A Multi-Country NOEM Analysis of China with Cross-Country Heterogeneity

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A Multi-Country NOEM Analysis of China with Cross-Country Heterogeneity

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Abstract

This thesis develops a multi-country model for China based on the New Open Economy Macroeconomics to study China's interactions with the United States, the Euro Area and the rest of the world. The model is estimated to identify heterogeneous structural characteristics of these economies using the Bayesian approach. Then the estimated model is simulated to find the international transmission of productivity improvements originated in each area. In particular, the model is applied to the modelling of heterogeneous external asset and liability positions and to analysis of the influences of international investment on the spillover effects of the shocks. Our model provides a comprehensive framework with heterogeneous structural features for open economy analysis between multiple countries, while the scale of the model is moderate and the identification is robust. In addition, our work broadens the family of general equilibrium models designed for the Chinese economy.

Our estimation finds large heterogeneity of structural parameter values and policy functions between these economies. China and the US have more distorted consumption patterns than other areas, and the production of the Euro Area is more vulnerable to shocks. The monetary policy of China can be described by both interest rate and money quantity rules with different targets, while other economies generally follow interest rate rules. Simulations show that productivity improvements from the US and the EA have larger spillover effects than the improvements originated in China. The US can promote trade surplus by stimulating growth. For China, productivity increase cannot easily build up her international investment position further, due to the adjustment costs induced by her large net position. The valuation effects are significant under large gross positions. Such effects are caused by interest rate differentials more than by exchange rate movements.

Table of Contents

List of Tables

List of Figures

Abbreviations

Abbreviation	Full term
A^j	Productivity
$a_j^{j'}$	Share of goods from country j in the consumption of country j’
$a_{C,j}^{j'}$	Share of goods from country j in the consumption final goods of country j’
$a_{I,j}^{j'}$	Share of goods from country j in the investment final goods of country j’
AWM	Area Wide Model
$B_j^{j'}$	Bond issued by country j held by country j’
$b_j^{j'}$	Ratio of external liability of country j held by country j’, to the output of country j
BEA	Bureau of Economic Analysis
BOPS	Balance of Payments Statistics
C^j	Consumption
CA^j	The current account
CEEC	Central and East Europe countries
CES	Constant elasticity of substitution
CN	China
CPI	Consumer price index
DOTS	Direction of Trade Statistics

Abbreviation	Full term
DP	Dollar pricing
DSGE	Dynamic stochastic general equilibrium
$\mathcal{E}_j^{j'}$	The exchange rate: number of currency j per currency j'
EA	The Euro Area
ECB	European Central Bank
EMU	European Monetary Union
EU	The European Union
G^j	Government consumption
GDP	Gross Domestic Product
GEM	Global Economy Model
GPM	Global Projection Model
GVAR	Global VAR
H^j	Consumption habit term
$\mathcal{H}^j$	Hamiltonian
h^j	Consumption habit coefficient
HP	Hodrick-Prescott
I^j	Domestic investment
i^j	Interest rate

Abbreviation	**Full term**
IFS	International Financial Statistics
IIP	International investment position
IMF	International Monetary Fund
IRF	Impulse response function
J	Set of countries
K^j	Domestic capital
L^j	Labour
LCP	Local currency pricing
LOOP	The law of one price
M^j	Money
MC^j	Marginal cost
MEI	Main Economic Indicators
n^j	Share in the world population
NA_j	Net international investment position of country j
$NA_j^{j'}$	Net international investment position between country j and j'
NAWM	New Area Wide Model
NBS	National Bureau of Statistics
NK	New Keynesian

Abbreviation	Full term
NNS	New Neoclassical Synthesis
NOEM	New Open Economy Macroeconomics
NT_j	Net trade of country j
$NT_j^{j'}$	Net trade between country j and j’
OECD	Organization of Economic Co-operation and Development
P^j	Consumer price index
P_j^j	Producer price index
$\tilde{P}_j^j$	Adjusted price of firms
P_I^j	Investment final goods price index
PCP	Producer currency pricing
PPI	Producer price index
PPP	Purchasing power parity
Pr_B^j	Profits of financial intermediates
Pr_Y^j	Profits of firms
Q^j	Discount rate
r^j	Rental of domestic capital
RBC	Real business cycle
RMB	Renminbi

Abbreviation	**Full term**
ROW	The Rest of the World
S	State of the economy to evaluate contingent bonds
SOE	Small open economy
T^j	Tax or transfer
TC^j	Total cost of production
U^j	Utility function
UIP	Uncovered interest parity
UK	The United Kingdom
US	The United States
V_0^j	Aggregate utility
VAR	Vector autoregression
VC_j	Aggregate valuation effects of country j
$VC_j^{j'}$	Valuation channel between country j and j’
W^j	Wage rate
WDI	World Development Indicators
X	Vector of endogenous variables
X^*	Observables
x	Output gap

Abbreviation	**Full term**
Y^j	Output
z	Type of differentiated goods
α^j	Capital share in production
β^j	Discount rate
δ^j	Capital depreciation rate
Γ	Coefficient in the measurement equations
$\Gamma_{B,j}^{j'}$	Adjustment cost of bond issued by country j held by country j’
Γ_C^j	Consumption adjustment cost
Γ_I^j	Investment adjustment cost
Γ_W^j	Wage adjustment cost
ε	Vector of shocks
ϵ_A^j	Productivity shocks
ϵ_G^j	Government spending shocks
ϵ_i^j	Interest rate policy shocks
ϵ_L^j	Preference shocks
ϵ_M^j	Money quantity shocks
ϵ_P^j	Mark-up shocks
ζ_C^j	Ratio of consumption to output

Abbreviation	Full term
ζ_G^j	Ratio of government spending to output
ζ_I^j	Ratio of domestic investment to output
ζ_L^j	Preference of labour in the utility function
ζ_P^j	Mark-up of optimal price
$\zeta_{Y,j}^{j'}$	Output ratio of country j' to j
η^j	Elasticity between domestic and foreign intermediate goods
η_C	Elasticity of different brands of goods
η_W	Elasticity of labours from different households
θ^j	Calvo pricing coefficient
κ	Share of labour utility in the utility function
κ_α	Coefficient on output gap
λ^j	Lagrange multiplier with respect to budget constraint; Marginal utility of consumption
λ_K^j	Lagrange multiplier with respect to law of motion of capital
μ	Monetary stance
ν	Measurement errors
Ξ	Estimated parameters
ρ_A^j	Persistence of productivity shocks
ρ_G^j	Persistence of government spending shocks

Abbreviation	Full term
$\rho_{i,1}^{j}$	Inertia of interest rate rule
$\rho_{i,2}^{j}$	Response of interest rate policy to inflation
$\rho_{i,3}^{j}$	Response of interest rate policy to output
ρ_{L}^{j}	Persistence of preference shocks
$\rho_{M,1}^{j}$	Inertia of quantity rule
$\rho_{M,2}^{j}$	Response of quantity rule to inflation
$\rho_{M,3}^{j}$	Response of quantity rule to output
ρ_{P}^{j}	Persistence of mark-up shocks
σ_{C}^{j}	Elasticity of consumption in the utility function
σ_{L}^{j}	Elasticity of labour in the utility function
σ_{M}^{j}	Elasticity of money in the utility function
Φ	Structural equations
$\phi_{B,j}^{j'}$	Coefficient on international investment adjustment cost
$\phi_{C,1}^{j}$	The first coefficient on consumption transaction cost
$\phi_{C,2}^{j}$	The second coefficient on consumption transaction cost
ϕ_{I}^{j}	Coefficient on domestic investment adjustment cost
ϕ_{W}^{j}	Coefficient on wage adjustment cost
χ	Share of money utility in the utility function

Abbreviation	Full term
Ψ	State equations

Statement of Copyright

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Chapter 1

Introduction

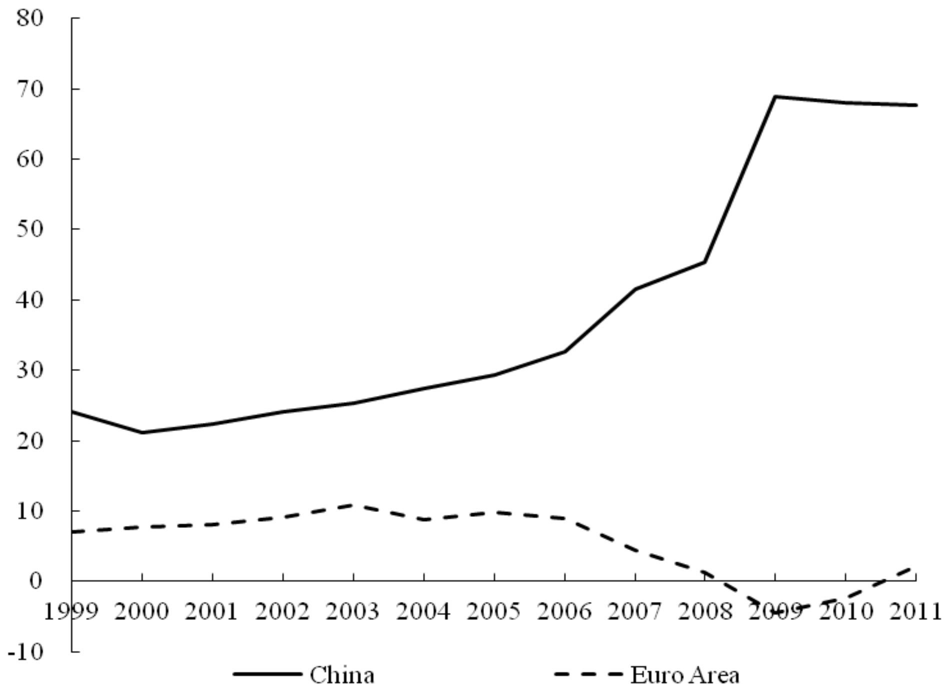
1.1. Overview

Economic heterogeneity is defined as diversity in preferences and political orientations due to differences in institutions and policies (Corsetti 2006). The elements of heterogeneity include sectoral composition of output, the degree of nominal rigidities, financial structure, labour market institutions, and the degree of liberalization. This thesis aims to study the dynamics of the Chinese economy while considering the heterogeneity between China and other major world economies in a global context. Although the structural features cannot be described easily, some of the effects of heterogeneity between these areas can be observed from certain facts.

The modelling and analysis in this thesis consider four economies. We use the political geographic definition of country for China (CN) and the United States (US), while the Euro Area (EA) is defined following the official definition of the economic and monetary union of 17 countries (or, the Eurozone). We use the Rest of the World (ROW) to describe the world economy excluding the three economies above. Different scenes of development of these areas lead to the structural surpluses and deficits between them. China has a persistently increasing weight in US deficit; since 2009 this has represented around 68 percent of the total deficit of the US (Figure 1.1). The EA traditionally accounts for a small fraction of US deficit, although from 2009 to 2010 the situation reversed. The strategy of promoting economic growth through export and high investment has improved the trade position of China vis-à-vis the US. Demographic factors, together with currency and exchange rate policies, provide explanations for a large trade surplus.

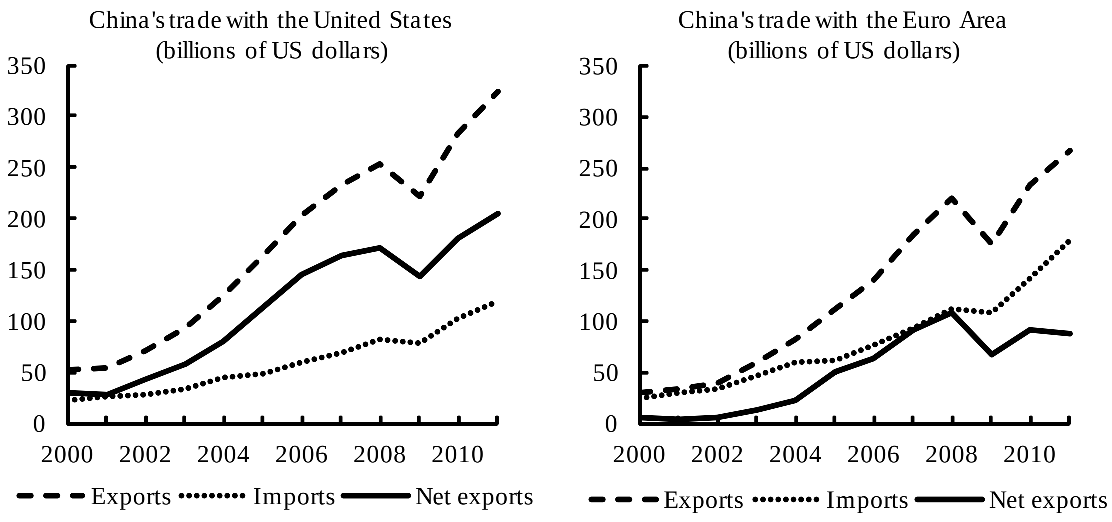
In addition to the imbalances with the United States, the US and the EA are two of the largest foreign trade partners of China. In 2011, China's total volume of trade with the EA reached 445 billion US dollars, exceeding that with the US (444 billion US dollars). Nevertheless, the characteristics of China's trade with these two economies are quite distinct. For example, imports from the US are less than half China's exports (Figure 1.2). This is reflected in China's large surplus with the US. On the other hand, China exports less to and imports more from the EA than from the US. The combined effect is a surplus with the EA only about half that with the US. Considering the importance of these economies as foreign partners of China, and their distinct interdependence with China, we consider these two blocks separately in the model.

Figure 1.1 Share in the US current account deficit by area (percent)



Source: Bureau of Economic Analysis, US Department of Commerce

Figure 1.2 China’s trade with United States and Euro Area

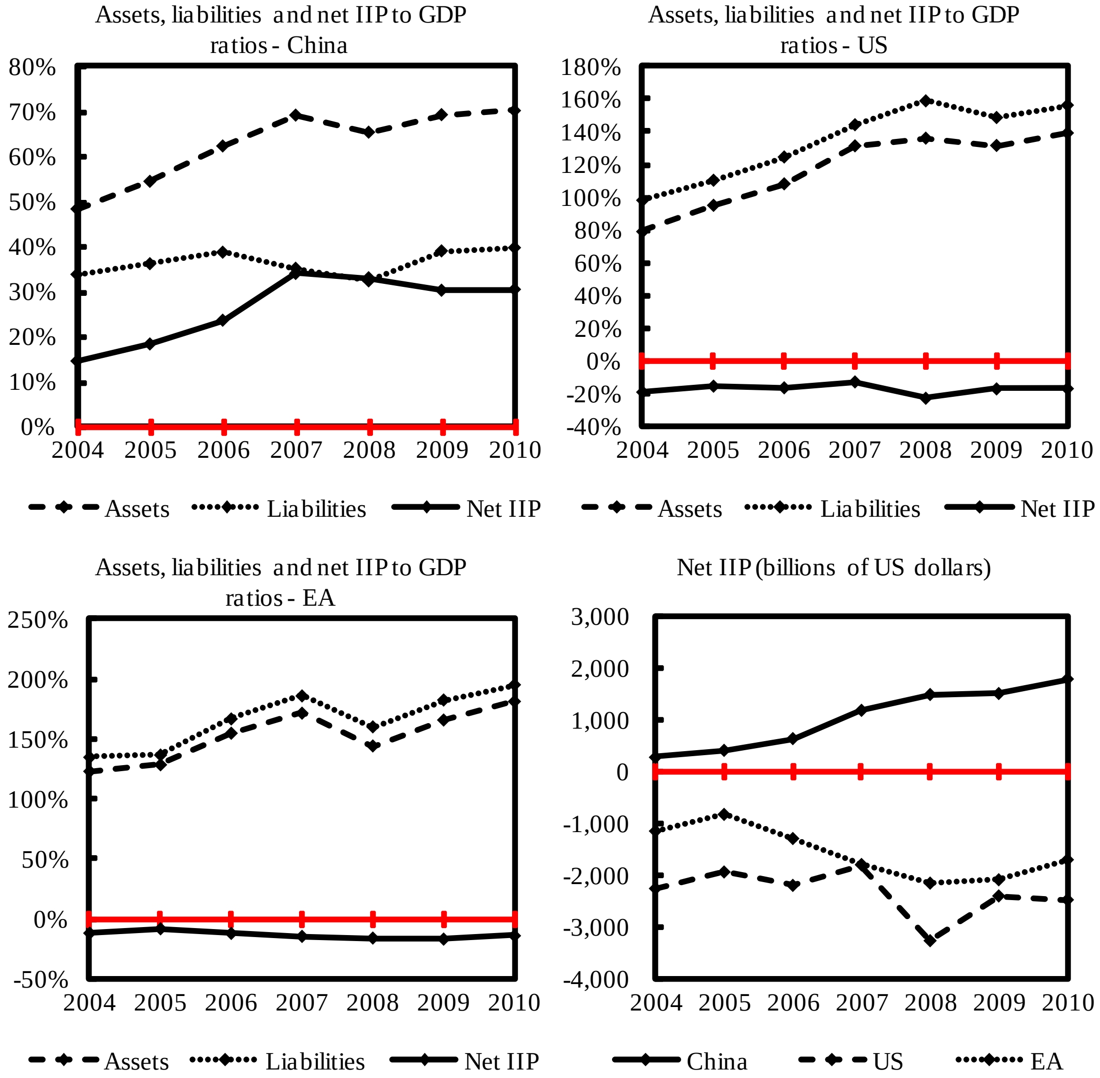


Source: International Monetary Fund, Direction of Trades Statistics

With globalization and financial market integration, there is also a boom in cross-country investment, which further distinguishes the roles of these areas. The magnitudes of net International Investment Positions (IIP) of China, the US and the EA have been over billions of US dollars (Figure 1.3). Globally, China is one of the major creditors, with her net IIP reaching almost 40 percent of her gross domestic product (GDP) by the end of 2010. In contrast, the US and the EA are found to be large borrowers, with their net IIPs accounting for about 17 percent and 14 percent of their GDPs in debt, respectively. In addition, the structures of the external assets and liabilities of these areas are different. The US and the EA have fast growth in gross positions of both assets and liabilities. However, the picture in China is different, in that her external liabilities remain steady, while large external assets dominate the increase in net IIP.

