_{on}: onshore spot exchange rate RMB/USD; S_{off}: offshore spot exchange rate RMB/USD; F_{on}: one-year onshore deliverable forward exchange rate RMB/USD; F_{off}: one-year offshore non-deliverable forward exchange rate RMB/USD.

[3]on 1/12/2016 c=-57.9054, b=-61.04023; on 1/5/2017 c=-52.4599, b=-54.8629; on 6/1/2017 c=-21.1185, b=-21.14572

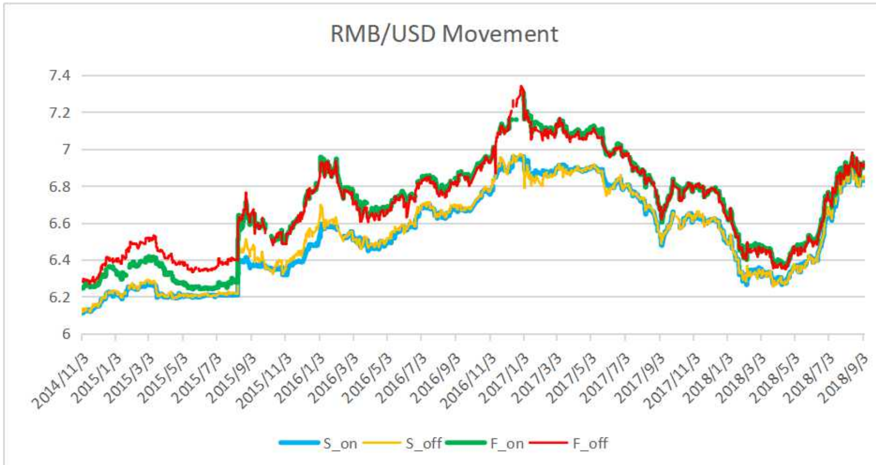

Figure 3.1: RMB/USD movement

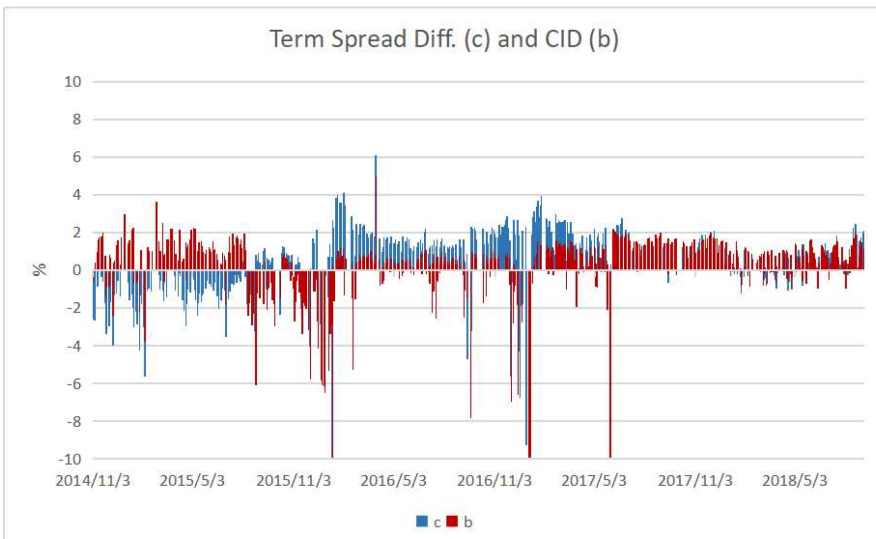

Figure 3.2: Term spread and CIP deviations

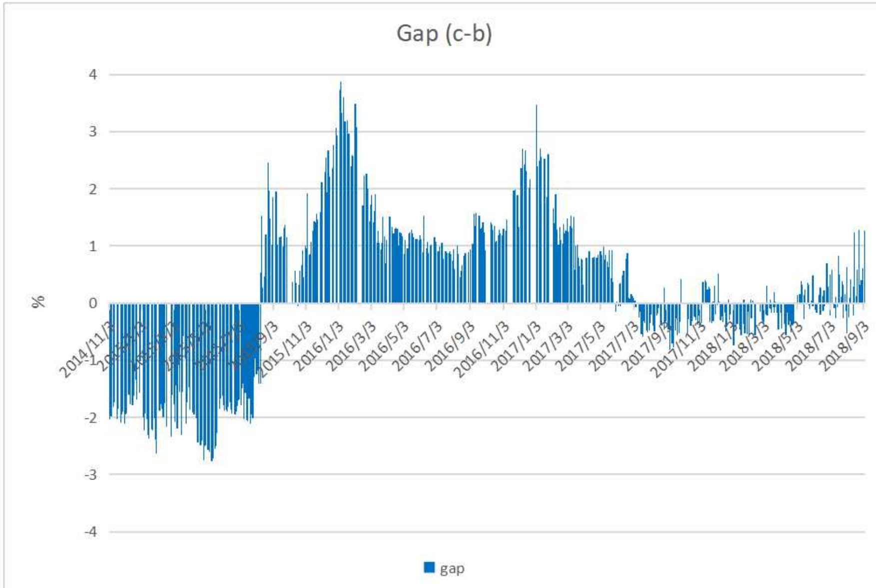

Figure 3.3: Offshore-relative-to-onshore total cost

Figure 3.3 reveals the consideration of representative bank that faces the total funding cost of offshore relative to onshore. Before 8/10/2015, offshore funding was better than onshore for this representative bank. Between 8/11/2015 and 7/5/2017, this representative bank would prefer to issue onshore bond rather than borrow offshore money, due to positive gaps $c - b > 0$. Nowadays, the gaps are more random deviation. This paper is structured as follows: literature review in Section 3.2; modeling bank's strategy in onshore-offshore RMB money and currency markets in Section 3.3; empirical data analysis and Bayesian local projections in Section 3.4; conclusion in the last Section 3.5.

3.2 Literature Review

The expanding Chinese currency forward markets have revitalized research interest in the capital control effect on onshore-offshore carry trades and the significance of CIP deviation. Existing studies on onshore and offshore foreign exchange markets tend to focus on causality between the two, e.g., Burdekin and Tao [2013]. They used the Granger causality test on the onshore-offshore spread. By cointegration method Ding et al. [2014] found that price discovery is absent between the onshore and offshore spot markets; however, the price discovery exists between onshore spot and offshore nondeliverable forward (NDF) rates. Owyong et al. [2015] implemented bidirectional linear and nonlinear causality on several sets of spot and forward prices. Their results suggested stronger causality running from the spot onshore rate to the spot offshore rate than vice versa, which implies that foreign impulses have influenced the domestic market. Despite trading and capital restrictions, Peng et al. [2007] found that sentiment can spillover between the onshore and offshore markets and that over time, the relative contribution of price leadership has shifted between the onshore and offshore centers.

GARCH model is another quantitative method used in the research. Maziad and Kang [2012] employed a bivariate GARCH model to understand the interlinkages between onshore and offshore markets and found that, while developments in the onshore spot market exert an influence on the offshore spot market, offshore forward rates have a predictive impact on onshore forward rates. Funke et al. [2015] implemented an extended GARCH model to measure the policy effect on both the conditional level and volatility of CNH-CNY spread. Cheung and Rime [2014] used a specialized microstructure dataset to study the CNH exchange rate dynamics and its links with onshore exchange rates (CNY). They concluded that the offshore CNH exchange rate has an increasing impact on the onshore rate CNY and significant predictive power for the official RMB central parity rate. Craig et al. [2013] attributed the CNH-CNY price differential to onshore investor risk sentiment and capital account liberalization. They applied an asymmetric self-excited threshold auto-regression (SETAR) model to the daily CNY-CNH price differential from September 2010 to January 2013 and found limited integration between CNY and CNH market. These works of literature conclude the existence of CIP deviation on both onshore and offshore RMB forward markets.