Given the above facts, we propose a multi-country analysis for China considering her major foreign partners and the heterogeneity between these economies. In the second section of this chapter, we introduce our research questions and the motivations underlying them. Section 1.3 gives details of the organization of the thesis.

Figure 1.3 Assets, liabilities and net IIPs of China, US and EA



Source: International Monetary Fund, International Financial Statistics, various issues

1.2. Motivations and Research Questions

This thesis is devoted to the study of the role of China in the global economy using a multi-country New Open Economy Macroeconomics (NOEM) model with cross-country heterogeneity. The thesis covers modelling of the Chinese and world economies, estimation of the model, and simulation of it for different scenarios. In this section, we list the research questions in the thesis and demonstrate the motivations for investigating each of these questions.

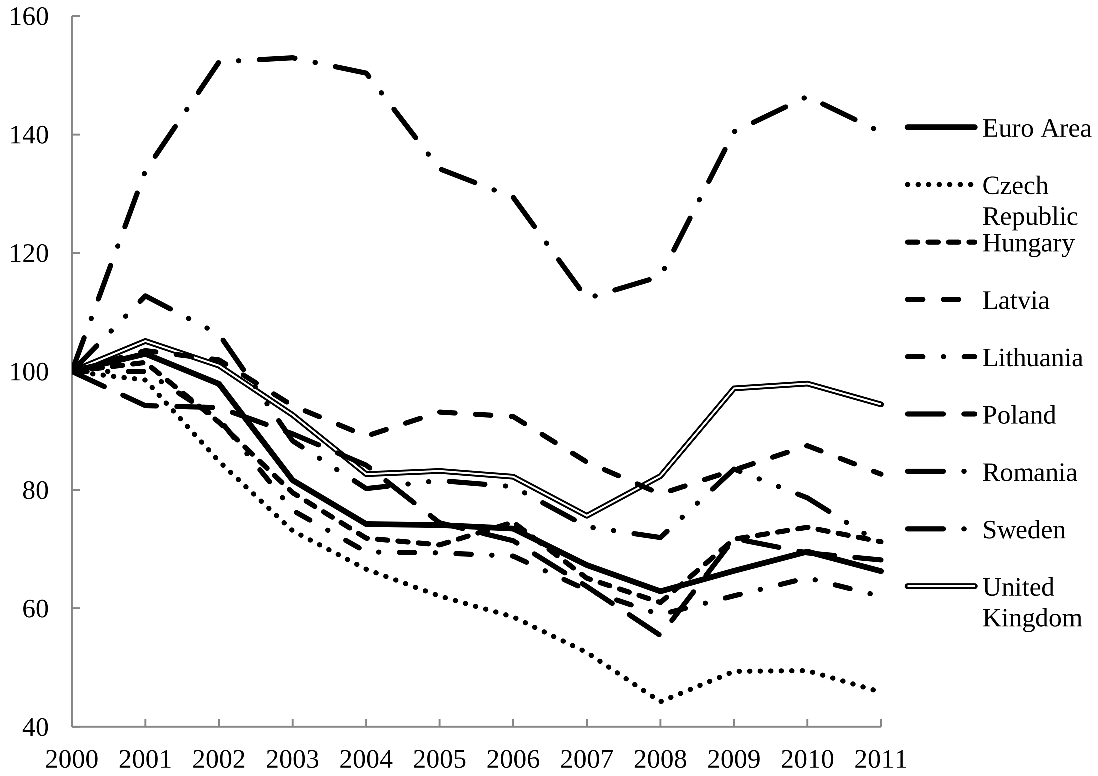
1) What is the appropriate framework for multi-country analysis of China and other major world economies?

In the context of open economy research, an increasing number of studies focus on multi-country analysis with general equilibrium models and rational expectations. In particular, the NOEM consists of a stream of studies to investigate open economy topics in a general equilibrium framework while overcoming the Lucas critique (Lucas 1976). The NOEM starts from the development of two-country models to understand exchange rate volatility and other dynamics of the economies (Obstfeld and Rogoff 1995). With increasing interest in empirical analysis, researchers have developed estimated NOEM models for many countries, areas and even the world economy. Recent development of this field incorporates cross-country heterogeneity into multi-country frameworks to analyze the interactions between various distinctive economies.

Open economy studies using NOEM models for China are still at a preliminary stage. The US and the EA are the two largest partners of China in international trade and investment. They have not been studied in a comprehensive framework in the existing literature. In addition, if a number of economies are incorporated in a model, that model should contain the necessary structural setups to reflect the characteristics of those economies. Meanwhile, the model should maintain a moderate scale so that it is applicable to empirical estimation and testing. The ultimate purpose of this thesis is to provide a model that could be used to draw implications for the role of China in the world economy. To do so, development of a China model is the crucial first step.

We consider the Euro Area rather than the European Union (EU) as an economy to analyze, since the shared single currency characteristic of the union benefits the analysis. Figure 1.4 illustrates the exchange rates of EU member countries. With the exceptions of Bulgaria and Demark, which are pegging to the euro, the other economies have distinct exchange rate levels against the euro. Assuming a single currency for the EU largely ignores these differentials, while considering the various currencies in the model would bring great complexity. In addition to the co-movement of the exchange rates, business cycle correlations of the Euro Area with the United Kingdom (UK) and the Central and East Europe countries (CEEC) still display mixed evidence (De Haan, Inklaar, and Jong-A-Pin 2008; Bussière, Fidrmuc, and Schnatz 2008; Fidrmuc and Korhonen 2006). Our methodology follows the literature on open economy studies of the EA (Lubik and Schorfheide 2006; Laxton and Pesenti 2003;

Figure 1.4 Exchange rates of European Union member states (index: 100 in 2000)



Source: International Monetary Fund, International Financial Statistics, various issues, and author's own calculation.

Bayoumi, Laxton and Pesenti 2004). The study by Haberis et al. (2011) is an example of modelling the UK and the EA separately.

We use ROW instead of other economic region or area to serve as the fourth block in the model. Neglecting ROW induces an extra assumption that the first three blocks in the model have balanced trade with other world countries. China, the United States and the Euro Area maintain large unbalanced trades with the world excluding these three economies (Table 1.1). In particular, the US has had consistently large deficits

Table 1.1 Trade balance with ROW (billions of dollars)

Time	China	United States	Euro Area
2000	-12.37	-325.30	-105.06
2001	-8.46	-300.84	-70.76
2002	-18.37	-325.99	-60.77
2003	-46.05	-365.10	-60.13
2004	-70.50	-442.49	-76.64
2005	-61.62	-510.56	-134.40
2006	-29.82	-532.04	-140.30
2007	8.39	-485.94	-3.16
2008	17.75	-498.40	-99.50
2009	-11.34	-252.73	55.38
2010	-86.69	-328.60	-10.78
2011	-134.02	-377.17	-34.18

with ROW since 2000, which conflicts with the assumption. Using other economic region rather than ROW would bring similar assumptions, and thereby lead to bias of the model. This approach to dealing with the aggregation of economies in the model has been adopted by the NOEM literature, particularly for the medium-scale and large-scale models.

2) How do financial market completeness and symmetric structural features affect international risk sharing and welfare transfer through international trade?

General equilibrium models with complete financial markets and symmetric international trade elasticity imply perfect international risk sharing. By trading Arrow-Debreu securities, consumers can insure against consumption shocks. Marginal utilities of consumption are the same for different countries (Lewis 1999). However, empirical evidence rejects high correlation between consumption of countries. For example, Backus, Kehoe, and Kydland (1992) find that the correlations between the outputs of the US and other economies are much higher than the correlations of consumption, which contradicts the highly linked consumption predicted by the complete market theory. Obstfeld and Rogoff (2001) find that the average value of the correlation between the consumption of six major developed economies is 0.4. In order to overcome the shortfall of market completeness, Corsetti, Dedola, and Leduc (2008) revise an international business cycle model with incomplete markets to capture the imperfect risk sharing. Their model expresses the relative consumption in the function of trade elasticity and provides a mechanism to gauge the low correlation. They find that asymmetry in international trade elasticity is a cause of low risk sharing. However, in the NOEM literature, a number of studies use complete financial markets to simplify their analysis. Others use incomplete market settings, yet they do not provide explicit equations about relative consumption to demonstrate how risk sharing between two countries is affected by other factors.

In order to investigate the dynamics of international trade under complete markets, in Chapter 3 we develop a workhorse model based on complete financial markets. We also simulate the model to derive the trade dynamics. Following that, the effect of completeness in the theoretical framework is examined. In Chapter 5, we compare an incomplete markets model with symmetric steady state international asset position and the workhorse model. The purpose of this comparison is to find whether the widely adopted symmetric setting for incomplete markets could derive different dynamics from complete markets. Finally, we develop an incomplete market with heterogeneous features to generate the imperfect risk sharing dynamics between the economies.

3) How well can Bayesian estimation identify the heterogeneous structural features of the economies in the multi-country model?

Structural models are criticized for the problems of misspecification and identification. The models are likely to be in incorrect forms, owing for example to the omission of non-linearity, the inclusion of incorrect structural relationships, or wrongly set exogenous processes (Lubik and Schorfheide 2006). With misspecification, estimation results may be inconsistent with micro studies. In addition, different methods of estimation match a model with data in different ways. They may lead to distinct estimates of parameters even with the same equations and data. On the other hand, when data are not sufficiently informative, the density function is flat with different parameter values. Estimation approaches based on likelihood have difficulties in identifying results. In this case, different parameter values may lead to the same likelihood, so that values of estimates are not stable. With regard to both problems, prior information about parameters may help identify credible estimation. Bayesian estimators are the joint products of informative priors and observations. This approach has been adopted to provide better estimation for vector autoregression models (VAR), and is applied to the estimation of structural models.

In practice, there are a few difficulties in the estimation of models of China. Macroeconomic data of China lack some important series. For example, employment data published by the government statistical department is not consistent with internationally adopted definitions. Also, even the most used series have shorter sample periods. In a multi-country analysis, small sample size may magnify the problems of misspecification and identification. We aim to estimate a model for the world economy including China. Both intuitive priors and informative data will help draw reliable estimates.

With these considerations, Chapter 4 estimates a multi-country model for China using the Bayesian approach. Choices of priors are based on the evidence from theoretical and empirical studies, so that they provide rich presumptions about the parameters of the structural model. However, in some cases, posteriors are close to priors and move with changes in the priors. Even the Bayesian approach is criticized for being unable to generate posteriors based on the information in data. To examine the robustness of the estimation, different sets of priors are attempted to evaluate the sensitivity of the estimation.

4) What are the major heterogeneous structural features of China and other economies?

Structural models describe the differences between economies in terms of the different values of various parameters. According to the parameterization, the model can generate forecasts for variables that are consistent with data. Therefore, exceptional features of an economy should be reflected by different parameter values or structural functions in the model. For example, Bils and Klenow (2004) find that the median length of period to change prices for US firms is between 4.3 and 5.5 months, which corresponds to the coefficient value between 0.77 and 0.82 in the Calvo pricing. However, the Euro Area has a different degree of price stickiness. Angeloni et al. (2004) find the Euro Area to have a Calvo coefficient of 0.75. Thus, assuming symmetry for structural parameters ignores the differences between economies. Moreover, the costs for ignoring heterogeneity and adopting policies based on symmetric models could be large (Breuss and Fornero 2009).

The Chinese economy has a different policy regime from other economies. Although the exchange rate reform has largely released the authority from pegging to the US dollar (Zhang, Shi, and Zhang 2011), China's exchange rate regime still has its own complications. Similarly, as regards monetary policy, the regime is characterized by both a deposit rate ceiling and a lending rate floor (He and Wang 2011; PBC 2004). At the same time, the quantity rule is adopted as a policy instrument (Zhang 2009). In contrast, policies of the US and the EA can be described by certain forms of the Taylor rule (Orphanides 2003; Sauer and Sturm 2007; Taylor 1998; Woodford 2001; Peersman and Smets 1999). Hence, it is inappropriate to use the same policy function for estimating these economies in the model. The best description of the monetary policy of China should be tested in the multi-country framework with different policy rules.

Heterogeneity between countries can be identified by estimating the structural parameters and the policy functions. There are studies in the literature aiming to identify cross-country differences (Kolasa 2008; Breuss and Fornero 2009; Plasmans, Michalak, and Fornero 2006; Jondeau and Sahuc 2008). However, China has not been viewed as an objective in this area, or analyzed with emphasis on various distinctive features of her economy. In Chapter 4, we estimate a multi-country model including a block representing China. The estimation is designed to begin with symmetric distribution for priors. The asymmetry in posteriors will then trace to the information in the data. We aim to show whether multi-country estimation can distinguish heterogeneity between these countries.

5) How do heterogeneous external asset and liability positions affect international trade and investment?

Firstly, significantly large and persistent cross-country investment is an important factor in the evaluation of international transmission of shocks. Large cross-country investment has become a by-product of globalization and financial markets integration. Our study covers the most active creditors and debtors in international financial markets. Both the US and the EA have large amounts of external assets and liabilities, and China is viewed as one of the largest international lenders. A few studies observe these phenomena and consider the external positions in their analysis (Blanchard, Giavazzi, and Sa 2005; Caballero, Farhi, and Gourinchas 2008; Lane and Milesi-Ferretti 2007a and 2007b). Devereux and Sutherland (2011) criticize the analysis of cross-country linkages in terms of net foreign assets in that it does not distinguish assets and liabilities. Most studies focus on the US, and our thesis differs from them by investigating international investment with a framework that comprises both borrowers and lenders in international financial markets.

Secondly, valuation effects are crucial channels in the adjustment of global imbalances. Valuation effects are defined as the wealth effects due to changes in exchange rates and asset prices of international assets and liabilities. Given the cross-country investment, differences in investment positions bring huge wealth transfer through interest rate differentials and asset price movements. Even balanced in the net position, a large gross position and different denomination of currency can lead to changes in the value due to volatile exchange rates. A group of studies have found the valuation effects as a complement to the traditional trade channel in international adjustment. Gourinchas and Rey (2007) conclude that current account deterioration predicts future surplus and excess return on net foreign asset position. Cavallo and Tille (2006) perceive that the US can finance a persistent deficit in trade with capital gains. Ghironi, Lee, and Rebucci (2009) apply a dynamic stochastic general equilibrium (DSGE) model to study this channel, but their work is limited in that differences in the amount of international investment are not captured by their model. They only consider the effects of currency denomination on wealth.

Both the examination of international transmission of shocks and the evaluation of the valuation effects require consideration of the IIP. However, in the earlier open economy research for China there is no comprehensive study with rich structure of international financial markets in a general equilibrium framework. Nor do earlier studies include asymmetric cross-country positions and non-zero net IIP.

6) What are the dynamics of China and other economies facing productivity shocks?

Studies of productivity shocks in specific countries using general equilibrium models have covered many major economies. Within this branch of literature, there is also research on the spillover effects of productivity improvements from specific countries to other economies, for example Smets and Wouters (2007) for the US, Jacquinot and Straub (2008) for the EA, Haberis et al. (2011) for the UK, Pytlarczyk (2005) for Germany, Plasmans, Michalak, and Fornero (2006) for the Netherlands, Breuss and Rabitsch (2009) for Austria. However, there are few studies of the dynamics of China, the US and the EA under productivity improvements. Also, in order to understand the influences of heterogeneity on these economies it is necessary to find international transmission and their responses to the shocks. Among the general equilibrium research of China, Mehrotra, Nuutilainen, and Pääkkönen (2011) simulate a closed economy model. Open economy studies such as Huang (2009) focus on evaluating the exchange rate pass-through. Liu (2008) and Jian (2011) investigate the monetary and fiscal policy of China, respectively. Our research aims to analyze the effects of China's productivity improvement on herself and other major economies. In addition, we simulate shocks from major foreign partners of China. The analysis will draw implications about international trade and investment under productivity improvements from different areas of the world.

1.3. Organization of the Thesis

The thesis is structured from analytical development to empirical applications. In Chapter 2, we present a review of the literature covering the development of the NOEM theory for the framework used throughout the thesis. The review justifies our choice of NOEM framework for analysis of China and other economies. The NOEM literature is developing from small-scale models to multi-country models with consideration of the heterogeneity of the countries. In using multi-country heterogeneous analysis, our thesis stands at the forefront of the NOEM studies.

In Chapter 3, we construct a NOEM model to serve as the workhorse model for the thesis. The model is established with multi-country framework and includes major sectors for cross-country analysis. It incorporates micro-foundations such as monopolistic competition and nominal rigidity. In addition, we examine the dynamics of international trade and investment between countries in complete financial markets and symmetric structural form. The dynamics of international trade under market completeness are drawn analytically and through simulation of the workhorse model in various shocks.

In Chapter 4, the model is solved to derive an estimated form, and we make inferences concerning the structural parameters and policy functions of the four economies using the Bayesian approach. We set symmetric priors for these economies and update the posteriors using data. Our estimation evaluates the cross-country heterogeneity and generates implications for the differences between these economies reflected by the different values of the parameters. Further, we consider the policy regime of China by using different versions of the model, incorporating either interest rate policy or quantity rule. Finally, different sets of priors are tried in the sensitivity tests to demonstrate the robustness of the model.

Chapter 5 presents extensions of the analytical framework and simulation of the model. The model is extended to incorporate incomplete financial markets and to draw implications for the degree of international risk sharing. Our approach enriches the family of mechanisms to induce stationarity for incomplete markets models. We express the relation between heterogeneous IIPs and international risk sharing. Then, the model is simulated to examine the impulse response functions (IRF) of the economies to productivity shocks. We investigate how shocks in each economy can affect the others through international trade and investment. In particular, we lay emphasis on the heterogeneous IIPs between these economies. The purpose of this chapter is to find the influences of external asset positions on the international transmission of shocks.

Chapter 6 summarizes the findings and contributions of the thesis and proposes potential areas for future research.

Chapter 2

Development of the New Open Economy Macroeconomics

2.1. Overview

The New Open Economy Macroeconomics refer to the framework designed for open economy modelling and policy analysis with the features including general equilibrium, nominal rigidities, imperfect competition, etc., to overcome the limitations of the Mundell-Fleming model (Corsetti 2008). The agenda of the development of NOEM models shares large similarities with the New Neoclassical Synthesis (NNS). Woodford (2009) views the NNS as the product of the convergence of views in macroeconomics. The general consensus of researchers for macroeconomic analysis is the requirement for intertemporal general equilibrium models with econometric validity. The models should also be equipped with endogenous expectations of participants in the economy, real disturbances as sources of economic fluctuations, and monetary policy serving a stabilizing role.

The current stage of the development is to construct models that are both theoretically and empirically consistent. The central debate is the choice between scientific rigor and validity in application. Goodfriend and King (1997) group the NNS models into three categories by scale: small analytical models, median-scale ones for researchers to address empirical issues, and large-scale ones for central bankers' analysis and policy decision. Since they follow similar development agenda as the NNS, the NOEM models can also been distributed into these three groups. Based on this categorization, we separate our review of the literature about the NOEM into two sections, i.e. the analytical and empirical developments, respectively. The analytical developments focus on two important types of theoretical models, the Redux model and the CP-OR models. These models are important milestones of the development of the analytical approaches of the NOEM. Then we review extensions to the basic models for a series of applications. The empirical branch progresses from open economy modelling for small and large economies to large-scale multinational heterogeneous models. This chapter is organized in the following structure. Sections 2.2 and 2.3 introduce the analytical and empirical developments, respectively. Section 2.4 summarizes our review.

2.2. Analytical Development

The core of the NNS originates from two schools of macroeconomic theories (Goodfriend and King 1997). The new classical theory and real business cycle (RBC) analysis contribute to the NNS with a framework of intertemporal optimization and rational expectations, as a response to the Lucas's critique (Lucas 1976). On the other hand, the NNS incorporates imperfect competition and nominal rigidities usually adopted by the New Keynesian (NK) economists. Similar to the NNS, the NOEM also incorporates these elements, reflecting the convergence of the views of macroeconomic researchers. The NOEM models are initially developed with relatively simple framework and mainly focus on the implications of these micro-foundations. Among these studies, Obstfeld and Rogoff (1995) is the seminal work and a series of works defined as the CP-OR models experiment distinctive elements for the framework, particularly different views about the rigidities and monetary policy.

2.2.1. The Redux Model

Obstfeld and Rogoff (1995) propose a two-country dynamic general equilibrium model, known as the Redux model. The model is the first of the Mundell-Fleming analysis equipped with micro-foundations, including nominal rigidities and monopolistic competition. From the perspective of the NNS, the Redux model starts a branch of study of the dynamic general equilibrium models with open economy features.

The Redux model includes a variety of participants in different markets, the interaction of which forms the basis of a general equilibrium framework. Individuals in this model are both households and producers at the same time. Each individual household produces a single type of differentiated goods $z \in [0,1]$. Home ($z \in [0,n]$) and foreign households ($z \in (n,1]$) have the same type of preference over different brands of goods. n is the population share of the home country in the world. Consumption C displays constant elasticity of substitution (CES) of different goods:

$$C = \left[\int_0^1 C(z)^{\frac{\eta_C - 1}{\eta_C}} dz\right]^{\frac{\eta_C}{\eta_C - 1}}, \ \eta_C > 1, \tag{2.1}$$

where $C(z)$ is the consumption over product z. η_C is the elasticity of substitution (EOS) of different goods. The government spending G has the same structure of preference as the households:

$$G = \left[\int_0^1 G(z)^{\frac{\eta_C - 1}{\eta_C}} dz\right]^{\frac{\eta_C}{\eta_C - 1}}, \tag{2.2}$$

where $G(z)$ is the government consumption of product z.

The model assumes no segmentation in the goods market. Without barriers and transaction costs of international trade, the law of one price (LOOP) holds for every product:

$$P(z) = \mathcal{E} P^*(z), \tag{2.3}$$

where $P(z)$ and $P^*(z)$ are prices denominated in home and foreign currencies, respectively. $\mathcal{E}$ is the exchange rate, which is defined as the number of home currency per foreign currency. (An asterisk denotes a foreign variable.) The consumer price index (CPI) of the home country P is given by:

$$P = \left[\int_0^1 P(z)^{1-\eta_C} dz \right]^{\frac{1}{1-\eta_C}}. \tag{2.4}$$

Because home and foreign households have the same preferences of consumption and the law of one price holds for each product, the purchasing power parity (PPP) is satisfied between the two countries:

$$P = \mathcal{E} P^*. \tag{2.5}$$

In addition to the goods market, the Redux model also assumes perfectly integrated international capital market. There is an internationally traded real bond B_t paying interest rate i_t. The world asset market clears, hence:

$$nB_t + (1-n)B_t^* = 0. \tag{2.6}$$

Households of the two countries also have identical preferences about consumption, money holding, and leisure. Each household maximizes lifetime utility, which is specified by:

$$U_t = \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[\ln C_\tau + \frac{\chi}{1-\sigma_M} \left(\frac{M_\tau}{P_\tau} \right)^{1-\sigma_M} - \frac{\kappa}{2} Y_\tau(z)^2 \right], \ 0 < \beta < 1, \ \sigma_M > 0, \tag{2.7}$$

where M_τ is the money stock and $Y_\tau(z)$ is the output of the individual producer. β is the discount rate, which expresses the individual's intertemporal preference. σ_M is the intertemporal elasticity of substitution of money. χ is the share of money utility in the utility function. Obstfeld and Rogoff (2000) interpret κ as (negative) productivity shocks. This equation means that utilities from consumption, money and leisure are separately considered before summing together. The maximization problem is subject to the individual's budget constraint:

$$P_t B_t + M_t = P_t B_{t-1}(1 + i_{t-1}) + M_{t-1} + P_t(z) Y_t(z) - P_t C_t - P_t T_t. \quad (2.8)$$

T_t is the tax paid by the individual or the transfer received from the government. The government always has a balanced budget:

$$G_t = T_t + \frac{M_t - M_{t-1}}{P_t}. \quad (2.9)$$

Solving the dynamic programming problem with respect to C_t, B_t, M_t, and $Y_t(z)$ leads to the first-order conditions:

$$C_{t+1} = \beta(1 + r_t) C_t, \quad (2.10)$$

$$\frac{M_t}{P_t} = \left[\chi C_t \left(\frac{1 + i_t}{i_t} \right) \right]^{\frac{1}{\sigma_M}}, \quad (2.11)$$

$$Y_t(z)^{\frac{\eta_C - 1}{\eta_C}} = \left(\frac{\eta_C - 1}{\eta_C \kappa} \right) C_t^{-1} (C_t^W + G_t^W)^{\frac{1}{\eta_C}}. \quad (2.12)$$

C_t^W and G_t^W are the world consumption and government spending, respectively. Equation (2.10) is the consumption Euler equation. Equation (2.11) is the condition of optimal real balance, which implies that money demand correlates positively with consumption and relates negatively to the interest rate. Equation (2.12) is the optimal output of the representative individual.

The authors are the first to incorporate monopolistic competition and nominal rigidity into a general equilibrium framework for open economy analysis. The firms in the model produce differentiated goods and make decisions about their supply while they perceive that their market powers are small. However, this micro structural setting does not have strong implication for the issues addressed by the Redux model. The paper focuses on the terms of trade and the dynamics of the exchange rate and there is no explicit solution about the optimal price set by the producers. Later models following the Redux often separate firms from households and describe explicitly the maximizing profits decision of the firms. Nominal rigidity is adopted through the assumption that prices cannot be changed in the short run. This type of setting is often used by analytical works such as the CP-OR models. Models for empirical purposes usually use different mechanisms to allow a certain degree of flexibility in price setting for firms to change prices.

Finally, the two countries are assumed to start from the initial steady state and move towards the new long-run state. At its initial level, the position of the net foreign assets is assumed to be zero and the government spending of the two countries equals.

Then the log-linearized equations around the initial state describe the short-run deviations. The comparison between the short-run equilibrium and the new long-term steady state implies the dynamics of the system.

The Redux model does not have rich findings about the rational expectation of individuals. The model simulates unexpected monetary policy shocks and draws responses of the agents facing these permanent shocks. The model does not reflect the expectation of the households about the monetary policy. The model uses log-deviation $(d\ln)$ around the initial state to reformulate the short-run $\hat{X}$ and long-run dynamics $\bar{X}$. Equation (2.10) immediately tells that consumption jumps to the long-term level immediately:

$$\widehat{C} - \widehat{C}^{*} = \overline{C} - \overline{C}^{*}. \tag{2.13}$$

Combining the money demand of the home country, equation (2.11), with its foreign counterpart, we can express the exchange rate as a function of consumption and money supply:

$$\widehat{\mathcal{E}} = (\widehat{M} - \widehat{M}^{*}) - \frac{1}{\sigma_M}(\widehat{C} - \widehat{C}^{*}). \tag{2.14}$$

This equation implies that given a permanent monetary shock, the exchange rate also shifts to its new steady sate level immediately, since consumption and money demand are both determined.

In addition to equation (2.14), short-run equilibrium determines that the exchange rate is a function of the relative consumption of the two countries:

$$\widehat{\mathcal{E}} = \frac{\bar{i}(1+\eta_C) + 2\eta_C}{\bar{i}(\eta_C^2 - 1)}(\widehat{C} - \widehat{C}^*). \tag{2.15}$$

Equation (2.15) is arrived at using the relative output of the two countries. So it expresses the new equilibrium decided by the supply side of the economies. Equation (2.14) exhibits how monetary policy affects consumption and the exchange rate from the demand side. We can find that equations (2.14) and (2.15) determine the new level of the exchange rate. Obstfeld and Rogoff (1995) concluded a new equilibrium with a depreciation of the exchange rate and higher relative consumption of the home country in their experiment.

The Redux model assumes incomplete financial markets, which opens international trade between the two countries. This assumption is also utilized by many works for open economy analysis. The changes of the level of bond holdings tell the current account of a country:

$$\frac{\widehat{B}}{\overline{C}_0^W} = \widehat{y} - \widehat{C} - (1-n)\widehat{\mathcal{E}} - \frac{\widehat{G}}{\overline{C}_0^W}. \tag{2.16}$$

$\overline{C}_0^W$ is the world aggregate consumption level at the initial state. The per capita current account of the foreign country is expressed as:

$$\frac{\widehat{B}^*}{\overline{C}_0^W} = \widehat{Y}^* - \widehat{C}^* + n\widehat{\mathcal{E}} - \frac{\widehat{G}}{\overline{C}_0^W} = -\left(\frac{n}{1-n}\right)\frac{\widehat{B}}{\overline{C}_0^W}. \tag{2.17}$$

As a benefit of the general equilibrium framework, the researchers can use welfare measurement to evaluate the international spillovers of shocks and policies. The Redux model implies that a positive monetary shock not only increases world aggregate production, but also leads to a shift of the home household income relative to the foreign household. Home depreciation makes products relatively cheaper than foreign goods, and foreign consumers increase the share of home products in their consumption basket. The share of home household income in world income increases, because the elasticity between home and foreign goods is greater than one ($\eta_C > 1$). This income shift leads to the short-run surplus of the home country's current account. In fact, assuming that there is no change to the government spending, combining equation (2.16) and (2.17) can derive the current account change:

$$\frac{\widehat{B}}{\overline{C}_0^W} = (1-n)\left[(\widehat{Y} - \widehat{Y}^*) - (\widehat{C} - \widehat{C}^*) - \widehat{\mathcal{E}}\right], \tag{2.18}$$

where the relative output is determined by:

$$\widehat{Y} - \widehat{Y}^* = \eta_C \widehat{\mathcal{E}}\,. \tag{2.19}$$

The effects of monetary shocks on the relative output are greater than on the consumption and the exchange rate, leading to the surplus. It is also worth noting that the short-run current account surplus also depends on the relative population of the two countries. In terms of welfare, the domestic monetary expansion increases home and foreign welfare by the same amount. The welfare gain comes from the reduction of the monopolistic power by the increased demand driven by monetary expansion, though the distortion of imperfection is not explicitly shown by the Redux model.