In addition to these works of literature on the research for the correlation of RMB FX markets, two kinds of literature focusing on the deviation of CIP through decomposition to investigate the market segmentation. The first strand is that the liquidity of the global market affects the funding of arbitrage and then induces the deviation. Ivashina et al. [2015] concluded that banks can borrow in euros and swap into dollars to make up for the dollar shortfall, but this may lead to violations of covered interest parity when there is limited capital to take the other side of the swap trade. Bräuning and Ivashina [2016] further explored the role of monetary policy in affecting global bank's funding sources and the use of FX hedges. Iida et al. [2016] provided theoretical evidence to show that monetary policy divergence between the Federal Reserve and other central banks widens CIP deviations and that regulatory reforms such as stricter leverage ratios raise the sensitivity of CIP deviations to monetary policy divergence by increasing the marginal cost of global banks' USD funding. Cetorelli and Goldberg [2012] reported that global banks actively manage liquidity using internal cross-border financing in response to domestic shocks. The other strand is the banking sector issues. Sushko et al. [2017] and Du et al. [2016] focused on the banking sector and the ability of banks to take on leverage. The key message is that the value of the dollar plays the role of barometer of risk-taking capacity in global capital markets. When the dollar strengthens, CIP deviations widen. Du et al. [2016] formally established CIP arbitrage opportunities that cannot be explained away by credit risk or transaction costs, and present evidence that bank balance sheet costs and asymmetric monetary policy shocks are the primary drivers of CIP deviations. Borio et al. [2016] constructed empirical proxies for net hedging demand of different national banking systems and show that they are consistent with the cross-sectional variations in CIP deviations. Liao [2016] documented economically significant and persistent discrepancies in the pricing of credit risk between corporate bonds denominated in different currencies. This violation of the Law-of-One-Price (LOOP) in credit risk is closely aligned with violations of covered interest rate parity in the time series and the cross-section of currencies. One recent work, Ho et al. [2018] applied a Mixture of Distribution Hypothesis and Veronesi [1999]'s theory to the exchange rate market and examined the respond of exchange rate volatility to the market information.

3.3 A Model of Onshore-Offshore Money Market and Currency Market Deviations

This static model includes three agents (bank, investors in the money market, and traders in the forward currency market) and two exogenous shocks. **Bank** issues bonds in onshore and offshore money markets and uses currency forward to hedge offshore bond issuance. The representative bank minimizes borrowing cost and financing time cost to choose the share of onshore issuance. **Investors** in onshore and offshore money markets buy bonds. Investors would maximize investment return to choose the investment amount. **Traders** in the forward currency market do carry trade with forward contracts. Traders would also maximize investment return to choose the investment amount. $\varepsilon_{\mathbf{c}}$ is offshore-relative-to-onshore bond demand shock in the money market. Furthermore, $\varepsilon_{\mathbf{b}}$ is other non-issuance-related use of currency forward contracts shock in the currency forward market.

3.3.1 Bank Decision

A bank chooses a fixed amount of RMB debt D that needs to be borrowed and faces two costs for issuing onshore-relative-to-offshore bonds: term spread differential onshore and offshore RMB $-c = (r^a_{on} - r^{o/n}_{on}) - (r^a_{off} - r^{o/n}_{off})$, and transaction cost (CID) across the onshore and offshore boundary $b = r^{o/n}_{on} + s - f - r^{o/n}_{off}$. For term spread differential, one is the onshore CNY bond yield r^a_{on}. The other is offshore CNH bond yield r^a_{off} in offshore financial centers like Hong Kong, Singapore, or London. Then, the bank observes a credit spread differential between onshore and offshore RMB bond yields to adjust the risk-free interest rate difference denoted as $-c = (r^a_{on} - r^a_{off}) - (r^{o/n}_{on} - r^{o/n}_{off})$, which also measures the interest rate term spread differential. If the money market does not have an arbitrage opportunity, the credit/term spread $c = 0$ fails most of the time due to market segmentation. For transaction costs (CID), furthermore, if the bank borrows money from the offshore market, it has an add-on cost b across the onshore and offshore boundary. This paper uses the U.S. currency as a bridge to measure this transaction cost b. If CIP holds between CNY/CNH and USD, it means $(1 + r^{o/n}_{on}) = \frac{F_{on}}{S_{on}}(1 + r_{us})$ and $(1 + r^{o/n}_{off}) = \frac{F_{off}}{S_{off}}(1 + r_{us})$, where S_{on} or S_{off} is spot exchange rate and F_{on} or F_{off} is forward exchange rate both expressed in onshore CNY or offshore CNH per USD. Then the spot exchange rate between onshore CNY and offshore CNH is $1 + s \equiv \frac{S_{on}}{S_{off}}$, and the forward exchange rate is $1 + f \equiv \frac{F_{on}}{F_{off}}$. If currency forward market onshore-offshore RMB CIP holds, the transaction cost $b = r_{on}^{o/n} + s - f - r_{off}^{o/n} = 0$, which means there would be no carry trade opportunity. What's more, if the onshore issuance share μ deviates the threshold share θ, it would cause financing time cost ω. Therefore, the bank chooses onshore issuance share μ to minimize onshore-relative-to-offshore bond cost and financing time cost.

$$\min_{\mu} \Big(\underbrace{-c}_{\text{interest rate term spread diff}} + \underbrace{b}_{\text{transaction cost}} \Big)\mu D + \underbrace{\frac{\omega}{2}(\theta - \mu)^2}_{\text{financing time cost}} \tag{3.1}$$

which has the solution $c - b = \frac{\omega(\mu - \theta)}{D}$.

First, if the net deviation is more negative $c - b \downarrow$, then the bank chooses a lower onshore issuance share $\mu \downarrow$ because onshore issuance is costly; otherwise, it chooses $\mu \uparrow$. Second, if the total amount of debt D is large enough, then $c - b$ is driven to zero as a result of arbitrage. According to these two derivations, two deviations c and b are aligned when a large amount of cross-market capital flows exist.

3.3.2 Money Markets

There exist three main market participants: active offshore investors, active onshore investors, and the representative bank from above that has access to both onshore and offshore money markets. Offshore active investors focus on the investment of the offshore money market, and onshore investors invest in the onshore money market exclusively. Investors borrow at the risk-free interest rate $r_i^{o/n}$ and invest at the money market with a guaranteed yield to maturity of r_i^a, where i represents either onshore or offshore. The two bonds have an identical default probability π, loss-given-default L. The payoff of bonds has a variance of V, which is treated as an exogenous constant in the model for tractability. Onshore and offshore investors have a mean-variance preference with identical risk tolerance τ and choose investment amount X_i to solve the following

$$\underset{X_i}{max} \left[X_i((1-\pi)r_i^a - \pi L - r_i^{o/n}) - \frac{1}{2\tau} X_i^2 V \right] \tag{3.2}$$

which has the solution $X_i = \frac{\tau}{V}((1-\pi)r_i^a - \pi L - r_i^{o/n})$ for $i =$ onshore or offshore.

Money market clearing conditions

There are exogenous offshore-relative-to-onshore bond demand ε_c, perhaps representing demand shocks that emerge from monetary policy, investor preference, and money market regulatory. Combining the demand with bank supply showed earlier, the market clearing conditions for onshore and offshore money markets are

$$X_{on} = \mu D \tag{3.3}$$

$$X_{off} + \varepsilon_c = (1 - \mu)D \tag{3.4}$$

Combining the investor demands with the market clearing conditions and applying first-order Taylor approximation for π around 0, money market section can derive the CNH-CNY interest rate term spread differential as:

$$\underbrace{c}_{\text{term spread differential}} = \underbrace{\frac{V}{\tau}}_{\text{elasticity}} \underbrace{\left(\underbrace{(1-2\mu)D}_{\text{relative bond supply}} - \underbrace{\varepsilon_c}_{\text{exog. bond demand}} \right)}_{\text{net bond supply offshore relative to onshore}} \tag{3.5}$$

The interest rate term spread differential c represents arbitrage opportunity in the money market since the default probability and loss given default are identical for the two bonds. Equation (3.5) induces that c is determined by the net bond supply between offshore and onshore money markets multiplied by the elasticity.

3.3.3 Currency Forward Market

This section describes the dynamics of the currency forward market. The insight is similar to that of money market violation, but intermediary collateral and capital constraints limit deviation in CIP. There are two main participants in this market: currency forward traders and issuers.

Currency forward traders choose the amount of capital to allocate to either CIP deviation, denote as b, or other investment opportunity with profit of $f(I)$, where I is the amount of investment. The arbitrage has to set aside a haircut H when it enters the forward transaction to trade the CIP violation. Following Garleanu and Pedersen [2011], the amount of haircut is assumed to be proportional to the size s of the forward position, $H = \gamma|s|$. So, the capital allocated towards alternative investment is $I = W - \gamma|s|$. Forward traders have total wealth W and maximize the following

$$\underset{s}{max} \quad bs + f\left(W - \gamma|s|\right) \tag{3.6}$$

which generates the direct result that the expected benefit from carrying an extra unit of CIP arbitrage is equal to the marginal profitability of the alternative investment, $b = sign[s]\gamma f^{'}(W - \gamma|s|)$. In a simple case, assume the alternative investment activity is quadratic, $f(I) = \phi_0 I - \frac{1}{2}\phi I^2$, $b = sign[s]\gamma(\phi_0 - \phi W + \gamma\phi|s|)$.

The model makes a further simplifying assumption that CIP deviation b is linearly related to the net demand for forwards, equivalently to stating $W = \frac{\phi_0}{\phi}$, which means that arbitrageur has just enough wealth W to take advantage of all positive-NPV investment opportunities in the alternative project $f(I)$. This assumption helps to reduce the constant intercept term in the equation for b, and derives that CIP deviation is proportional to forward trader position, $b = \phi\gamma^2 s$. The model normalizes $\phi = 1$.

Currency forward market clearing conditions

The representative bank from above relies on the forward currency market to hedge its offshore debt issuance - amount $(1-\mu)D$ CNH. Also, there are exogenous shocks to CIP basis ε_b that represent other non-issuance-related use of currency forward contracts. Market clearing condition of the currency forward market shows that the equilibrium level of CIP deviation satisfies

$$\underbrace{b}_{\text{CIP basis}} = -\underbrace{\gamma^2}_{\text{haircut on collateral}} \underbrace{((1-\mu)D + \varepsilon_b)}_{\text{net hedging demand}} \tag{3.7}$$

Equation (3.7) indicates that CIP deviation b is proportional to net hedging demand multiplied by the elasticity, which is determined by the collateral margin. Higher haircut γ strengthened the shock of hedging demand, but without net hedging demand, b does not deviate from zero.

3.3.4 Summary of Equilibrium Conditions

The three equilibrium conditions are summarized as follows (endogenous variables: c, b, μ; exogenous shocks: ε_c, ε_b.):

(1) Term spread differential (offshore-onshore):

$$\underbrace{c}_{\text{interest rate term spread differential}} = \underbrace{\frac{V}{\tau}}_{\text{elasticity}} \underbrace{((1-2\mu)D - \varepsilon_c)}_{\text{net bond supply offshore relative to onshore}} \tag{3.8}$$

(2) CIP basis:

$$\underbrace{b}_{\text{CIP basis}} = -\underbrace{\gamma^2}_{\text{haircut on collateral}} \underbrace{((1-\mu)D + \varepsilon_b)}_{\text{net hedging demand}} \tag{3.9}$$

(3) Bank choice of bond issuance ratio:

$$\mu = \frac{(c-b)D}{\omega} + \theta \begin{cases} \text{if } c - b \uparrow\text{, cheaper to issue in onshore} \\ \\ \text{if } c - b \downarrow\text{, cheaper to issue in offshore} \end{cases} \tag{3.10}$$

With these equilibrium conditions, this model can analyze the transmission of ε_c and ε_b shocks from one market to the other.

Proposition 1. *(Spillover of deviations)* If $\varepsilon_c \downarrow$, then $c \uparrow \Rightarrow \mu \uparrow \Rightarrow b \uparrow$. If $\varepsilon_b \downarrow$, then $b \uparrow \Rightarrow \mu \downarrow \Rightarrow c \uparrow$. One market shock can transmit to the other market through capital flows. Interest rate term spread differential c and CIP deviation b reflect in the same direction to either exogenous bond demand shocks ε_c or exogenous currency forward demand shocks ε_b. RMB bond issuance μ reflects oppositely to the two shocks.

Proposition 2. *(Issuance flow and net deviation)* $(c - b) \downarrow \Rightarrow \mu \downarrow$ Cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore.

Proposition 3. *(Arbitrage capital and aligned deviations)* Since $\frac{\partial |c-b|}{\partial D} < 0$ so that $\lim_{D\to\infty} c - b = 0$. A large amount of debt issuance may decrease the absolute value of the net deviation. With infinity capital flows, the two deviations become identical.

3.4 Empirical Results

Variable	Description	Frequency
Market		
CNY (S_{on})	onshore spot exchange rate RMB/USD	D
CNH (S_{off})	offshore spot exchange rate RMB/USD	D
DF (F_{on})	1 year onshore deliverable forward exchange rate RMB/USD	D
NDF (F_{off})	1 year offshore non-deliverable forward exchange rate RMB/USD	D
SHIBOR ($r^a_{on}, r^{o/n}_{on}$)	Shanghai interbank offered rate (1 year and overnight)	D
HIBOR ($r^a_{off}, r^{o/n}_{off}$)	Hong Kong interbank offered RMB rate (1 year and overnight)	D
Bond ETFs (μ)	5-year bond ETFs traded in Shanghai and Hong Kong volume/amount	D
Shock		
RRR (ε^1_c)	required deposit reserve ratio for Mainland China	D
CSI 300 (ε^2_c)	a blue chip index for top 300 stocks in Mainland China stock exchanges	D
HSI (ε^2_c)	a blue chip index for top 50 stocks in Hong Kong stock exchanges	D
R-REPO (ε^3_c)	reverse repurchase agreements in Mainland China open market	D
BAS (ε^1_b)	bid-ask spread for exchange rate CNY/USD and CNH/USD	D
DCPR (ε^2_b)	deviations between on/offshore spot RMB/USDs and central parity rate	D
CCI (ε^3_b)	capital control index by computation	D

Table 3.1: Data description

Source: Bloomberg, FRED, Wind and China Bureau of Statistics

3.4.1 Dataset

This section uses empirical data to generate endogenous variables (c, b, μ) and exogenous shocks (ε_c, ε_b) in the model. The period is from 11/3/2014 to 9/5/2018, daily data. **Interest rate term spread differential** $c = (r^a_{off} - r^{o/n}_{off}) - (r^a_{on} - r^{o/n}_{on})$ is calculated by Shanghai interbank offered rate (1 year and overnight) and Hong Kong interbank offered RMB rate (1 year and overnight). This paper assumes the overnight rate is a risk-free rate. **Transaction cost CIP deviation** $b = r_{on}^{o/n} + \frac{S_{on}}{S_{off}} - \frac{F_{on}}{F_{off}} - r_{off}^{o/n}$ is estimated by onshore and offshore risk-free rates, and CNY/CNH spot and forward exchange rates which use RMB/USD as a connection. **Capital flow onshore share** $\mu = \frac{volume_{on}}{volume_{on}+volume_{off}}$ or $\mu = \frac{amount_{on}}{amount_{on}+amount_{off}}$ is measured by 5-year bond ETFs traded in Shanghai and Hong Kong (same underlying assets) volume/amount. The two methods are highly correlated ($\rho = 0.9997$); the paper would use volume calculated μ to measure capital flow. **Exogenous bond demand shocks** ε_c in the money market are caused by monetary policy, investor preference, and money market regulatory. **Exogenous currency forward demand shocks** ε_b (non-issuance-related use of currency forward contracts) in the forward currency market are influenced by central bank policy - FX intervention, trader expectation driven hedging and arbitraging demands, and currency market regulatory - capital control.

3.4.2 Source of Shocks

Money Market Shocks

Monetary policy People's Bank of China sets a reserve ratio to influence the money supply. Commercial banks are required to hold reserves against their total reservable liabilities, rather than lend out or invest. Any changes in reserve ratio would cause money market shocks, which could affect bond demand because of the different responses in onshore and offshore money markets. For instance, the central bank increases the required reserve ratio (RRR) to reduce the money supply in the economy. Therefore, the risk-free rate rises and financial capital would flow from risky assets to safe assets. The older bonds with a relatively low premium (original yield minus new risk-free rate) would become less attractive. Demand for the bonds would decline in both onshore and offshore money markets because the low premium would not be worth taking on the risk. Due to different responses of investors, the offshore demand would reduce more than onshore, which is a negative shock on ε_c. Finally, the yield of bonds would rise until supply and demand reached a new equilibrium in each market, then interest rate term spread differential c rises. This paper uses the changed RRRs as shocks in the money market.