The Redux model can materialize the dynamics of the current account, because the model contains two important assumptions. The first is that the elasticity of substitution between home and foreign goods is not unity. The second is the incomplete financial markets assumption which allows welfare transfer between the two countries. In the studies following the Redux, there are thorough discussions about the fact that either a unitary elasticity or complete financial markets will shut down the current account as a channel between countries. Hence these two assumptions are the key to the current account modelling in the NOEM.

2.2.2. The CP-OR Models

In the NOEM literature, a critical improvement to the original framework comes from the CP-OR models, known after a series of works including Obstfeld and Rogoff (2000), Corsetti and Pesenti (2001; 2005a; 2005b), etc. The CP-OR models can be solved explicitly without log-linearization. They also incorporate labour market and pricing theory in international trade. In this section, we focus on the model developed by Corsetti and Pesenti (2005a), since this model provides structural settings that are applied by many following studies. Also, we will explore how the authors are able to capture the expectation of individuals about monetary policy.

The CP-OR models separate the households and the producers in the economy. Slightly different from the Redux model, Corsetti and Pesenti (2005a) assume the utility function $U_t(j)$ of the household j to be:

$$U_t(j) = \ln C_t(j) - \kappa L_t(j) + \chi \ln \frac{M_t(j)}{P_t}, \tag{2.20}$$

where $L_t(j)$ is the working effort of labour supply by household j. The consumption bundle $C_t(j)$ is the Armington aggregation of home and foreign goods:

$$C_t(j) = C_{H,t}(j)^{\frac{1}{2}} C_{F,t}(j)^{\frac{1}{2}}. \tag{2.21}$$

Equation (2.21) assumes the elasticity of substitution between home and foreign goods to be one. Home and foreign baskets are similar as in the Redux model:

$$C_{H,t}(j) = \left(\int_0^1 C_t(h,j)^{\frac{\eta_C - 1}{\eta_C}} dh \right)^{\frac{\eta_C}{\eta_C - 1}}, \; C_{F,t}(j) = \left(\int_0^1 C_t(f,j)^{\frac{\eta_C - 1}{\eta_C}} df \right)^{\frac{\eta_C}{\eta_C - 1}}. \tag{2.22}$$

$C_t(h,j)$ is the consumption of home goods h by household j, and $C_t(f,j)$ is the consumption of foreign goods f. Under these settings, consumption has constant elasticity of substitution intertemporally, intratemporally, and between home and foreign goods.

The model assumes a Cobb-Douglas form in the aggregation. This implies unit elasticity of substitution between home and foreign goods, while in the Redux model the value of the elasticity is assumed to be greater than one. Unit elasticity leads to equal share of home and foreign goods in the consumption basket of the households:

$$P_{H,t}C_{H,t}(j) = P_{F,t}C_{F,t}(j) = \frac{1}{2}P_tC_t(j). \tag{2.23}$$

This condition exhibits that the amount of nominal income between the two countries is distributed equally. Equal income share always holds and shuts down the current account as a channel of welfare transfer, since there is no difference between home and foreign income. Households do not rely on international financial market to save or borrow even if the financial market is incomplete.

The CP-OR also improves the Redux model by a more explicit framework to reveal the implications of monopolistic competition. Firms set prices according to their own benefits and ignore their effects on the market. In addition, the CP-OR models serve well for evaluation of currency choice of the firms in the pricing. Different pricing choices can also have effects on optimal policies. For example, the model may generate different optimal monetary policies in response to the shocks under producer currency pricing (PCP) or local currency pricing (LCP). The nominal rigidity is similar as that assumed by the Redux. Prices are fixed in the short run and wages are fully flexible. The production function is linear in labour supply:

$$Y_t(h) = A_t L_t(h), \tag{2.24}$$

where A_t is the productivity. Under nominal rigidity, firms preset prices to maximize expected profits. The optimal domestic price of home goods is:

$$P_t(h) = \frac{\eta_C}{\eta_C - 1} E_{t-1}\{MC_t\} = \frac{\eta_C \kappa}{\eta_C - 1} \frac{\mu_t}{A_t}. \tag{2.25}$$

The monetary stance μ_t is equal to $P_t C_t$. From equation (2.25), it can also be found that κ is a negative productivity process similar to the one in the Redux. The first implication of the model is that monopolistic competition leads to a distortion to the production. Prices are a mark-up over marginal costs so that the production level is below the natural level if the market is fully competitive.

In addition, the optimal foreign price of home goods depends on the pricing currency of the firm. If exports are invoiced in domestic currency (PCP), which is the same as the Redux, the optimal price is :

$$P_t^*(h) = \frac{1}{\mathcal{E}_t} \frac{\eta_C}{\eta_C - 1} E_{t-1}\{MC_t\} = \frac{1}{\mathcal{E}_t} \frac{\eta_C \kappa}{\eta_C - 1} E_{t-1}\left\{\frac{\mu_t}{A_t}\right\}. \tag{2.26}$$

In this case, the export price in terms of home currency $E_t P_t^*(h)$ is unchanged and foreign households bear the full effects of exchange rate volatility. In other words, foreign households face full exchange rate pass-through of imports.

On the other hand, in the case of LCP, exports are invoiced in the foreign currency. The optimal price becomes:

$$P_t^*(h) = \frac{\eta_C}{\eta_C - 1} E_{t-1}\left(\frac{MC_t}{\mathcal{E}_t}\right) = \frac{\eta_C \kappa}{\eta_C - 1} E_{t-1}\left(\frac{1}{\mathcal{E}_t}\frac{\mu_t}{A_t}\right). \qquad (2.27)$$

Equation (2.27) implies zero exchange rate pass-through. Besides these two scenarios where pricing choices are symmetric for the firms in the two countries, the model can also consider a world where the prices are all in one international currency, or dollar pricing (DP). This case is more realistic when modelling trade between the US and many emerging markets.

Based on the CP-OR models, Corsetti and Pesenti (2005b) extend the analysis of monetary policy. Obstfeld and Rogoff (2000) and Corsetti and Pesenti (2001, 2005a) introduce monetary policy by considering it as an unexpected shock. However, the rational expectation perspective requires taking into account the expectation of the participants of the economy about monetary policy and also their reaction to it. First, Corsetti and Pesenti (2005b) examine the optimal monetary policy for a closed economy. The paper proves that the optimal monetary policy eliminates the negative effects of the distortion of fixed prices in the rational expectation equilibrium. If the central bank stabilizes the economy by targeting the interest rate, the optimal policy follows the ‘Taylor principle’. Moving on to the open economy discussion, they find that whether monetary authority should cooperate with the foreign depends on the currency pricing of the economies. Under both PCP and LCP, the inward looking monetary policy already achieves efficiency in the world. However, in a dollar pricing world, the issuance country of the world currency should respond to the world shocks, while the other countries only need to stabilize shocks from their own economies.

However, the CP-OR models are not suitable for modelling the current account, unless some assumptions are released. In order to derive at analytical solutions, the CP-OR models assume zero initial asset position. As a result, the current account is always balanced because the equal share in international income distribution between the two countries. The assumption that leads to such an effect is the unit elasticity of substitution between home and foreign goods.

2.2.3. Extensions

A branch of studies follow the Redux model and the CP-OR models to analyze the implications of various extensions to the NOEM framework. Lane (2001), Bowman and Doyle (2003), and Corsetti (2008) provide extensive reviews of these extensions. In this section, we focus on the extensions that can influence the open economy features of NOEM models.

Some studies extend the models by more a complicated structure of preference of households. It has been proved that unit elasticity between home and foreign goods shuts down the trade channel. Additionally, the elasticity of substitution can also determine the spill-over effects of monetary shocks. Tille (2001) compares two different elasticities at different levels of aggregation, i.e. the elasticity between domestic and foreign goods η and the one between different brands of goods η_C. He finds that when these two elasticities equal, monetary expansion of any part in the world improves the welfare of all equally. This is the same case discussed in the Redux model. The CP-OR models all assume $\eta = 1$ and $\eta_C > \eta$. Home monetary expansion improves home welfare more than foreign welfare. When $\eta_C \gg \eta$, a positive monetary shock can even have the 'beggar-thy-neighbour' effects. The spill-over effects are adverse when $\eta_C < \eta$. In the extreme case when $\eta_C \ll \eta$, the expansionary policy is 'beggar-thyself'. Moreover, there are further ways to introduce the distinctive preference between domestic and foreign goods. For example, Warnock (1998) introduces home bias by assuming that home products receive greater weight in the consumption basket. Hau (2000) and Obstfeld and Rogoff (2000) arrive at similar effects by introducing non-tradables in the consumption.

Currency choice affects the optimal price setting by the firms in the CP-OR models. For example, Corsetti and Pesenti (2005a) assumes either full or zero exchange rate pass-through. However, evidence from empirical studies agrees that pass-through is less than unitary and zero pass-through is often not the case. Under zero pass-through, the nominal and real exchange rates are perfectly correlated in the short run. Evidence from the US also indicates that there the pass-through to domestic prices is very low. On the other hand, Obstfeld and Rogoff (2000) point out that the contradiction of assuming zero pass-through in the NOEM models is that it leads to terms of trade improvement when the exchange rate depreciates.

Other than the two extreme cases of either zero or full exchange rate pass-through, some authors experiment with the degrees of pass-through in between these two extremes and the effects thereof. Betts and Devereux (2000a; 2000b) introduce the fraction s of foreign firms that set prices in domestic currency in the price index:

$$P = \left[\int_0^n P(z)^{1-\eta_C} dz + \int_n^{n+(1-n)s} P^*(z)^{1-\eta} dz + \int_{n+(1-n)s}^1 \mathcal{E} P^*(z)^{1-\eta_C} dz\right]^{\frac{1}{1-\eta_C}} . \quad (2.28)$$

There can be more direct means. Corsetti and Pesenti (2005) introduce the degree of the pass-through in the price index by a parameter that controls the magnitude of the effects of exchange rate volatility on the price index:

$$P = \left[\int_0^n P(z)^{1-\eta_C} dz + \int_n^1 (\mathcal{E}^{1-s} P^*(z))^{1-\eta_C} dz\right]^{\frac{1}{1-\eta_C}} . \quad (2.29)$$

In this case, $s = 1$ corresponds to the full pass-through (PCP), and $s = 0$ corresponds to the zero pass-through and the LCP. Some other works even consider endogenous currency pricing choice, such as in Devereux and Engel (2001), Bachetta and van Wincoop (2000) and Corsetti and Pesenti (2002). The choice of pricing currency of the firms has bearings for the degree of international risk sharing, the dynamics of the exchange rate, and the market share of the product of a country.

Other studies aim to enrich the structure of the goods market. Some authors consider that goods market with only tradables cannot simulate the real world. Goldberg and Knetter (1997) add the whole-sale import prices and exchange rate volatility affects whole-sale prices rather than the final goods directly. Non-tradable goods can also been added to the composition of consumption. For example, Corsetti and Dedola (2005) require the use of non-tradable goods in the distribution of traded goods. Some works distinguish final goods and intermediate goods sectors. In Obstfeld (2001), the production of final goods needs to combine home and foreign intermediates. Even with PCP, the exchange rate pass-through is low since the effects of exchange rate movements on the intermediate goods only partially impact the final goods prices.

The asset market is another element in the model that can have many distinctive structures. Obstfeld and Rogoff (1995) assume an incomplete world financial market and an internationally traded risk-free bond. Monetary shocks have spill-over effects through the current account and lead to welfare shifts between two countries. Devereux and Engel (2003) introduce complete financial markets. They find that households trade assets in the domestic market to smooth consumption in a rational expectations framework. In the face of shocks, consumption is smoothed and there is no need to borrow or lend in international financial market, thanks to the domestic bonds that are contingent to all possibilities. The market completeness has the same effects as the unit elasticity of substitution between home and foreign goods. For open economy modelling with current account consideration in the NOEM, the assumption of complete financial markets shall be released.

Before we end this section and review the studies of testable models in the NOEM, we list a few techniques to close the open economy models. Schmitt-Grohe and Uribe (2003) explore how to close small open economy (SOE) models with different financial market settings. Under incomplete market assumption, three alternatives are available, including using endogenous discount factor, debt-elastic interest-rate premium, and convex portfolio adjustment cost. Any one of these instruments can induce stationarity for small scale models. However, they may not work for large open economy models (Bodenstein 2011), since these models may also suffer from multiple steady states.

2.3. Empirical Analysis with NOEM Models

The most important empirical models of the NNS include closed economy models for the US (Christiano, Eichenbaum, and Evans 2005; Smets and Wouters 2007) and those for the Euro Area (Smets and Wouters 2003). Similarly, the NOEM literature starts to focus on the development of empirical models on the basis of a thorough discussion on the analytical elements. Although the techniques provided by Schmitt-Grohe and Uribe (2003) and Bodenstein (2011) may bring different dynamics, they allow the open economy models to overcome the problems of non-stationarity and multiple steady states, so that the models become testable and can proceed with calibration and estimation. Following the categorization of Goodfriend and King (1997) for the NNS models, we also group the NOEM empirical models into medium-scale models and large-scale multi-country or heterogeneous models. In this section, we separately discuss these models in the three sub-sections below.

2.3.1. Medium-Scale Models

Two streams of research converge to the empirical modelling based on the NOEM framework. They either start from the analytical NOEM models aiming to make the models testable, or incorporate open economy features into empirical models based on the NNS. Early attempts at developing the NOEM empirical analysis have problems with some structural settings, e.g. one period ahead price setting by firms. Gali and Monacelli (2005) offer the seminal work in the empirical NOEM because they incorporate major elements of the NOEM into a testable framework. Among these elements, the nominal rigidity which is realized by their work using Calvo type price setting is the most important one in the model. They assume that a fraction θ of the firms must sell products with their previously set prices and the rest of the companies can change prices in the current period. They derive the new optimal price by these flexible companies as:

$$\tilde{P}_{H,t} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k \mathrm{E}_t\{MC_{t+k} + P_{H,t}\}. \tag{2.30}$$

Equation (2.30) expresses that the optimal price $\tilde{P}_{H,t}$ considers the expectation of future marginal cost MC_{t+k}. They derive the current aggregate price level as:

$$\widehat{P}_{H,t} = \beta \mathrm{E}_t\{\widehat{P}_{H,t+1}\} + \lambda \widehat{MC}_t. \tag{2.31}$$

Both equations (2.30) and (2.31) have forward looking variables on the right hand side. This reveals that under rational expectations, the decision of the firms is affected by future changes in the economy including expected monetary policy responses. Moreover, they also generate the Phillips curve since the NOEM models should inherit the features of the New Keynesian analysis:

$$\widehat{P}_{H,t} = \beta \mathrm{E}_t\{\widehat{P}_{H,t+1}\} + \kappa_\alpha x_t. \tag{2.32}$$

Inflation is expressed as a function of future inflation and the output gap x_t. This is consistent with the fact that the NOEM can be understood as the open economy analysis based on the NNS approach.

While Gali and Monacelli (2005) obtain their empirical results by calibration, a group of researchers start using the Bayesian approach to estimate the NOEM models. Lubik and Schorfheide (2006) estimate their model for the US and the EA, which is different from Gali and Monacelli (2005) in that their model is based on large open economy framework. Adolfson et al. (2007) also estimate their model for the Euro Area. Although their theoretical framework is developed by making the DSGE model 'open', their model finally falls within the scope of the NOEM and is similar to Gali and Monacelli (2005) from the perspective of small open economy modelling. Both these studies appraise the Bayesian approach with general fitness and ease of interpretation.

Also, the research field sees increasing works focusing on two-country modelling. The testable Gali and Monacelli (2005) model is designed for a small open economy, which describes the home individuals' behaviour facing the rest of the world and presumably ignores the market power of the home economy. The model of Adolfson et al. (2007) is similar in this regard, but is designed to estimate the Euro Area.

Examples of the two-country NOEM models include International Monetary Fund's (IMF) Global Economy Model (GEM) (Laxton and Pesenti 2003; Bayoumi, Laxton, and Pesenti 2004). The most notable feature of GEM is that it separates the production into final goods and intermediate goods sectors. The final goods producers are monopolistic competitive and the intermediate goods production sector is perfectly competitive. In terms of other distortions to the economies, they impose various adjustment costs on changes of imports, wage, consumption, investment, bond holdings, etc. The model in Laxton and Pesenti (2003) is designed for an emerging market facing the rest of the world and is applied to evaluate the effectiveness of different monetary policy rules. Bayoumi, Laxton, and Pesenti (2004) focus on the euro economy facing the world. They calibrate positive effects of increasing competition in the Euro Area on both itself and the rest of the world.