Investor preference The stock market is a crucial part of the financial market to investors. CSI 300 is a blue chip index for top 300 stocks in Mainland China stock exchanges to measure the performance of the onshore stock market. What's more, HSI is a blue chip index for top 50 stocks in Hong Kong stock exchanges to measure the performance of the offshore stock market. The detrended indices of daily log-form closing price are the cyclical components as shocks. The index shocks of both onshore and offshore markets are a positive correlation ($\rho = 0.44$). A positive shock of offshore-relative-to-onshore stock market indices would cause capital inflow from the bond market to the stock market because of investor preference (seeking high return and low risk assets) and substitution effect. Therefore, the offshore-relative-to-onshore bond demand shock is negative ε_c. A new equilibrium of the bond market has a higher yield c, which is consistent with the prediction of the model.

Money market regulatory People's Bank of China could use a repurchase agreement (REPO) or a reverse repurchase agreement (Reverse REPO), classified as a money market instrument, to decrease or increase short-term liquidity as one of open market operations. A positive shock of the reverse repurchase agreement (R-REPO) means the central bank increases short-term liquidity. In other words, the central bank purchases bonds now and agrees to sell them in the future. Then, the central bank pushes the traditional government bond investors in search of high-yielding bonds. Therefore, onshore bond demand rises (offshore-relative-to-onshore bond demand drops), which has a negative impact on ε_c. The increasing short-term liquidity would trigger that onshore yield falls, so interest rate term spread differential c rises.

Currency Market Shocks

Central bank policy People's Bank of China can implement foreign exchange intervention through changing currency liquidity. The bid-ask spread is a reflection of the demand and supply for the asset. Due to the difference in liquidity of each asset, the size of the bid-ask spread from one asset to another varies. Here, this paper uses onshore and offshore RMB/USD exchange rate bid-ask spreads to measure the onshore-offshore CNY/CNH liquidity.[4] The liquid asset has a small bid-ask spread in the currency market. A positive shock on CNY/CNH liquidity means that the spot exchange rate CNY/CNH currency market has less liquidity. From a currency market trader's perspective, liquidity is usually experienced in terms of the volatility of price movements. A liquid asset will tend to see prices move very gradually and in small increments. An illiquid asset will tend to see

[4] Because the spot exchange rate between onshore CNY and offshore CNH is $1+s \equiv \frac{S_{on}}{S_{off}}$, the CNY/CNH bid price is $1+s^b \equiv \frac{S^b_{on}}{S^a_{off}}$ and the CNY/CNH ask price is $1+s^a \equiv \frac{S^a_{on}}{S^b_{off}}$. However, the onshore-offshore liquidity gap used in this paper is the difference between onshore CNY/USD bid-ask spreads ($S^a_{on} - S^b_{on}$) and offshore CNH/USD bid-ask spreads ($S^a_{off} - S^b_{off}$).

prices move abruptly and in large price increments. When traders face a risky currency market, non-issuance-related use of currency forward contracts ε_b increases. Thus, the offshore strategy becomes costly, then the onshore-relative-to-offshore transaction cost (CIP basis) b would fall.

Trader expectation In China's onshore spot foreign exchange market, RMB is allowed to rise or fall by 2 percent from the central parity rate each trading day, but the daily trading band does not impose on the offshore foreign exchange market. Therefore, the risk could be from a sizeable uncertain movement of CNH/USD in the offshore currency market. The gap of CNH/USD and central parity rate is divided by the gap of CNY/USD and central parity rate to measure offshore-relative-to-onshore exchange rate volatility. If the result is less than the threshold -2, the offshore exchange rate is more volatile than onshore one in the opposite direction.[5] When traders see a more volatile offshore market and opposite deviation from the central parity rate against the onshore market, they will use currency forward contracts ε_b to hedge risk or pursue arbitrage opportunity. As a result, the excess demands of currency forward contracts increase the cost of offshore strategy, and CIP basis b would fall.

Currency market regulatory Capital control represents any methods taken by the People's Bank of China to limit the capital inflow and outflow to and from the domestic economy. Capital controls can affect many assets, such as bonds, stocks, and foreign exchange trades. Because the de jure indices like IMF's AREAER and Chinn-Ito with annual frequency would not reflect an effectiveness

[5]If $\frac{DCPR_{off}}{DCPR_{on}} < -2$, $\varepsilon_b = 1 + \frac{DCPR_{on}}{DCPR_{off}}$; otherwise, $\varepsilon_b = 0$. Therefore, ε_b is between 0 (less risky) and 1 (more risky).

after a policy changing, this paper calculates a daily capital control index which follows the basic index construction method according to Schindler [2009] with 7 AREAER asset subcategories including portfolio equity investment, bond investment, money market investment, collective investment, derivative investment, commercial credits and real estate investment. The capital control index is between 1 and 0 to measure the degree from full capital controls to free capital flows. A positive shock of changed daily capital control index would cause more controls on free capital movement. The capital control could lower risks associated with the volatility of capital flows in the onshore currency market, but this regulatory would expand the gap between offshore and onshore currency markets. Consequently, the demands of currency forward contracts ε_b increase, and onshore-relative-to-offshore CIP basis b decreases.

Correlation	ΔRRR ↑	HSI-CSI ↑	R-REPO ↑
ε_c	↓	↓	↓
c ↑	0.0287	0.1276	0.0448
	BAS ↑	DCPR ↑	ΔCCI ↑
ε_b	↑	↑	↑
b ↓	-0.0678	-0.0473	-0.0320

Table 3.2: Correlation

3.4.3 Proposition 1 Test

Bayesian Local Projection Method

Miranda-Agrippino and Ricco [2017] provided a flexible econometric method - Bayesian local projections robust to misspecifications that bridges between vector autoregressions (VARs) and local projections (LPs). The VARs produce IRFs by iterating up to the relevant horizon the coefficients of a one-step-ahead model. However, because of a small-size information set, underestimated lag order, and non-linearities, misspecified VARs can fail to capture all of the dynamic interactions. $y_{t+1} = C + B_1 y_t + .. + B_p y_{t-p+1} + \epsilon_{t+1}$ The LPs, Jordà [2005], estimate the IRFs from the coefficients of direct projections of variables onto their lags at the relevant horizon. However, due to the moving average structure of the residuals, and the risk of over parametrization, LPs are likely to be less efficient, and hence subject to volatile and imprecise estimates. $y_{t+h} = C + B_1 y_t + .. + B_p y_{t-p+1} + \epsilon_{t+h}$ Therefore, choosing between iterated and direct methods involves a sharp trade-off between bias and estimation variance: the VAR produces more efficient parameter estimates than the LP, but it is prone to bias if the one-step-ahead model is misspecified.

Miranda-Agrippino and Ricco [2017] proposed a regularization for LP-based IRFs, which builds on the prior that a VAR can provide, in first approximation, a decent description of the behavior of most variables. As the horizon grows, however, BLPs are allowed to optimally deviate from the restrictive shape of VAR-based IRFs, whenever these are poorly supported by the data. This, while the discipline imposed by the prior, allows to retain reasonable estimation uncertainty at all horizons. Hence, BLP can sensibly reduce the impact of compounded biases over the horizons, effectively dealing with model misspecifications.

Impulse Response Functions

The main results of this section are that impulse response functions (IRFs) with two exogenous shocks differ along some important dimensions, using the

VAR equation (3.11)[6]. Figure 3.4 to Figure 3.6 show exogenous offshore-relative-to-onshore bond demand shocks from different sources in the money market with the Bayesian local projection method. Figure 3.7 to Figure 3.9 display exogenous non-issuance-related use of currency forward contracts shocks from different sources in the currency market with the Bayesian local projection method.[7]

$$\begin{bmatrix} \omega & -D & D \\ 2D & \frac{\tau}{V} & 0 \\ -D & 0 & \frac{1}{\gamma^2} \end{bmatrix} \begin{bmatrix} \mu_t \\ c_t \\ b_t \end{bmatrix} = B_0 + B_1 \begin{bmatrix} \mu_{t-1} \\ c_{t-1} \\ b_{t-1} \end{bmatrix} + B_2 \begin{bmatrix} \mu_{t-2} \\ c_{t-2} \\ b_{t-2} \end{bmatrix} + B_3 \begin{bmatrix} \mu_{t-3} \\ c_{t-3} \\ b_{t-3} \end{bmatrix} + B_4 \begin{bmatrix} \mu_{t-4} \\ c_{t-4} \\ b_{t-4} \end{bmatrix} - \begin{bmatrix} 0 \\ \varepsilon_{c,t} \\ \varepsilon_{b,t} \end{bmatrix} \tag{3.11}$$

For money market shocks, Proposition 1 test, if $\varepsilon_c \downarrow$, then $c \uparrow \Rightarrow \mu \uparrow \Rightarrow b \uparrow$. In Figure 3.4, the changed reserve ratio would cause that simultaneous effect of a 1% increase in interest rate term spread differential (offshore-relative-to-onshore money market cost) will lead a 0.3% increase in the share of onshore bond issuance which would raise transaction cost by 0.85% (onshore-relative-to-offshore currency market cost). In Figure 3.5, the stock market substitution effect influences the term spread differential by a 1% raise; then, offshore money market cost raises 1.1% of onshore transaction cost following by onshore issuance share 0.16% jump. In Figure 3.6, the result of reverse repurchase agreement operations is consistent with model prediction. A 1% increase in c triggers around a 1% increase in b through the more onshore issuance μ by 0.5%.