The standard NOEM models simplify the structure of fiscal policy. Government spending is expressed as a share of production and fiscal policy is thus related to the evolvement of that share. Erceg, Guerrieri and Gust (2006) develop a model named 'SIGMA' which provides a structure that is more suitable for fiscal policy analysis. Their model breaks the Ricardian equivalence by assuming that a fraction of the households cannot access financial markets to smooth their intertemporal choice of consumption. The Ricardian and non-Ricardian households have different decisions with regard to transfer from or tax paid to the government. Their calibration shows compatible dynamics of their models with conventional econometric models for policy analysis. Non-Ricardian feature is then the mechanism to capture fiscal multiplier in the NOEM or the NNS (Pesenti 2008).

Ferrero, Gertler, and Svensson (2008) are different from other researchers in that the authors start from the perspective of Obstfeld and Rogoff (2005) and develop a simple DSGE model incorporating production and nominal price rigidities with a critical extension that endogenizes the dynamic adjustment path. This work overcomes the problem that Obstfeld and Rogoff (2007) base their study in a static framework.

The above studies use the NOEM framework for the study of a specific country facing the rest of the world. The two-country framework is also able to analyze a country with regard to the monetary union which the country stays within. Pierdzioch (2004) investigates how financial market integration affects the two countries under analysis. Similar studies also apply the framework to specific country analysis within the Euro Area. Pytlarczyk (2005) developes a two-country DSGE for Germany and European Monetary Union (EMU), and Breuss and Rabitsch (2009) have a similar model for Austria and EMU.

A few researchers are cautious about the power of the NOEM models in empirical analysis. Bergin (2006) empirically tests a NOEM model using G7 data and finds that the model performs reasonably well for capturing dynamics of the exchange rate and the current account. However, Chari, Kehoe, and McGrattan (2002) find distinct conclusions about the explanatory power of the NOEM models about the volatility of exchange rates. Further, Chari, Kehoe, and McGrattan (2009) point out the possibility of wrong implication for policy analysis from reduced form shocks and emphasize the micro foundation for structural modelling.

2.3.2. Multi-Country Frameworks

Before the development of multi-country model in the NOEM and the NNS, similar intuition to model international economics is already applied by other research. Obstfeld and Rogoff (2007) explain the current account imbalances from the perspective of the US, the Europe and Asian countries. Although their analysis does not reflect intertemporal choice, they already contain a few micro foundations used by DSGE, such as Dixit-Stigliz index for prices. Dees et al. (2007) develop a Global VAR (GVAR) model, in which they consider the Euro Area and the other 25 countries. This model has different settings with the DSGE, but their purpose is similar to DSGE quantitative analysis, which is to generate impulse responses to structural shocks from within or outside the economies. In the later work Dees et al. (2010), they base their analysis from a New Keynesian structure for 33 countries. International Monetary Fund introduce a series of works based on the multi-country Global Projection Model (GPM) (Carabenciov et al. 2008a, 2008b). These models are combinations of small quarterly projection models and do not use the theoretical underpinnings in the DSGE models.

The model in this thesis is partly intuited by three-country modelling in the literature. Breuss and Fonero (2009) model the Austria economy, and they distinguish the impact of the Euro Area and the rest of the world (especially the US) on the home economy. The three-country model contains a home economy, a monetary union that the home country is within, and the rest of the world. The model can be used to analyze the effects of a common monetary policy from the union and of shocks from the rest of the world. Their work is an extension of the two-country German economy model by Pytlarzcyk (2005) and it examines the interactions between the home country, the monetary union and the rest of the world. Also, the model of Breuss and Fornero (2009) is an extension to the earlier three-country model of Plasmans, Michalak, and Fornero (2006), in which the framework for a small open economy, a monetary union and the rest of the world is already well established. However, this work is not designed for a specific country and uses a simplified setting for the investment sector as the NOEM. Our model follows the three-country idea and sets the system for China, the US, the EA, and the ROW. Markovic and Povoledo (2011) use a three-country model to simulate the spillover effects of shocks to the America's demand and preference on the Europe and the ROW. Haberis et al. (2011) apply a similar model to find out how the deficits of the US and the UK adjust with respect to the surplus of the ROW.

Moreover, the models developed by the policy makers that we list above also have their multi-country versions. Faruqee et al. (2007) use IMF GEM to explore the possibility of a gradual depreciation of the US dollar. In their paper, they emphasize the different roles of Europe and Japan in the process and separate them from the emerging Asia and the ROW. Jacquinot and Straub (2008) start from European Central Bank's (ECB) New Area Wide Model (NAWM) and calibrate the effects of globalization of the emerging Asia on the US, the EA and the ROW. Straub and Thimann (2010) further apply the model to the study of China's exchange rate reform and its implications.

A multi-country framework is a convenient base allowing heterogeneous structures of the countries. The third country in the framework is not a duplicate of the two countries and this setting is as important as large open economy assumption, given that none of the parties in the system can be presumed as exogenous. Chudik (2007) argues that an economy as 'small' cannot automatically justify the exogeneity of foreign economies, nor can it justify the ad hoc aggregation of foreign variables. The appropriate selection of countries to be grouped when evaluate the foreign sectors should be carefully justified. Due to the apparently heterogeneity between China, the US, and the EA, we argue that it is necessary to distinguish the US from the foreign country group and thereby a three-country framework is necessary. Also, in this model we no longer assume that any of the economy is exogenous to the other, and so all countries in the system are large open economies.

2.3.3. Cross-Country Heterogeneity

One recent trend in the development of multi-country analysis is to include the economies in question in one framework while preserving the heterogeneous features of each that may affect the findings of the research. De Grauwe and Piskorski (2001) compare the losses of two alternative ways to generate stabilizing monetary policy for the Euro Area. The first way is to express policy goals in terms of national data of member countries and the alternative is to use the Euro Area wide aggregate data. Although they generally conclude that policies based on these two options yield close stabilization effects, countries that are more responsive to the policy instrument tend to be better off under the national rule than the aggregate rule. They attribute the asymmetry between countries to two possible sources, the transmission mechanism of monetary policy and the stochastic disturbances. However, their loss function is not measured by welfare. The NOEM models are welfare based and attract the attention of many studies.

Corsetti (2006) evaluates the cost of substituting the country-specific optimal monetary policies with a single monetary policy in a union. The study lists the sources of heterogeneity including sector composition of output, the degree of nominal rigidities, financial structure and labour market institutions, and the degree of liberalization and deregulation. This work finds lower output than the efficient level for adopting single monetary policy, but the growth rates are not affected. The model used is the CP-OR model (Corsetti and Pesenti 2005b) which is a seminal analytical milestone of the NOEM theory, as introduced in Section 2.2.2.

There are also empirical evaluations of the costs of ignoring the heterogeneity in setting optimal policy. Kolasa (2008) estimate the possible welfare cost to the Polish economy in the process of joining the Euro Area. The study uses Bayesian estimation to identify major sources of heterogeneity between Poland and the union. The findings support entering the monetary union due to the fact that there is no strong evidence of large differences between the structural parameters of Poland and the Euro Area and the structural shocks of the two economies are weakly correlated. There are also a few more works to study the interaction between economies within Euro Area and the rest countries, e.g. Breuss and Fornero (2009) for Austria and Plasmans, Michalak, and Fornero (2006) for the Netherlands.

Jondeau and Sahuc (2008) compare the heterogeneous multi-country model with ECB's preceding Area Wide Model (AWM) and find significant differences in structural parameters and correlation of shocks. They also estimate the models using the Bayesian approach to find discrepancies of structural parameters, for Germany, France and Italy. They record significant welfare losses and attribute them to the inaccuracy of using homogeneous model in forecasting. Thus, using a model with aggregation bias for policy analysis can lead to large welfare costs.

There is a group of rich structural settings and parameters that can distinguish the economies in a model. The list includes, but is not limited to, habit persistence, non-Ricardian households, consumption transaction cost, consumption basket and production inputs shares, elasticities of substitutions, import share adjustment cost, price stickiness, bond transaction cost or interest rate premium, monetary policy, exchange rate regime, correlation of shocks, and even time preference. Pesenti (2008) offers modelling details for many of the variations above. Chudik (2007) criticizes the convention to group countries used by many studies. The appropriate selection of countries to be grouped when evaluate the foreign sectors should be carefully justified.

2.4. Summary

In this chapter, we review the development of the NOEM models and explore the forefront in this field. The NOEM approach is born with theoretical two-country model sharing similar features as the NNS but focusing on the international transmissions and policies. Early works such as the Redux model and the CP-OR models explore the implications of a wide range of structural settings for the dynamics of the variables. These structural features include monopolistic competition that distorts the economies from the efficient production level, nominal rigidities, and rational expectations of participants. Also, the distinctive trade and welfare behaviours of the economies depend on the value a few structural parameters, such as the elasticity of substitution and the degree of exchange rate pass-through.

We summarize the techniques to close the theoretical models and make it feasible to write them in the testable form. The 'modern' empirical models of the NOEM incorporate all the important elements we have listed above and are able to inference their features by simulation and estimation. At the current stage, the modelling develops to the multi-national heterogeneous framework for the empirical testing of the specific country or economy. Our thesis utilizes the theoretical underpinning and modelling techniques of the NOEM to study a comprehensive model for China and major economies in the world.

Chapter 3

The Workhorse Model

3.1. Introduction

In this chapter, we develop a multi-country NOEM workhorse model for the thesis and analyze financial market completeness based on this model. Models in the thesis are all extensions of the workhorse by adding elements relevant to the specific questions. This workhorse model provides a basic model with a NOEM framework for the following work. The solution to the model is expressed as equations representing the optimal decisions and other conditions. These structural equations will be taken as given in the following chapters to avoid replication. Also, we demonstrate the role of financial market completeness in international transmission of shocks. We aim to understand the mechanism of exchange rate adjustment to balance international trade under perfect international risk sharing. More important, the case with market completeness provides a benchmark scenario where trade balance is achieved in both short and long run. Then we can compare the model with future discussion based on financial market incompleteness.

Our model follows the spirit of classic CP-OR models, which are defined by Corsetti (2008) as a group of models used in a series of seminal work in the NOEM and DSGE literature, including Obstfeld and Rogoff (2000), Corsetti and Pesenti (2001, 2005a, 2005b), etc. Similar to these studies, our model is equipped with rich microstructures such as monopolistically competitive firms and price and wage rigidities. On the other hand, the workhorse model is different from the CP-OR models in a few features due to different aims and perspectives of our analysis.

To provide the basis for the following chapters, the workhorse model has all major sectors and channels with which we can capture structural features and policies. The workhorse model introduces a group of structural features to incorporate distortions to the economies. The CP-OR models assume fully fixed prices and wages in the short run to ease their analysis. Differently, we use the Calvo-type setting for price rigidity, which is also applied by Smets and Wouters (2003), Gali and Monacelli (2005), etc. Households have habit of consumption, and face consumption transaction cost, which is a function of the consumption to money ratio. Changes in the consumption level are staggered, and moreover, monetary supply can bring about real effects through the changing consumption money velocity. This eases the comparison of different regimes of monetary policy, such as the interest rate rule versus the quantity rule.

The workhorse model has the similar assumption of complete financial markets to the CP-OR models. However, we prove that financial market completeness is a sufficient condition for short-term and long-term balance in trade. Our proof is different from Corsetti and Pesenti (2005b) in terms that we have weaker assumptions about utility and trade elasticity. We simulate the workhorse model and analyze the dynamics of the current account to derive at short-term and long-term equilibrium. In both short and long run, a complete financial market facilitates the perfect risk sharing between two countries. The exchange rate links the optimal paths of home and foreign paths, so that under perfect international risk sharing, there is no international borrow or lending. Change in the exchange rate controls the relative price of goods produced by each country, and thus the demand. Under perfect risk sharing, the change in the world output is distributed proportionally to each country and thereby there is no trade deficit or surplus. From this perspective, we conclude that the trade imbalances are equilibrium results of imperfect correlation of consumptions between two countries due to incomplete financial markets.

3.2. The Model

The world consists of N countries, indicated by $j \in J = \{1, 2, ..., N\}$. In each country, there are sectors of final goods, intermediate goods, households and governments. Each country is an open economy, in which households import from and export tradable goods to foreign counterparts.

3.2.1. Household and Preference

First, we provide a set of assumptions about bond holding, consumption, money demand and wage setting in the optimization problem of the households. Then we derive at the optimal choice of the households. The aggregate utility $V_0^j(i)$ for household i in country j is defined as the sum of discounted utility of each period:

$$V_0^j(i) = E_0\left\{\sum_{t=0}^{\infty}\left(\beta^t U_t^j(i)\right)\right\}, \text{ for } i \in [0, n^j], \tag{3.1}$$

where $0 < \beta < 1$ is the intertemporal discount rate for utility, and n^j is the population of the country. $U_t^j(i)$ is the utility of the household at time t. The utility function is a variation of that developed by Greenwood, Hercowitz and Huffman (1988). The utility is consisted of three components, units of final goods in consumption $C_t^j(i)$, holding of money $M_t^j(i)$, and working effort $L_t^j(i)$:

$$U_t^j(i) = \frac{1}{1-\sigma_C^j}\left(\frac{C_t^j(i) - \overline{A}^j H_t^j}{A_t^j}\right)^{1-\sigma_C^j} + \frac{1}{1-\sigma_M^j}\left(\frac{M_t^j(i)}{P_t^j}\right)^{1-\sigma_M^j} - \frac{\zeta_L^j\left(L_t^j(i)\right)^{1+\sigma_L^j}}{1+\sigma_L^j}, \tag{3.2}$$

where P_t^j is the consumer price index. $\sigma_C^j > 0$ is the risk aversion coefficient. When $\sigma_C^j = 1$, the utility of consumption reduces to the log-form. $\sigma_M^j > 0$ and $\sigma_L^j > 0$ are the elasticities of substitution of money and working, respectively. $\zeta_{L,t}^j$ is the weight of disutility of work in the utility function and it determines the preference between consumption and labour. H_t^j is a term with which households compare the current consumption with previous level. A_t^j is the productivity and $\overline{A}^j$ is its steady state level. Households generate utility from consumption and compare it with previous consumption level and technological growth.

The expenses of the households are constrained by the incomes and savings in each period. The budget constraint is:

$$\left(1+\Gamma_{C,t}^j(i)\right)P_t^j C_t^j(i)+P_{I,t}^j I_t^j(i)+M_t^j(i)+E_t\left\{\sum_{S_{t+1}}\left(Q_{t,t+1}^j B_{t+1}^j(S_{t+1},i)\right)\right\}$$
$$+T_t^j(i)\leq\left(1-\Gamma_{W,t}^j(i)\right)W_t^j(i)L_t^j(i)+Pr_{Y,t}^j(i)+M_{t-1}^j(i)+B_t^j(S_t,i), \quad (3.3)$$

where left hand side components are expenditures of the household and the right hand side contains the available resources in the current period. $I_t^j(i)$ is the domestic investment and $P_{I,t}^j$ is the price index of investment goods. $B_{t+1}^j(S_{t+1},i)$ is a set of contingent claims whose payments are depending on the state S_t in the payment period, and $Q_{t,t+1}^j$ is the discount rate for the claims. The set of states S_{t+1} covers all possible outcomes of the economy in the next period. With this definition of contingent claims, we allow the households trading a complete set of bonds in the financial markets. $T_t^j(i)$ is the tax paid to or the transfer received from government. Household incomes contain wage income, which is the product of wage rate $W_t^j(i)$ and working hour, the money carried forward from previous period, principal due for the claims bought, and the profit $Pr_{Y,t}^j(i)$ from ownership of firms in the country.