[6] The VAR appendix shows the link between the theoretical model and the empirical equation.

[7] All IRFs have a 90% confidence interval. Variables pass the augmented Dickey-Fuller test and conclude a stationary process. Akaike's information criterion (AIC), Schwarz's Bayesian information criterion (SBIC), and the Hannan and Quinn information criterion (HQIC) lag order selection statistics provide an optimal lag number 4. Please see the IRFs appendix for more details with other methods - VARs and LPs.

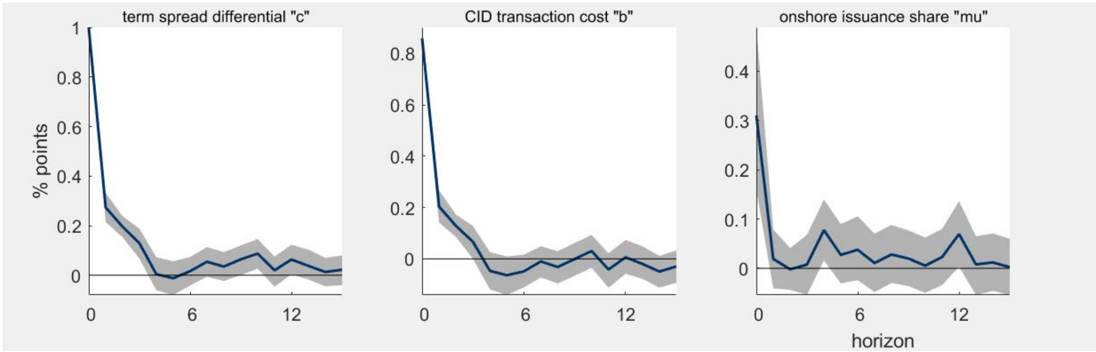

Figure 3.4: Monetary policy - changed reserve ratio $\varepsilon_c \downarrow$

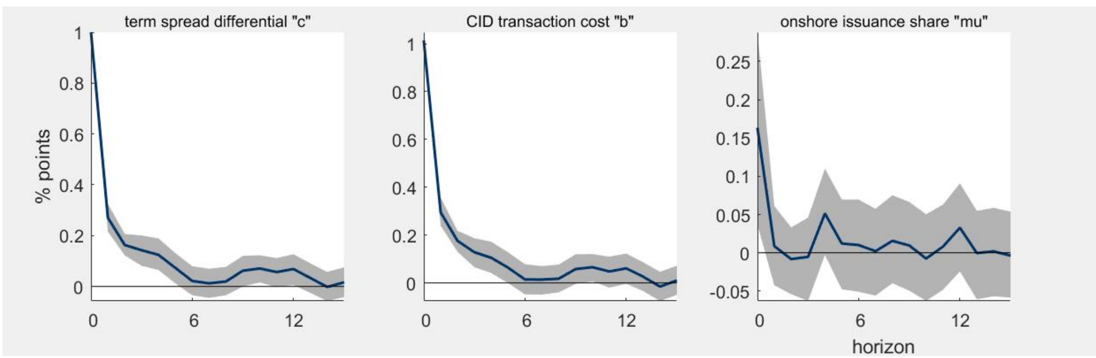

Figure 3.5: Investor preference - stock market substitution effect $\varepsilon_c \downarrow$

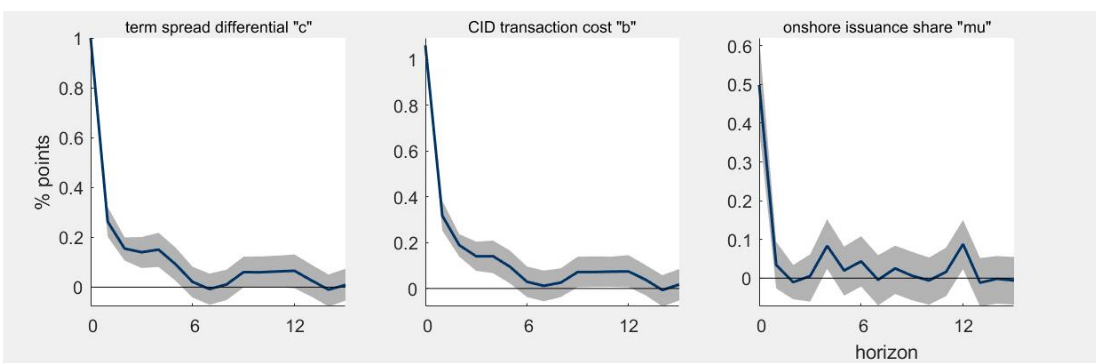

Figure 3.6: Money market regulatory - reverse REPO of open market $\varepsilon_c \downarrow$

For currency market shocks, Proposition 1 test, if $\varepsilon_b \downarrow$, then $b \uparrow \Rightarrow \mu \downarrow \Rightarrow c \uparrow$. In Figure 3.7, CNY/CNH liquidity would cause that simultaneous effect of a 1% increase in transaction cost (onshore-relative-to-offshore currency market cost) will be a 2.5% decrease in the share of onshore bond issuance which would raise interest rate term spread differential by 1% (offshore-relative-to-onshore money market cost). In Figure 3.8, offshore-relative-to-onshore exchange rate volatility affects transaction costs by a 1% increase; then, onshore currency market cost raises 2% of offshore money market cost following by onshore issuance share 1.4% fall. In Figure 3.9, the result of capital control is consistent with model prediction. 1% increase in b triggers around a 3% increase in c through the less onshore issuance μ by 3.5%.

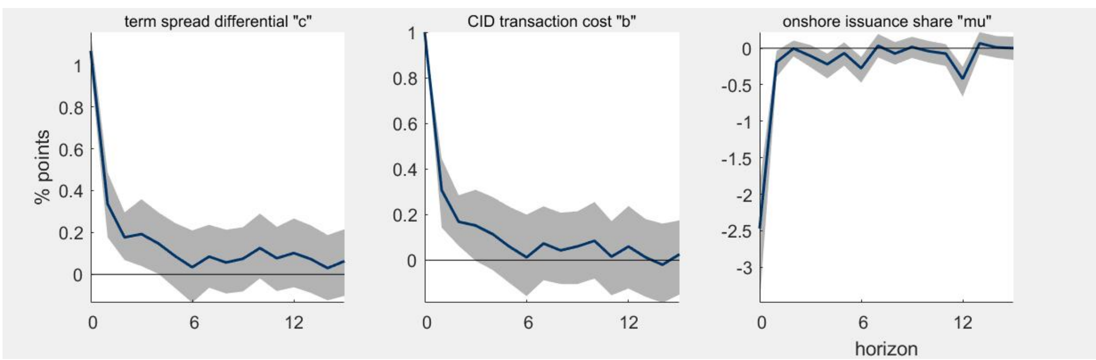

Figure 3.7: Central bank policy - liquidity of currency market $\varepsilon_b \downarrow$

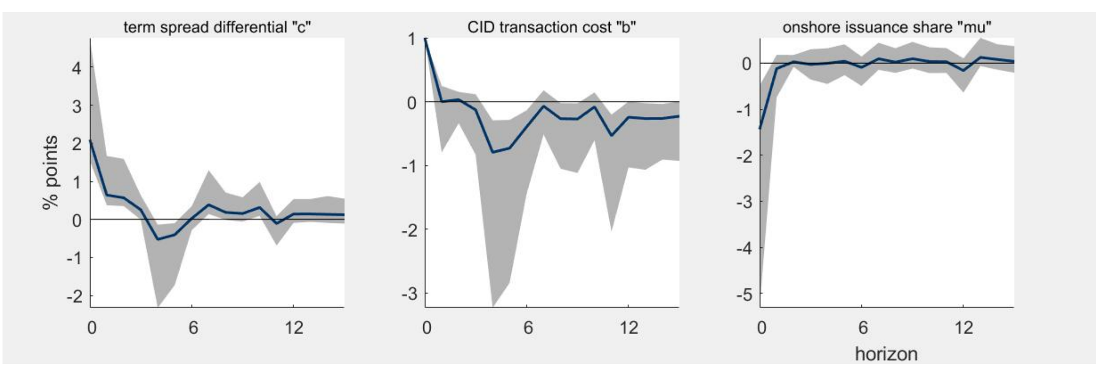

Figure 3.8: Trader expectation - volatility of currency market $\varepsilon_b \downarrow$

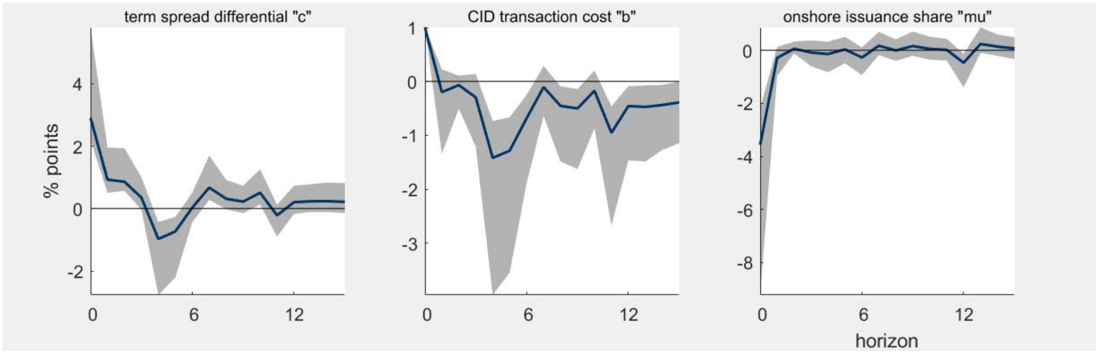

Figure 3.9: Currency market regulatory - capital control $\varepsilon_b \downarrow$

In shorts, one market shock can transmit to the other market through capital flows. The spot money market is more sensitive to shocks from the forward currency market through capital flows. The more significant capital flows under uncertainty shocks from the forward currency market would cause that transaction cost is more volatile, due to exchange-rate overshooting. The effects decay in a week after initial shocks, but the effect on capital flows is less persistent.

3.4.4 Proposition 2 & 3 Tests

Long Run Propensity

The cumulative effect of a permanent change in X_t on Y_t will be the sum of the coefficients, known as the long run propensity (LRP). This paper uses the Koyck (geometric lag) model to provide evidence of Proposition 2 and 3. This model allows for feasible estimation of $Y_t = \beta_0 + \delta_0 X_t + \delta_1 X_{t-1} + \delta_2 X_{t-2} + ... + \delta_q X_{t-q} + ... + u_t$ under assumption that $\delta_i = \delta_0 \lambda^i$ where $0 < \lambda < 1$. Thus, the value of the impact multipliers (δ) decreases geometrically as the associated lag (i) increases. A larger value of λ (closer to 1) means a greater persistence of lagged values. The estimation equation is $Y_t = \beta^* + \lambda Y_{t-1} + \delta_0 X_t + u_t^*$, so the long run propensity is

$LRP = \frac{\delta_0}{1-\lambda}$. [8] Therefore, this model shows not only simultaneous effect but also cumulative effect (LRP).

Regression

Koyck (geometric lag) model tests Proposition 2 & 3 to estimate long run propensity, also involving endogeneity, heteroskedasticity, and auto-correlated errors problems. Therefore, this paper uses two-stage least squares (2SLS) instrumental variables and robust standard errors method to solve these problems, also adds some control variables (ΔRRR, HSI-CSI, R-REPO, BAS, DCPR, ΔCCI) from money and currency markets into the estimation equation. For Proposition 2 with equation (3.12), the share μ and gap $c-b$ have endogenous problems, so the sixth lag of gap $c-b$ is the instrumental variable for current gap $c-b$. From Proposition 1 results, the sixth lag is deep enough for an instrumental variable. The Proposition 2 test $(c-b)\downarrow \Rightarrow \mu \downarrow$ estimates insignificant $\lambda_{p2} = 0.019$ which implies little persistence, and significant $\delta_{0,p2} = 0.305$ as model prediction. As a result, the simultaneous effect of a 1% decrease in offshore-relative-to-onshore bond issuance cost $c-b$ will be a 0.305% decrease in the share of onshore bond issuance. Therefore, cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore.

$$\mu_t = \beta^*_{p2} + \lambda_{p2}\mu_{t-1} + \delta_{0,p2}(c-b)_t + B_{p2}control\_variables_t + u^*_{p2,t} \quad (3.12)$$

$$|c-b|_t = \beta^*_{p3} + \lambda_{p3}|c-b|_{t-1} + \delta_{0,p3}log(D_t) + B_{p3}control\_variables_t + u^*_{p3,t} \quad (3.13)$$

For Proposition 3 with equation (3.13), the sum of onshore and offshore bond

[8] see Koyck model derivation appendix for more details

ETFs amount is the total debt issuance with logarithmic form. Also, there is an endogenous problem. This regression chooses the third lag of *debt* as its instrumental variable. The Proposition 3 test $\frac{\partial |c-b|}{\partial D} < 0$ provides significant $\lambda_{p3} = 0.854$ which implies high level of persistence, and significant $\delta_{0,p3} = -0.03$ as model prediction. The simultaneous effect of a 1% increase in total bond issuance will be a 0.03 basis point decrease in the absolute gap of interest rate $|c-b|$. However, the cumulative effect (LRP) of a 1% increase in total bond issuance will be a 0.205 basis point decrease in the absolute gap of interest rate $|c-b|$. In a word, a large amount of debt issuance may decrease the absolute value of the net deviation. With infinity capital flows, the two deviations become identical.

	μ_share		|c-b|
(c-b)	0.305*	*debt*_amount	-0.030*
	(0.1696)		(0.0183)
L1.μ_share	0.019	L1.|c-b|	0.854***
	(0.0293)		(0.0325)
control variables		control variables	
cons	97.634***	cons	0.690**
	(2.9035)		(0.3463)
N	410	N	274
Root MSE	3.031	Root MSE	0.273

Table 3.3: Regression - 2SLS IV and Robust method

3.5 Conclusion

China has both RMB onshore and offshore markets. The onshore CNY market is relatively regulated and controlled, but the offshore CNH market is relatively marketized and liberalized. The offshore market is the experimental field of RMB internationalization. This asymmetric phenomenon would cause many questions that are worth probing into. This paper implements the idea of Liao [2016] to explain Chinese onshore and offshore financial markets and fill the gap of the term spread differential and CIP violation spillover effects. From the model's results, there are three propositions under the financial institution - a bank's strategy in RMB money and currency markets. This paper also uses a flexible econometric method of Miranda-Agrippino and Ricco [2017], which can sensibly reduce the impact of compounded biases over the horizons and effectively deal with model misspecifications, to test Proposition 1 with different source of shocks. Another econometric method is two-stage least squares (2SLS) instrumental variables and robust standard errors under Koyck (geometric lag) model to test Proposition 2 & 3 simultaneous effect and long run propensity.