Additionally, we introduce a set of adjustment costs in household decisions for various purposes. $\Gamma^j_{C,t}(i)$ is the consumption transaction cost which is the function of the ratio of consumption to money holding:

$$\Gamma^j_{C,t} = \phi^j_{C,1}\frac{P^j_t C^j_t}{M^j_t} + \phi^j_{C,2}\frac{M^j_t}{P^j_t C^j_t} - 2\sqrt{\phi^j_{C,1}\phi^j_{C,2}}, \tag{3.4}$$

where $\phi^j_{C,1}$ and $\phi^j_{C,2}$ are two coefficients. Wage rigidity can be described as the reluctance of the households to change wage due to wage adjustment cost $\Gamma^j_{W,t}(i)$.

Household problem is a dynamic optimization of equation (3.1) as the objective function and equation (3.3) as the constraint. The state variables is $B^j_t(S_t,i)$, and the control variables are $C^j_t(i)$, $I^j_t(i)$ $M^j_t(i)$, and $W^j_t(i)$. To construct the Hamiltonian function, we introduce a co-state variable $\lambda^j_t(i)$ for the constraint. The Hamiltonian $\mathcal{H}^j(i)$ for the problem is as follows:

$$\begin{aligned}
\mathcal{H}^j(i) = E_0\Bigg\{ \sum_{t=0}^{\infty} \Bigg\{ \beta^t \Bigg[\frac{1}{1-\sigma^j_C}\left(\frac{C^j_t(i) - \overline{A}^j H^j_t}{A^j_t}\right)^{1-\sigma^j_C} \\
+ \frac{1}{1-\sigma^j_M}\left(\frac{M^j_t(i)}{P^j_t}\right)^{1-\sigma^j_M} - \frac{\zeta^j_L\left(L^j_t(i)\right)^{1+\sigma^j_L}}{1+\sigma^j_L}\Bigg]\Bigg\}\Bigg\} \\
-E_0\Bigg\{ \sum_{t=0}^{\infty} \Bigg\{ \beta^t \lambda^j_t(i) \Bigg[\left(1+\Gamma^j_{C,t}(i)\right) P^j_t C^j_t(i) + P^j_{I,t} I^j_t(i) + M^j_t(i) \\
+ \sum_{S_{t+1}} \left(Q^j_{t,t+1} B^j_{t+1}(S_{t+1},i)\right) + T^j_t(i) - \left(1-\Gamma^j_{W,t}(i)\right) W^j_t(i) L^j_t(i) \\
- Pr^j_{Y,t}(i) - M^j_{t-1}(i) - B^j_t(S_t,i)\Bigg]\Bigg\}\Bigg\}.
\end{aligned} \tag{3.5}$$

The first-order conditions for the Hamiltonian provide the necessary conditions for the dynamic optimization problem. The solutions to this dynamic optimization could be obtained by combining the first-order conditions.

The first equation in the solutions, which is known as the Euler equation for the dynamic programming, is the first-order condition with respect to bonds:

$$\lambda_t^j = \beta\left(1 + i_t^j\right) E_t\left\{\lambda_{t+1}^j\right\}. \tag{3.6}$$

i_t^j is the interest rate for the contingent bonds and is an analogue of the discount rate $Q_{t,t+1}^j$ between two periods. We may also observe that with complete financial market and symmetric initial states of all the households in a country, the time paths for $\lambda_t^j(i)$ are symmetric for these households. Thereby when facing a country wide shock, all households have the same responses λ_t^j.

First-order condition with respect to consumption derives the marginal utility of consumption:

$$\lambda_t^j P_t^j \left(1 + \Gamma_{C,t}^j + C_t^j \frac{\partial \Gamma_{C,t}^j}{\partial C_t^j}\right) = \frac{1}{A_t^j}\left(\frac{C_t^j - \overline{A}^j H_t^j}{A_t^j}\right)^{-\sigma_C^j}. \tag{3.7}$$

Similarly, consumption is the same among all households. In this problem, the co-state variables could be interpreted as the shadow price for extra consumption in the current period. Compared with standard models, our marginal utility has a term that represents the effects of the consumption transaction cost.

First-order condition with respect to money holding leads to another decision rule for the intertemporal choice of the households:

$$\lambda_t^j\left(\frac{i_t^j}{1+i_t^j}+P_t^jC_t^j\frac{\partial\Gamma_{C,t}^j}{\partial M_t^j}\right)=\frac{1}{P_t^j}\left(\frac{M_t^j}{P_t^j}\right)^{-\sigma_M^j}. \qquad (3.8)$$

Also, λ_t^j describes the shadow price for money holding, which is determined by the marginal utility of consumption at the same time. The choice between consumption and money implies that the marginal utility of consumption equals the marginal utility of money. The money demand will be decreasing if the interest rate gets higher. Higher interest rate drives households to invest in financial market rather than holding cash. Equation (3.8) enables us to incorporate the mechanism for evaluation of policies with regard to money quantity in the future.

Before obtaining the optimal wage setting, we first define the composition of labour demand. We assume that labour is fully mobile within a country and thus labour from a household is averagely distributed to all firms in the country, conditional on that firms provide the same wage rate. We define the per capita working hour L_t^j as:

$$n^j L_t^j = \left[\int_0^{n^j} \left(\frac{1}{n^j} \right)^{\frac{1}{\eta_W}} \left(L_t^j(i) \right)^{\frac{\eta_W - 1}{\eta_W}} \mathrm{d}i \right]^{\frac{\eta_W}{\eta_W - 1}}, \tag{3.9}$$

where $\eta_W > 0$ is the elasticity of substitution of labour from different households. Then demand for labour from a specific household can be found as:

$$L_t^j(i) = \left(\frac{W_t^j(i)}{W_t^j} \right)^{-\eta_W} L_t^j. \tag{3.10}$$

The optimal wage setting is a choice between disutility to work and wage income. The necessary condition for the last control variable is:

$$\begin{aligned} \eta_W \zeta_L^j \left(L_t^j \right)^{1+\sigma_L^j} = \lambda_t^j W_t^j \left[\left(\eta_W - 1 \right) \left(1 - \Gamma_{W,t}^j \right) L_t^j + W_t^j L_t^j \frac{\partial \Gamma_{W,t}^j}{\partial W_t^j} \right] \\ + \beta E_t \left\{ \lambda_{t+1}^j W_{t+1}^j L_{t+1}^j \frac{\partial \Gamma_{W,t+1}^j}{\partial W_t^j} \right\}. \end{aligned} \tag{3.11}$$

The marginal utility of working is compensated by the marginal utility of consumption. The optimal wage setting considers the adjustment cost of change to the wage and households will be reluctant to change wages immediately facing shocks. This mechanism brings the rigidity for the labour market.

3.2.2. Domestic Investment and Capital Market

Households invest in the firms of the home country and receive rentals from the capital invested. Firms pay the rental and use the capital in the process of production. The law of motion for capital is defined as:

$$K_{t+1}^{j} = \left(1-\delta^{j}\right) K_{t}^{j} + \zeta_{I,t}^{j}\left(1-\Gamma_{I,t}^{j}\right) I_{t}^{j}, \tag{3.12}$$

where K_t^j is the per capita capital stock in country j at the beginning of period t. I_t^j is the per capital investment in the current period. $\zeta_{I,t}^j$ is an autoregressive process that contains shocks to the investment. δ^j is the depreciation rate of capital. Investment is subject to quadratic adjustment costs $\Gamma_{I,t}^j$:

$$\Gamma_{I,t}^{j} = \frac{\phi_{I}^{j}}{2} \frac{\left(I_{t}^{j}/I_{t-1}^{j}-1\right)^{2}}{I_{t}^{j}/I_{t-1}^{j}}, \tag{3.13}$$

where ϕ_I^j is the coefficient that reflects the level of the costs. The adjustment costs decrease the current accumulation of capital, but they also ease future accumulation by reducing future costs.

With respect to the demand of capital investment from the intermediate producers, households choose the level of future capital stock and investment amount and maximize their utility. First-order condition with respect to future capital stock K_{t+1}^j gives the condition of rental price r_{t+1}^j:

$$\lambda_{K,t}^{j} = \beta^{j} \mathrm{E}_{t}\left\{\lambda_{t+1}^{j} r_{t+1}^{j}\right\} + \beta^{j}\left(1-\delta^{j}\right) \mathrm{E}_{t}\left\{\lambda_{K,t+1}^{j}\right\}. \tag{3.14}$$

Equation (3.14) links the marginal propensity of consumption λ_t^j with the marginal propensity of capital investment $\lambda_{K,t}^j$, which expresses the choice between the consumption and investment sectors. First-order condition with respect to investment level I_t^j leads to the following condition:

$$P_{I,t}^{j}\lambda_t^{j} = \zeta_{I,t}^{j}\lambda_{K,t}^{j} - \phi_I^{j}\zeta_{I,t}^{j}\lambda_{K,t}^{j}\left(\frac{I_t^{j}}{I_{t-1}^{j}} - 1\right)$$
$$+\mathrm{E}_t\left\{\frac{\phi_I^{j}\beta^{j}\zeta_{I,t+1}^{j}\lambda_{K,t+1}^{j}}{2}\left[\left(\frac{I_{t+1}^{j}}{I_t^{j}}\right)^2 - 1\right]\right\}. \quad (3.15)$$

Similar to other adjustment costs, the investment adjustment cost reduces the increase of current investment level and benefits future potential increases, since current increase in investment means less adjustment cost for the future. $P_{I,t}^{j}$ in equation (3.15) is the investment goods price index:

$$P_{I,t}^{j} = \left[\sum_{j'\in J} a_{I,j'}^{j}\left(\mathcal{E}_{j,t}^{j'}P_{j',t}^{j'}\right)^{1-\eta^{j}}\right]^{\frac{1}{1-\eta^{j}}}, \quad (3.16)$$

where the investment price index is the weighted average of intermediate goods from home and abroad. $a_{I,j'}^{j}$ is the share of intermediate goods from country j’ used by households in country j. η^{j} is the elasticity of intermediate goods from different countries. $P_{j,t}^{j}$ is the price of intermediate goods produced by country j.

3.2.3. Final Goods Sector

Household consumption adjustment and government expenditures all demand non-tradable final consumption goods. There is one firm in the final goods production sector for each country. We assume that the final goods markets are perfectly competitive, and thereby firms in this sector do not earn profits. Firms produce final goods by combining intermediate tradable goods from both home and abroad. The production shows constant return-to-scale and constant elasticity of substitution.

The per capita final goods for consumption C_t^j is assumed to be a CES composition of per capita intermediate goods:

$$C_t^j = \left[\sum_{j' \in J} \left(a_{C,j'}^j \right)^{\frac{1}{\eta^j}} \left(C_{j',t}^j \right)^{\frac{\eta^j - 1}{\eta^j}} \right]^{\frac{\eta^j}{\eta^j - 1}}, \tag{3.17}$$

where $\eta^j > 0$ is the elasticity of substitution between domestic and imported goods in the final consumption goods production. $C_{j',t}^j$ is per capita units of goods from country j' in the final goods of country j, and $a_{C,j'}^j$ is the corresponding weight in the production ($\sum_{j' \in J} a_{C,j'}^j = 1$). In these weights, $a_{C,j}^j$ is the weight of home goods in the composition. The foreign goods share in final goods composition, $1 - a_{C,j}^j$, is also known as the degree of openness for a country. Similarly, $C_{j',t}^j$ is the composite of intermediate goods from different producers in a country:

$$C_{j',t}^j = \left[\int_0^{n^{j'}} \left(\frac{1}{n^{j'}} \right)^{\frac{1}{\eta_C}} \left(C_{j',t}^j(k) \right)^{\frac{\eta_C - 1}{\eta_C}} \mathrm{d}k \right]^{\frac{\eta_C}{\eta_C - 1}}, \tag{3.18}$$

where $C_{j,t}^j(k)$, for example, is the units of intermediate goods of brand k and has a weight $1/n^{j'}$ in the production. $\eta_C > 0$ is the elasticity of substitution of different brands of goods.

Firms select the units of different intermediate goods to minimize total cost in production. This leads to the price of consumption final goods P_t^j as an index of composition of intermediate goods prices:

$$P_t^j = \left[\sum_{j' \in J} a_{C,j'}^j \left(\mathcal{E}_{j,t}^{j'} P_{j',t}^{j'} \right)^{1-\eta^j} \right]^{\frac{1}{1-\eta^j}}, \tag{3.19}$$

where $\mathcal{E}_{j,t}^{j'}$ is the exchange rate, which is defined as the units of home currency j per foreign currency j'. $P_{j',t}^{j'}$ is price indices of composition of intermediate goods from different brands and they are derived by minimizing total costs for final goods:

$$P_{j',t}^{j'} = \left[\frac{1}{n^{j'}} \int_0^{n^{j'}} \left(P_{j',t}^{j'}(k) \right)^{1-\eta_C} \mathrm{d}k \right]^{\frac{1}{1-\eta_C}}, \tag{3.20}$$

where $P_{j',t}^{j'}(k)$ is the price of intermediate goods produced by firm k in country j'.

Under the assumptions above, per capita units of intermediate goods for production of final consumption goods satisfy the following demand function:

$$C_{j',t}^j = a_{C,j'}^j \left(\frac{P_{j',t}^{j'}}{P_t^j} \right)^{-\eta^j} C_t^j. \tag{3.21}$$

Demand for intermediate goods from a country is an increasing function of total consumption and a decreasing function of price of consumption goods. In addition, using equation (3.21) we can find that the total cost of all intermediates in the production equals to the price of consumption final goods, due to the completeness of final goods market. Demand for a brand of goods is also a function of its price:

$$C^j_{j',t}(k) = \frac{1}{n^{j'}}\left(\frac{P^{j'}_{j',t}(k)}{P^j_{j,t}}\right)^{-\eta_C} C^j_{j,t}. \tag{3.22}$$

If the prices for different brands of goods are symmetric, demand for these goods will be the same among all brands.

For government spending, we assume that government only has access to final goods that are produced from domestic intermediate goods. Thereby, the composition of government final goods G^j_t is:

$$G^j_t = \left[\left(\frac{1}{n^j}\right)^{\frac{1}{\eta_C}} \int_0^{n^j} \left(G^j_t(k)\right)^{\frac{\eta_C}{\eta_C-1}} \mathrm{d}k\right]^{\frac{\eta_C-1}{\eta_C}}, \tag{3.23}$$

and the demand for one type of intermediate goods is:

$$G^j_t(k) = \frac{1}{n^j}\left(\frac{P^j_{j,t}(k)}{P^j_{j,t}}\right)^{-\eta_C} G^j_t. \tag{3.24}$$

With intermediate goods as inputs for final goods, we introduce the production of intermediate goods in the next section.

3.2.4. Intermediate Goods Sector

Intermediate goods are tradable and are used as inputs for producing final goods. There is a continuum of firms $k \in [0, n^j]$ in each country which produce differentiated intermediate goods. The intermediate goods markets are monopolistic competitive. This means that firms in the sector set prices for their products and ignore the effect of their price setting on the aggregate price level. Nominal rigidity with regard to the price is introduced for firms in terms of the Calvo pricing.

Intermediate goods firms use capital and labour as inputs to produce differentiated goods. The intermediate goods production is of Cobb-Douglas form:

$$Y_t^j = A_t^j \left(K_t^j\right)^{\alpha^j} \left(L_t^j\right)^{1-\alpha^j}, \tag{3.25}$$

where α^j is the capital share in the production. A_t^j is the total factor productivity. The cost of production TC_t^j includes wages paid to labour and rental for capital:

$$TC_t^j(k) = W_t^j L_t^j(k) + r_t^j K_t^j. \tag{3.26}$$

Producers choose weights of capital and labour in the production process to minimize average costs. This leads to the optimal capital labour ratio condition:

$$\frac{K_t^j}{L_t^j} = \frac{\alpha^j}{1-\alpha^j} \frac{W_t^j}{r_t^j}. \tag{3.27}$$

Then the marginal cost of production MC_t^j is described as:

$$MC_t^j = \frac{1}{A_t^j} \frac{1}{(\alpha^j)^{\alpha^j} (1-\alpha^j)^{1-\alpha^j}} (W_t^j)^{1-\alpha^j} (r_t^j)^{\alpha^j}, \tag{3.28}$$

which reveals that the marginal cost is the same for all intermediate producers in a country, due to the symmetric wage rate offered by them.