The results are three-fold: First, Proposition 1 - spillover of deviations: one market shock can transmit to the other market through capital flows. The shocks from the forward currency market have a large impact on the spot money market through capital flows. Also, these shocks from the forward currency market would cause overreacted capital flows, which makes the transaction cost more volatile because of exchange-rate overshooting. The effects on both markets would die away in a week after initial shocks, but the effect on capital flows is less persistent. Second, Proposition 2 - issuance flow and net deviation: cheaper net cost of issuance in offshore induces more issuance flow in offshore and less issuance in onshore. The profit maximization behavior of financial institutions could cause bond issuance movement to lower costs. Third, Proposition 3 - arbitrage capital and aligned deviations: a massive amount of debt issuance may decrease the absolute value of the net deviation. With infinity capital flows, the two deviations become identical. The asymmetric phenomenon implies that RMB markets are less efficient, so there would be some arbitrage opportunities. However, strict regulations and high costs can turn a possible arbitrage situation into an unfavorable one that has no benefit to investors and traders.

Appendix 3.A Daily Capital Control Index

The daily capital control index is calculated by the unweighted average index of the following related financial categories in order to reflect the sensitivity of capital control policy changing. For each following financial related category, the index is between 1 and 0 where 1 means totally controlled and 0 vice versa (4th Jan 2010 is a benchmark date). If there is a policy change from full control to semi-open, the index becomes 0.5 from 1. Also, the index would be unchanged if there is not a newly released policy. The novel capital control index of China on a daily basis from 2010 to 2018 is based on the public information provided from the SAFE website and PBoC annual policy reports.[9]

[9] Qing Ge calculates the daily capital control index.

Variable	Description
ka	Overall restrictions index
kai	Overall inflow restrictions index
kao	Overall outflow restrictions index
eq	Average equity restrictions
eqi	Equity inflow restrictions
eqo	Equity outflow restrictions
eq_plbn	Purchase locally by nonresidents (equity)
eq_siln	Sale or issue locally by nonresidents (equity)
eq_pabr	Purchase abroad by residents (equity)
eq_siar	Sale or issue abroad by residents (equity)
bo	Average bond restrictions
boi	Bond inflow restrictions
boo	Bond outflow restrictions
bo_plbn	Purchase locally by nonresidents (bonds)
bo_siln	Sale or issue locally by nonresidents (bonds)
bo_pabr	Purchase abroad by residents (bonds)
bo_siar	Sale or issue abroad by residents (bonds)
mm	Average money market restrictions
mmi	Money market inflow restrictions
mmo	Money market outflow restrictions
mm_plbn	Purchase locally by nonresidents (money market instruments)
mm_siln	Sale or issue locally by nonresidents (money market instruments)
mm_pabr	Purchase abroad by residents (money market instruments)
mm_siar	Sale or issue abroad by residents (money market instruments)
ci	Average collective investments restrictions
cii	Collective investments inflow restrictions
cio	Collective investments outflow restrictions
ci_plbn	Purchase locally by nonresidents (collective investments)
ci_siln	Sale or issue locally by nonresidents (collective investments)
ci_pabr	Purchase abroad by residents (collective investments)
ci_siar	Sale or issue abroad by residents (collective investments)
de	Average derivatives restrictions
dei	Derivatives inflow restrictions
deo	Derivatives outflow restrictions
de_plbn	Purchase locally by nonresidents (derivatives)
de_siln	Sale or issue locally by nonresidents (derivatives)
de_pabr	Purchase abroad by residents (derivatives)
de_siar	Sale or issue abroad by residents (derivatives)
di	Average direct investment restrictions
dii	Direct investment inflow restrictions
dio	Direct investment outflow restrictions
re	Average real estate restrictions
rei	Real estate inflow restrictions
reo	Real estate outflow restrictions
re_pabr	Purchase abroad by residents (real estate)
re_plbn	Purchase locally by nonresidents (real estate)
re_slbn	Sale locally by nonresidents (real estate)

Appendix 3.B VAR

From equilibrium conditions of the static model:

$$\mu = \frac{(c-b)D}{\omega} + \theta$$
$$c = \frac{V}{\tau}((1-2\mu)D - \varepsilon_c)$$
$$b = -\gamma^2((1-\mu)D + \varepsilon_b)$$

Then, static model with time subscript in matrix form:

$$\begin{bmatrix} \omega & -D & D \\ 2D & \frac{\tau}{V} & 0 \\ -D & 0 & \frac{1}{\gamma^2} \end{bmatrix} \begin{bmatrix} \mu_t \\ c_t \\ b_t \end{bmatrix} = \begin{bmatrix} \theta\omega \\ D \\ -D \end{bmatrix} - \begin{bmatrix} 0 \\ \varepsilon_{c,t} \\ \varepsilon_{b,t} \end{bmatrix}$$

$$\begin{bmatrix} \omega & -D & D \\ 2D & \frac{\tau}{V} & 0 \\ -D & 0 & \frac{1}{\gamma^2} \end{bmatrix} = M$$

Due to $det(M) = \frac{\omega\tau + \tau\gamma^2 D^2 + 2VD^2}{V\gamma^2} > 0$ (In other words, M^{-1} is the inverse of matrix M), this system has solution.

Therefore, VAR with optimal lags:

$$\begin{bmatrix} \omega & -D & D \\ 2D & \frac{\tau}{V} & 0 \\ -D & 0 & \frac{1}{\gamma^2} \end{bmatrix} \begin{bmatrix} \mu_t \\ c_t \\ b_t \end{bmatrix} = B_0 + B_1 \begin{bmatrix} \mu_{t-1} \\ c_{t-1} \\ b_{t-1} \end{bmatrix} + B_2 \begin{bmatrix} \mu_{t-2} \\ c_{t-2} \\ b_{t-2} \end{bmatrix} + B_3 \begin{bmatrix} \mu_{t-3} \\ c_{t-3} \\ b_{t-3} \end{bmatrix} + B_4 \begin{bmatrix} \mu_{t-4} \\ c_{t-4} \\ b_{t-4} \end{bmatrix} - \begin{bmatrix} 0 \\ \varepsilon_{c,t} \\ \varepsilon_{b,t} \end{bmatrix}$$

Reduced Form VAR:

$$\begin{bmatrix} \mu_t \\ c_t \\ b_t \end{bmatrix} = M^{-1}B_0 + M^{-1}B_1 \begin{bmatrix} \mu_{t-1} \\ c_{t-1} \\ b_{t-1} \end{bmatrix} + M^{-1}B_2 \begin{bmatrix} \mu_{t-2} \\ c_{t-2} \\ b_{t-2} \end{bmatrix} + M^{-1}B_3 \begin{bmatrix} \mu_{t-3} \\ c_{t-3} \\ b_{t-3} \end{bmatrix} + M^{-1}B_4 \begin{bmatrix} \mu_{t-4} \\ c_{t-4} \\ b_{t-4} \end{bmatrix} - M^{-1} \begin{bmatrix} 0 \\ \varepsilon_{c,t} \\ \varepsilon_{b,t} \end{bmatrix}$$

Appendix 3.C IRFs

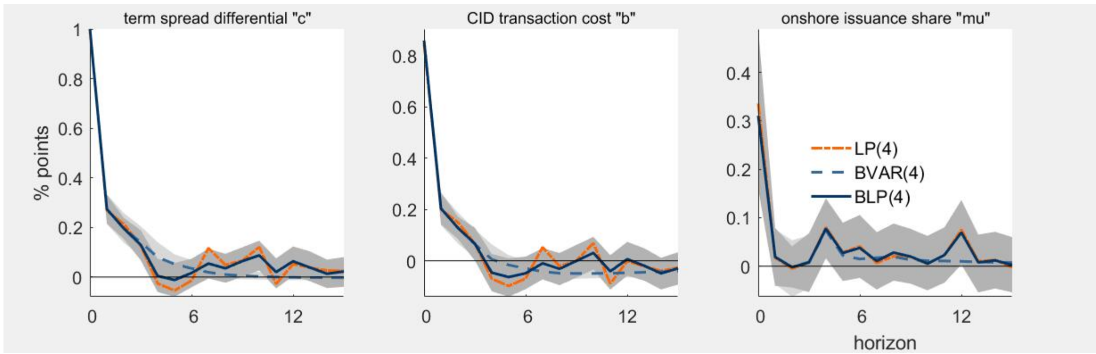

Figure 3.10: Monetary policy - changed reserve ratio $\varepsilon_c \downarrow$

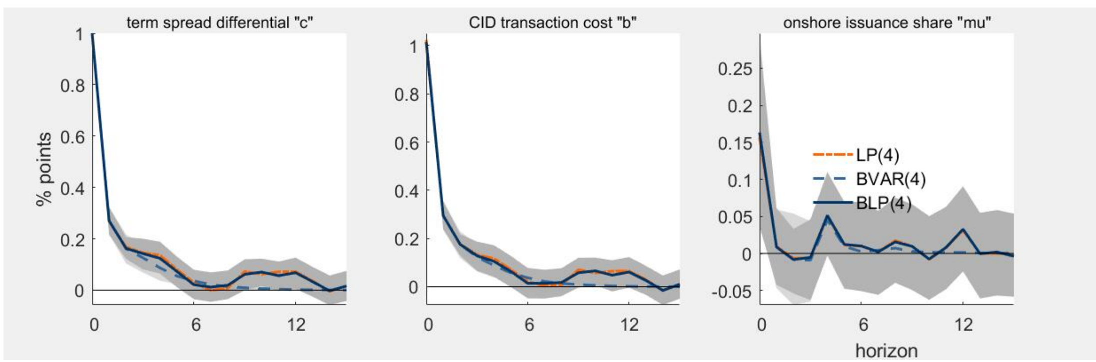

Figure 3.11: Investor preference - stock market substitution effect $\varepsilon_c \downarrow$

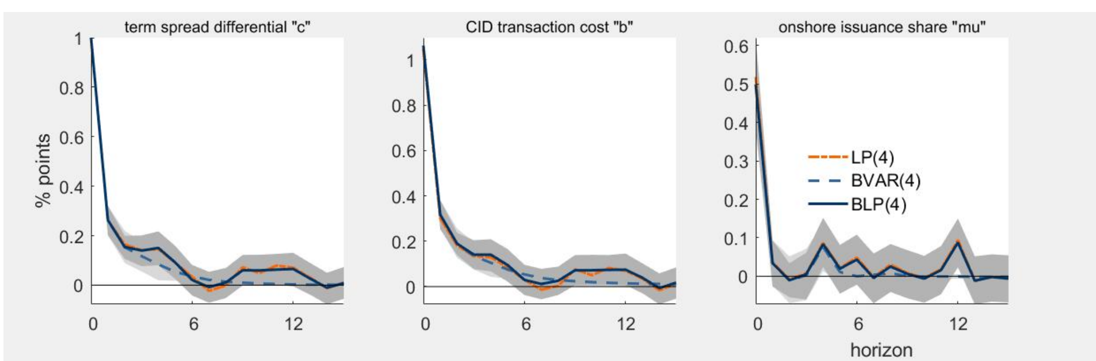

Figure 3.12: Money market regulatory - reverse REPO of open market $\varepsilon_c \downarrow$

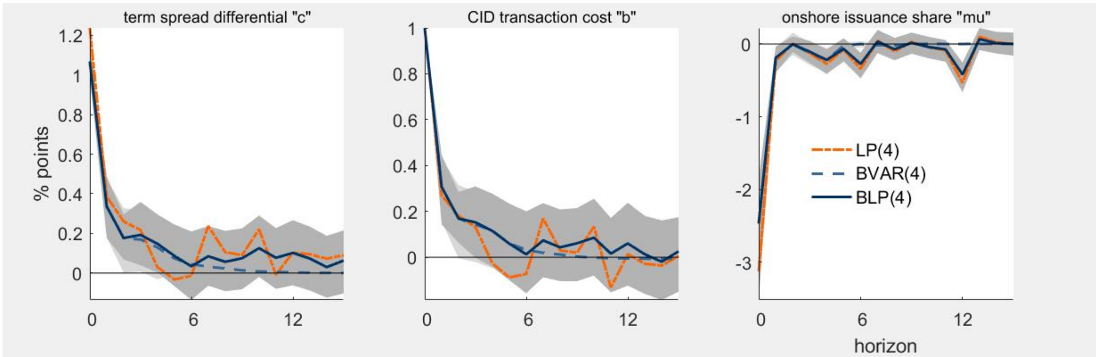

Figure 3.13: Central bank policy - liquidity of currency market $\varepsilon_b \downarrow$

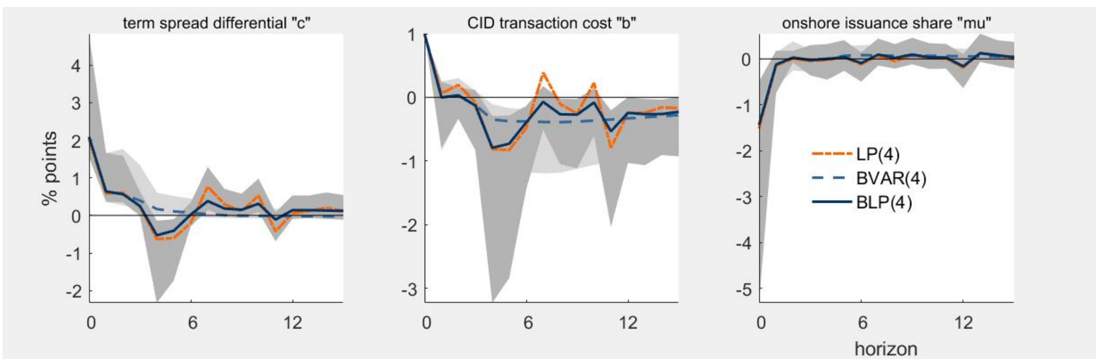

Figure 3.14: Trader expectation - volatility of currency market $\varepsilon_b \downarrow$

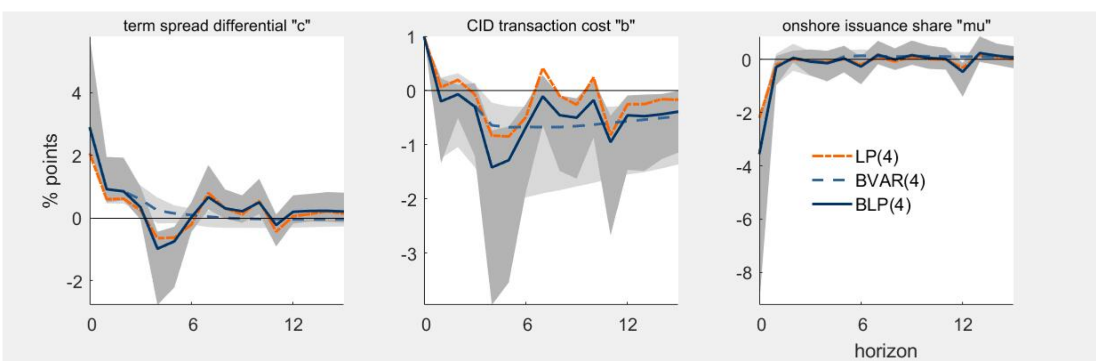

Figure 3.15: Currency market regulatory - capital control $\varepsilon_b \downarrow$

Appendix 3.D Koyck Model Derivation

Substitute $\delta_i = \delta_0 \lambda^i$ into

$Y_t = \beta_0 + \delta_0 X_t + \delta_1 X_{t-1} + \delta_2 X_{t-2} + ... + \delta_q X_{t-q} + ... + u_t$

and lag one period:

$Y_{t-1} = \beta_0 + \delta_0 X_{t-1} + \delta_0 \lambda X_{t-2} + \delta_0 \lambda^2 X_{t-3} + ... + \delta_0 \lambda^q X_{t-q-1} + ... + u_{t-1}$

then multiply both sides of above equation by λ:

$\lambda Y_{t-1} = \lambda \beta_0 + \delta_0 \lambda X_{t-1} + \delta_0 \lambda^2 X_{t-2} + \delta_0 \lambda^3 X_{t-3} + ... + \delta_0 \lambda^{q+1} X_{t-(q+1)} + ... + \lambda u_{t-1}$

then use original equation minus this new equation:

$Y_t - \lambda Y_{t-1} = (1-\lambda)\beta_0 + \delta_0 X_t + u_t - \lambda u_{t-1}$

estimate the model:

$Y_t = \beta^* + \lambda Y_{t-1} + \delta_0 X_t + u_t^*$

where $\beta^* \equiv (1-\lambda)\beta_0$ and $u_t^* \equiv u_t - \lambda u_{t-1}$.

Therefore,

$$LRP = \sum_{i=0}^{n} = \frac{\partial Y_t}{\partial X_{t-i}} = \sum_{i=0}^{n} \delta_i = \sum_{i=0}^{n} \delta_0 \lambda^i = \frac{\delta_0}{1-\lambda}$$

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