The profits of the firm $Pr_{Y,t}^j(k)$ are the total revenue less the total cost:

$$Pr_{Y,t}^j(k) = P_{j,t}^j(k) Y_t^j(k) - TC_t^j(k), \tag{3.29}$$

where $P_{j,t}^j(k)$ is the price that the firms set for sales of products. We further assume that home households in one country have full ownership of all domestic firms and that firms pay all profits equally to all households through dividends.

Monopolistic competitive firms maximize discounted sum of profits and choose the optimal price of goods they sell. We incorporate nominal rigidities in the production sector. Following the Calvo type stickiness, we allow a fraction $1-\theta^j$ of firms to change price in each period. Firms that can adjust price $\tilde{P}_{j,t}^j(k)$ in the current period maximize their discounted expected profits:

$$\max_{\tilde{P}_{j,t}^j(k)} E_t \sum_{t=0}^{\infty} \left\{ (\beta^j \theta^j)^t Pr_{Y,t}^j(k) \right\}. \tag{3.30}$$

The optimal price satisfies the following equation:

$$E_0 \sum_{t=0}^{\infty} \left\{ (\beta^j \theta^j)^t Y_t^j(k) \left(\tilde{P}_{j,t}^j(k) - \frac{\eta_C}{\eta_C - 1} MC_t^j \right) \right\} = 0. \tag{3.31}$$

From equation (3.31), we can observe that optimal price is symmetric for all firms $\tilde{P}_{j,t}^j(k) = \tilde{P}_{j,t}^j$. Aggregating the new price for $1-\theta^j$ firms that newly set their prices and the θ^j firms that keep their previous price, the price for home goods is given by:

$$P_{j,t}^j = \left[\theta^j \left(P_{j,t-1}^j \right)^{1-\eta_C} + (1-\theta^j) \left(\tilde{P}_{j,t}^j \right)^{1-\eta_C} \right]^{\frac{1}{1-\eta_C}}. \tag{3.32}$$

The extent to which the producer price index (PPI) is distorted depends on the value of the Calvo coefficient θ^j.

3.2.5. Closing the Model

Government's policy is greatly simplified if we impose a balanced budget:

$$P_{j,t}^j G_t^j + M_{t-1}^j = T_t^j + M_t^j, \tag{3.33}$$

where the left hand side contains all government expenditures and the right hand side incomes. All variables in equation (3.33) are expressed in per capita term. We further assume that government spending can be expressed as a fraction of domestic intermediate goods output:

$$G_t^j = \zeta_{G,t}^j Y_t^j, \tag{3.34}$$

where $\zeta_{G,t}^j$ is the ratio of government spending to output.

If aggregated among all intermediate goods producers in a country, the equation for a brand of goods leads to the intermediate goods market clearing condition:

$$n^{j}\left(1-\zeta_{G,t}^{j}\right)Y_{t}^{j}=\sum_{j'\in J}\left[n^{j'}a_{C,j}^{j'}\left(\frac{\mathcal{E}_{j',t}^{j}P_{j,t}^{j}}{P_{t}^{j'}}\right)^{-\eta^{j'}}C_{t}^{j'}\right]$$
$$+\sum_{j'\in J}\left[n^{j'}a_{I,j}^{j'}\left(\frac{\mathcal{E}_{j',t}^{j}P_{j,t}^{j}}{P_{I,t}^{j'}}\right)^{-\eta^{j'}}I_{t}^{j'}\right]. \tag{3.35}$$

Output is distributed to demand by each country and the relative prices and weights determine the level of the demand.

The state contingent claims have zero net aggregate supply, which delivers the asset market clearing condition:

$$\int_{0}^{n^{j}}B_{t}^{j}(S_{t},i)\mathrm{d}i=0. \tag{3.36}$$

We aggregate the budget constraint of individual household and substitute the government budget equation and firms' profit into it. This finally leads to the resource constraint for a country:

$$\left(1+\Gamma_{C,t}^{j}\right)P_{t}^{j}C_{t}^{j}+P_{I,t}^{j}I_{t}^{j}=\left(1-\zeta_{G,t}^{j}\right)P_{j,t}^{j}Y_{t}^{j}-\Gamma_{W,t}^{j}W_{t}^{j}L_{t}^{j}. \tag{3.37}$$

All terms in the above equation are in per capita term. The consumption and investment of a country is equal to the output, taken into consideration all transaction and adjustment costs.

In addition, we further assume that capital is fully mobile internationally. Then the uncovered interest parity (UIP) holds between two countries:

$$1 + i_t^j = \left(1 + i_t^{j'}\right) \frac{E_t\left\{\mathcal{E}_{j,t+1}^{j'}\right\}}{\mathcal{E}_{j,t}^{j'}}. \tag{3.38}$$

If we use the Euler equations for both countries to substitute the interest rates in the UIP condition and then solve the equation backward, we can get the international risk sharing condition between the two countries:

$$\lambda_t^j = \frac{\lambda_t^{j'}}{\mathcal{E}_{j,t}^{j'}}. \tag{3.39}$$

This condition links the decisions of two countries and ensures perfect risk sharing between them, that is to say a country with relatively cheaper consumption basket should consume more (Corsetti, Dedola, and Leduc 2008). The exchange rate works as an instrument to adjust the relative price and then consumption between the two countries.

With the above equations, the workhorse model is solved and closed. Model equations are (3.7), (3.8), (3.11), (3.12), (3.14), (3.15), (3.16), (3.19), (3.25), (3.27), (3.28), (3.31), (3.32), (3.35), (3.37) and (3.39). In the following section, we present a series of analysis based on the model.

3.3. The Current Account under Complete Financial Markets

In this section, we first derive at analytical results of market completeness on the dynamics of trade balance by application of the multi-country workhorse model for a two-country world. In Section 3.3.2, we simulate the workhorse model receiving a real shock and an interest rate shock. The analysis first aims to explain the role of the exchange rate in balancing international trade between two countries. Secondly, the complete market case will be viewed as the benchmark for international adjustment since trade is balanced in both short and long run. It helps understand the role of the exchange rate in the rebalancing process.

3.3.1. Analytical Analysis

The workhorse model illustrates that the current account is balanced in each period given any country wide shock. The role of market completeness and the exchange rate can be explained from two perspectives, i.e. from international borrowing and lending and from international trade.

Considering international borrowing and lending, the conclusion is straightforward from equation (3.37), which is derived from the resource constraint. Contingent assets aggregate zero for a country due to bond market clearing condition (3.36). In the end, there is no international borrowing or lending in each period, which reflects the balance of international trade.

Considering the international trade in the long term, the steady state goods market clearing condition is:

$$\begin{aligned} n^j\left(1-\overline{\zeta_G}^j\right)\overline{Y}^j &= n^j a^j_{C,j}\left(\frac{\overline{P}^j_j}{\overline{P}^j}\right)^{-\eta^j}\overline{C}^j + n^{j'} a^{j'}_{C,j}\left(\frac{\overline{\mathcal{E}}^j_{j'}\overline{P}^j_j}{\overline{P}^{j'}}\right)^{-\eta^{j'}}\overline{C}^{j'} \\ &+ n^j a^j_{I,j}\left(\frac{\overline{P}^j_j}{\overline{P}^j_I}\right)^{-\eta^j}\overline{I}^j + n^{j'} a^{j'}_{I,j}\left(\frac{\overline{\mathcal{E}}^j_{j'}\overline{P}^j_j}{\overline{P}^{j'}_I}\right)^{-\eta^{j'}}\overline{I}^{j'}. \end{aligned} \tag{3.40}$$

Also, the reduced form of the resource constraint in the steady state is:

$$\overline{P}^j\overline{C}^j + \overline{P}^j_I\overline{I}^j = \left(1-\overline{\zeta}^j_G\right)\overline{P}^j_j\overline{Y}^j, \tag{3.41}$$

since all adjustment costs are zero in the steady state. Substituting (3.41) into (3.40), we get a condition for the steady state:

$$\begin{aligned} n^j\overline{\mathcal{E}}^{j'}_j\overline{P}^{j'}_{j'}a^j_{C,j'}\left(\frac{\overline{\mathcal{E}}^{j'}_j\overline{P}^{j'}_{j'}}{\overline{P}^j}\right)^{-\eta^j}\overline{C}^j + n^j\overline{\mathcal{E}}^{j'}_j\overline{P}^{j'}_{j'}a^j_{I,j'}\left(\frac{\overline{\mathcal{E}}^{j'}_j\overline{P}^{j'}_{j'}}{\overline{P}^j_I}\right)^{-\eta^j}\overline{I}^j \\ = n^{j'}\overline{P}^j_j a^{j'}_{C,j}\left(\frac{\overline{\mathcal{E}}^j_{j'}\overline{P}^j_j}{\overline{P}^{j'}}\right)^{-\eta^{j'}}\overline{C}^{j'} + n^{j'}\overline{P}^j_j a^{j'}_{I,j}\left(\frac{\overline{\mathcal{E}}^j_{j'}\overline{P}^j_j}{\overline{P}^{j'}_I}\right)^{-\eta^{j'}}\overline{I}^{j'}. \end{aligned} \tag{3.42}$$

The left hand side of the above equation is the aggregate value of imports for all households in the home country and the right hand side exports. This implies that the long-term trade is balanced, for the initial and terminating states of the economies.

In the short run, if we define the current account CA_t^j of the home country as:

$$CA_t^j = n^{j'} P_{j,t}^j C_{j,t}^{j'} - n^j \mathcal{E}_{j,t}^{j'} P_{j',t}^{j'} C_{j',t}^j + n^{j'} P_{j,t}^j I_{j,t}^{j'} - n^j \mathcal{E}_{j,t}^{j'} P_{j',t}^{j'} I_{j',t}^j. \tag{3.43}$$

Linearization of the above equation tells the short-run deviation of the current account as a ratio of output $\widehat{CA}_t^j = \mathrm{d}CA_t^j / \overline{Y}^j$:

$$\begin{aligned} \widehat{CA}_t^j = & \, n^{j'} a_{C,j}^{j'} \zeta_{Y,j}^{j'} \left[\left(1 - \eta^{j'}\right) \widehat{P}_{j,t}^j + \eta^{j'} \widehat{\mathcal{E}}_{j,t}^{j'} + \eta^{j'} \widehat{P}_t^{j'} + \widehat{C}_t^{j'} \right] \\ & - n^j a_{C,j'}^j \left[\left(1 - \eta^j\right) \widehat{\mathcal{E}}_{j,t}^{j'} + \left(1 - \eta^j\right) \widehat{P}_{j',t}^{j'} + \eta^j \widehat{P}_t^j + \widehat{C}_t^j \right] \\ & + n^{j'} a_{I,j}^{j'} \zeta_{Y,j}^{j'} \left[\left(1 - \eta^{j'}\right) \widehat{P}_{j,t}^j + \eta^{j'} \widehat{\mathcal{E}}_{j,t}^{j'} + \eta^{j'} \widehat{P}_{C,t}^{j'} + \widehat{I}_t^{j'} \right] \\ & - n^j a_{I,j'}^j \left[\left(1 - \eta^j\right) \widehat{\mathcal{E}}_{j,t}^{j'} + \left(1 - \eta^j\right) \widehat{P}_{j',t}^{j'} + \eta^j \widehat{P}_{C,t}^j + \widehat{I}_t^j \right]. \end{aligned} \tag{3.44}$$

We can observe that deviation of the current account from the steady state is a linear function of the exchange rate and the other variables. For any value of deviations of other variables, we can generate the deviation of the exchange rate that is positively large (or negatively small) enough to find a positive (or a negative) value for $\widehat{CA}_t^j$. Thus there exists a value of the exchange rate for the above equation to be zero, due to the monotonicity. Given that our solutions to the model are determinant by the first-order conditions, the value of $\widehat{CA}_t^j$ can only be zero at any given time period because the beginning and terminating steady states ensure the uniqueness of the solution and $\widehat{CA}_t^j$ in these two states are both zero.

From the illustration above, we can conclude that without international borrowing and lending, the exchange rate is an instrument to keep the value of exports and imports equal. From the demand side, the exchange rate adjusts the movement of the marginal utility for each country, and affects the relative level of consumption. On the other hand, the exchange rate affects the relative price of goods produced by each country and thus the relative output. In both short- and long-run equilibrium, changes in relative consumption offset the effects of relative price on production, and both country remain to have zero net export.

3.3.2. Simulation of a Two-Country World

In order to demonstrate the dynamics of the economies, especially dynamics of the trade balance, we simulate the workhorse model under one percent permanent home productivity improvement and one percent permanent increase in the interest rate. We choose these two cases to cover shocks for both real and financial sectors. The parameters for the model are listed in Table 3.1. These parameter values are based on standard settings adopted by the literature. We clarify two points here. First, these assumptions do not affect the generality of the results of our calibration, particularly,

Table 3.1 Parameter values for simulations

Parameter	Value		Description
	Home	Foreign	
β	0.99	0.99	Discount rate
$\zeta_{Y,1}^{2}$	1.00	1.00	Output ratio
n^j	0.50	0.50	Population share
σ_C^j	1.00	1.00	EOS consumption
σ_M^j	1.00	1.00	EOS money
σ_L^j	0.50	0.50	EOS working hour
$\overline{A}^j$	1.00	1.00	Steady state growth
$a_{C,1}^j$	0.70	0.30	Share of home goods
$a_{C,2}^j$	0.30	0.70	Share of foreign goods
η^j	1.00	1.00	EOS home and foreign goods
η_C	5.00	5.00	EOS different brands
η_W	5.00	5.00	EOS different labour
ζ_G^j	0.40	0.40	Government spending share
ζ_C^j	0.60	0.60	Consumption share
ζ_I^j	0.00	0.00	Investment share
h^j	0.80	0.80	Habit
$\phi_{C,1}^j$	0.01	0.01	Consumption transaction cost coefficient 1
$\phi_{C,2}^j$	0.01	0.01	Consumption transaction cost coefficient 2
ϕ_W^j	0.01	0.01	Wage adjustment cost
θ^j	0.30	0.30	Price adjustment cost

the dynamics of the current account according to the workhorse model. Second, since we prove the balance of current account in the theoretical framework. These specifications of parameters do not cause the loss of generality of the analytical illustration.

Tables 3.2 illustrates the percentage deviations of the variables from initial steady state when receiving productivity and interest rate shocks, respectively. The two

Table 3.2 Cumulative deviations from initial steady state (percent)

Variable	**Short run**		**Long run**	
	Home	**Foreign**	**Home**	**Foreign**
A. One percent permanent home productivity increase				
PPI	0.21	-0.21	-	-
Output	0.85	-0.42	1.37	-
CPI	0.47	-0.47	0.25	-0.25
Consumption	0.16	0.09	0.57	0.25
Marginal utility	-1.29	-	-0.82	-
Labour	-0.15	-0.42	0.37	-
Wage	1.21	-0.21	1.00	-
Marginal cost	0.21	-0.21	-	-
Current account	-	-	-	-
Exchange rate	1.29	-1.29	0.82	-0.82
Terms of trade	0.87	-0.87	0.82	-0.82
Real exchange rate	0.35	-0.35	0.33	-0.33
B. One percent permanent home interest rate increase				
PPI	0.10	-0.10	0.48	-0.48
Output	-0.12	-0.07	-0.41	-0.18
CPI	0.11	-0.11	0.52	-0.52
Consumption	-0.12	0.01	-0.48	0.12
Marginal utility	-0.16	0.07	-0.69	0.39
Labour	-0.12	-0.07	-0.41	-0.18
Wage	0.10	-0.10	0.48	-0.48
Marginal cost	0.10	-0.10	0.48	-0.48
Current account	-	-	-	-
Exchange rate	0.23	-0.23	1.08	-1.08
Terms of trade	0.03	-0.03	0.12	-0.12
Real exchange rate	0.01	-0.01	0.05	-0.05

Panel A: with one percent permanent home productivity increase; Panel B: with one percent permanent home interest rate increase. Short run: at the quarter of the shock; Long run: in 20 quarters after the shock.

columns report short-term and long-term equilibrium. Short term is defined as the period that the unexpected shock happens to the economies and long-term deviation is the cumulative percentage change of the variable from the initial state 20 periods after the shocks. In both panel A and B, we can find zero deviations of the current account from balance in both short and long terms. In panel A, we observe that home country is increasing output, consumption and prices facing a productivity shock. The exchange rate depreciates by 1.29 percent facing a one percent shock, suggesting a short-run overshooting. Home output rises by 0.85 percent, and the foreign effect is a decrease of output by 0.42 percent. In the long run, foreign output is not affected. Home increases output due to world consumption and relative price changes, which is achieved through depreciation of the exchange rate by 0.82 percent. Panel B displays the responses to home interest rate increase. The contraction effect is more bored by the home country than by foreign. Home decreases output by 0.12 percent in the short term and foreign by 0.07 percent. This contraction is worse in the long run, when home output decreases by 0.41 percent and foreign by 0.18 percent.

Figures 3.1 demonstrates the impulse response functions of the variables in 20 periods after productivity and interest rate shocks, respectively. We can find that the current account is always zero in both cases by the impulse response functions. The exchange rate plays a significant rebalancing role in the transmission of the shocks.

In the long term, the exchange rate depreciates by 0.82 percent facing one percent permanent home productivity improvement. Figure 3.2 illustrates how the variables link with each other towards the new long-run state under productivity shock. The top row of Figure 3.2 describes how international risk sharing links the marginal utility of each country. Home marginal utility decreases by 0.82 percent and the foreign

Figure 3.1 Impulse response functions to a home productivity shock (percent)

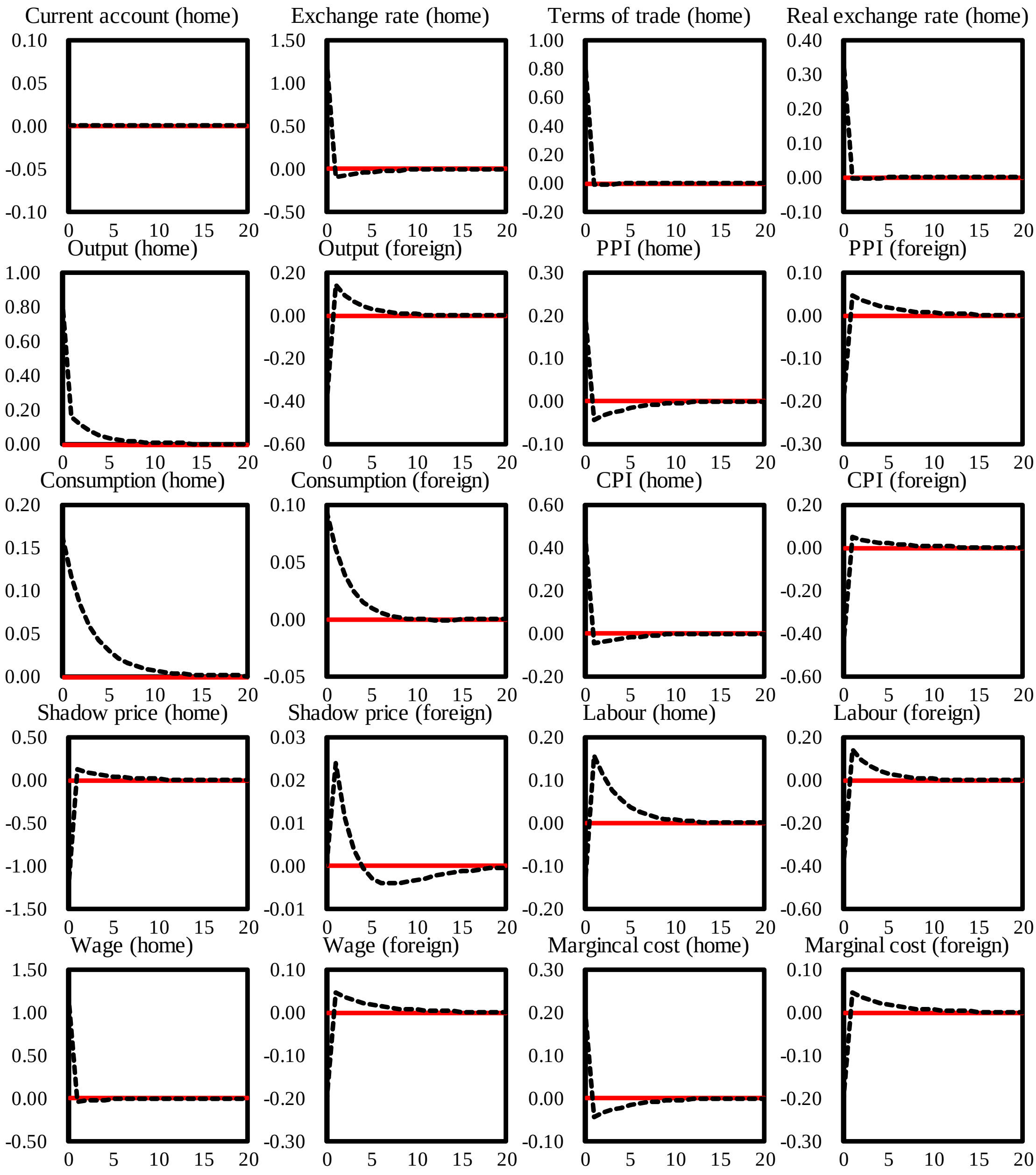
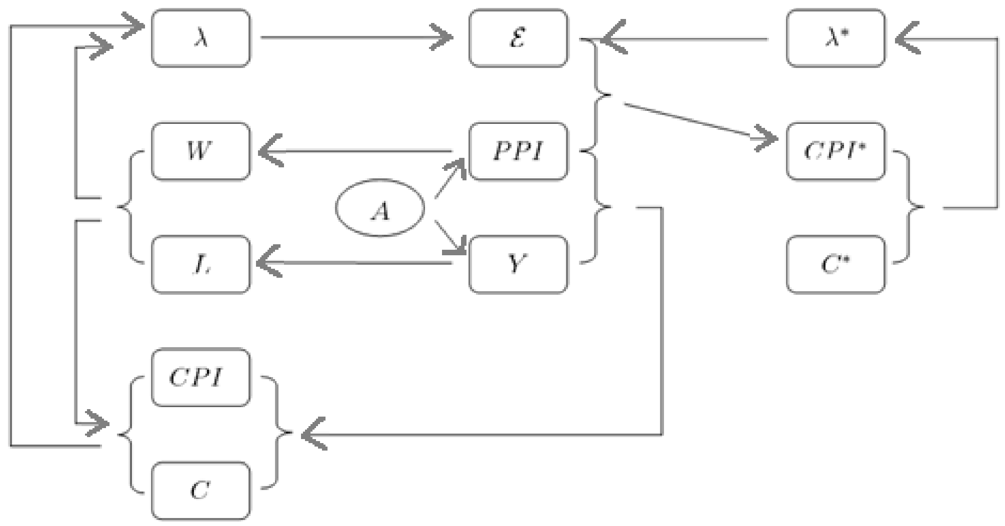


Figure 3.2 The long-term equilibrium under productivity shocks

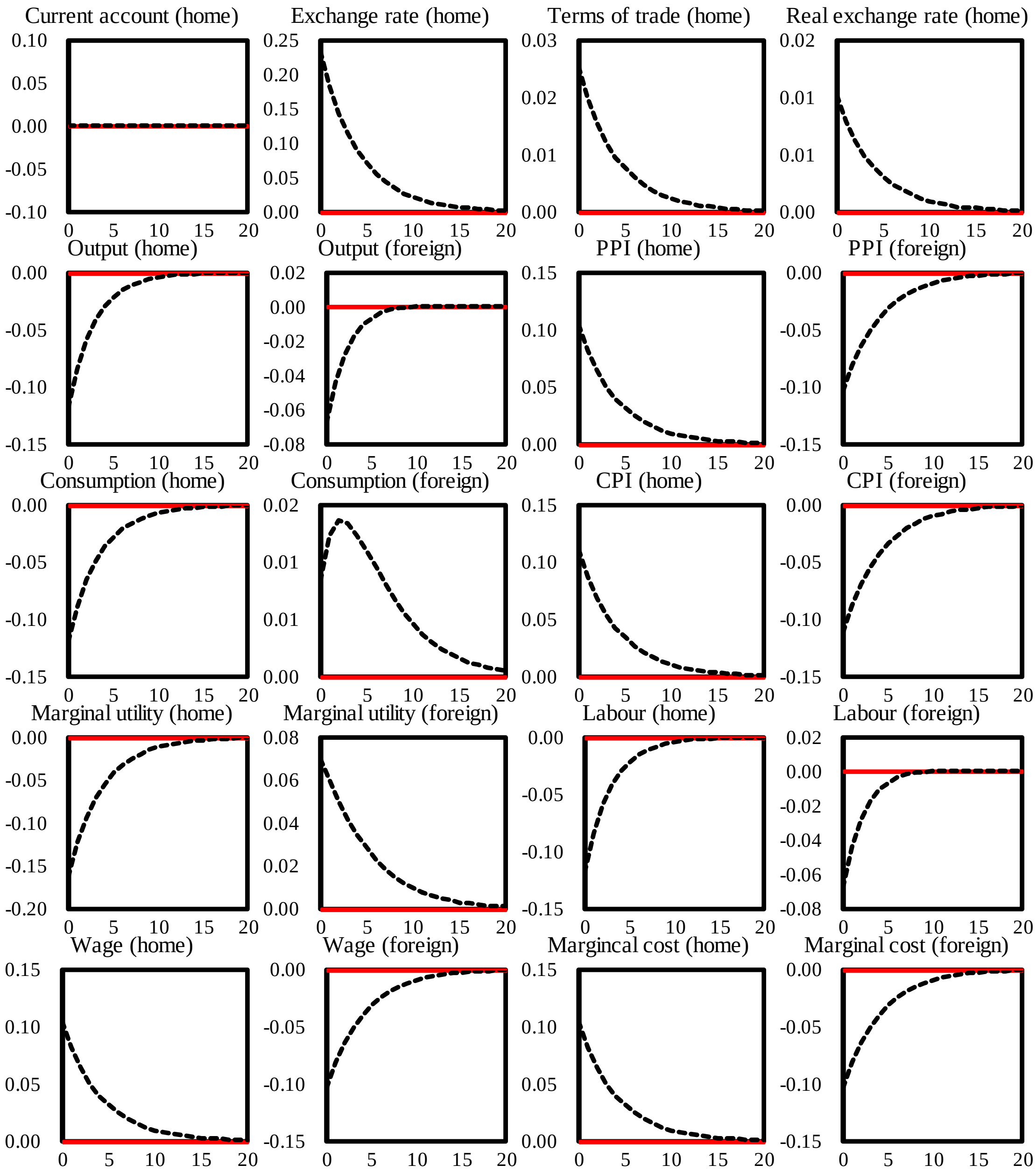


remains unchanged, which leads to the exchange rate depreciation. Perfect international risk sharing ensures the decrease in marginal utility fully hedged by the increase in the exchange rate. Home depreciation reduces foreign CPI and foreign consumption increases by the same proportion, thus the nominal expenditure of foreign households does not change. Given that foreign PPI and production also remain unchanged, the current account for the foreign economy is balanced. Domestic firms increase wage and demand for labour, maintaining the marginal cost and PPI at the same level as before. Increased productivity turns into surplus output, but the exchange rate depreciation boosts demand for home goods while sacrifices a fraction of the increase of nominal income. Home CPI increases due to the fact that depreciation deteriorates purchasing power. However, increase in incomes leads to higher consumption. Higher production and consumption offset and the home country is also balanced in trade. The new long-term equilibrium is the result of international risk sharing and redistribution of world incomes due to home productivity increase. The complete financial market leads to perfect risk sharing and proportional welfare increase for the two countries.

In the short run, due to consumption habit and nominal rigidities, consumption, PPI and wage levels are staggered (Figure 3.1). The exchange rate has an initial jump that is not only higher than the long-term level, but also higher than the level of productivity increase. This overshooting compensates the inefficiency of price and consumption adjustment in the short run, and the net trade is still zero. Similarly, from the perspective of international risk sharing, real shocks do not affect foreign marginal utility, but the exchange rate has a movement of the same scale as home marginal utility.

Unlike real shocks, nominal shocks do not bring about any overshooting or J curve dynamics in the variables. Figure 3.3 displays the impulse response functions to a home interest rate shock. Short-term deviations of most variables are smaller and then gradually move back to their long-term level. In the workhorse model, the interest rate only has a relation with money demand, through which interest rate affects marginal utility. Home marginal utility decreases due to the rise of interest rate. A part of this effect is born by the foreign economy through the channel that increases foreign

Figure 3.3 Impulse response functions to a home interest rate shock (percent)



marginal utility at the same time. The rest is offset by a depreciation of home currency. If we recall the UIP condition, given the current level of the exchange rate and foreign interest rate constant, an increase in domestic interest rate would lead to an expectation of exchange rate depreciation. This can be the effect of international financial market with full capital mobility and unlimited arbitrage. Provided that all effects of interest rate change are absorbed by both economies and the exchange rate depreciation, the current account is balanced in both short and long term.

The simulation confirms our demonstration of trade balance under complete financial markets in the previous section. Analysis of the current account based on the workhorse model explains the mechanism of exchange rate adjustment to maintain trade balance.

3.4. Summary

In this chapter, we follow the spirit of classical NOEM models and establish a workhorse model for the following chapters. The model is a multi-country general equilibrium model consisted of major structural elements of the CP-OR models. Differing from other studies, we relax a few assumptions and keep the possibility to introduce heterogeneity in the future. Then we demonstrate the current account balance under financial completeness from both analytical and simulation perspectives. Our simulation of the model under a productivity shock and an interest rate shock confirms the analytical conclusions.

We show that financial market completeness is sufficient to create short- and long-term balance of international trade. The first implication of this finding is that in order to analyze the trade surplus and deficit of countries, the model should relax the assumption of completeness. Secondly, under perfect risk sharing, the exchange rate plays an important role in adjusting international relative price, and therefore relative output and consumption. Exchange rate adjustment enables the balancing process. When considering the amount of exchange rate movement in rebalancing, we can use the complete market case as a benchmark to derive policy suggestion.

Building upon this workhorse model, we then move to develop the model to the extent that it can empirically capture the real data of major partners of China through Bayesian estimation in the following chapter.

Chapter 4

An Estimated Multi-Country Heterogeneous Model for China in the World Economy

4.1. Introduction

There is a growing interest in designing country-specific models and conducting analysis. Thereof China, as a growing economic power, has increasing global impacts. Following this trend, many researchers have started to consider the role of China in modelling the world economy. In particular, China is considered to be an important element in open economy topics such as international trade and investment. In this chapter, we develop a model for the Chinese economy and generate implications on China and the world based on empirical evidence derived by the model. The model is then examined for empirical validity using the Bayesian approach. The objective is to find a model with appropriate structure and empirical soundness. Particularly, we focus on how the model could find discrepancies between China and other major participants in the world economy.

There is a growing body of literature about Bayesian estimation for NOEM and DSGE models. The first paper to apply the Bayesian approach is Schorfheide (2000) who compares two DSGE models based on the relative level of posterior density. This approach is at the cutting edge of the field in the estimation of structural models by considering the effects of prior information on the posterior density of the model. Lubik and Schorfheide (2006) examine the possibility of using the Bayesian approach to estimate NOEM models. They develop a two-country NOEM model based on the work of Gali and Monacelli (2005) and discuss the settings of prior distributions and their findings about the posterior means. They conclude with intuitive posteriors to describe the United States and the Euro Area and search discrepancies between open economy and closed economy estimations. They attribute these discrepancies mainly to estimation without demeaning the data. The robustness of their estimation is examined by choosing different priors. Their work recommends that the information in the prior distributions could serve as a resolution to misspecification and identification for structural models.

Following their work, a group of researchers uses the Bayesian approach to study NOEM and DSGE models. Smets and Wouters (2003) not only provide an important DSGE framework for small open economy modelling, but also fit their model to the data of the Euro Area. They find that the results of Bayesian estimation are generally consistent with the evidence from Bayesian VAR, which is the previous generation approach in structural models. Thereby Bayesian estimation enriches available means of empirical testing for macroeconomic models. Justianno and Preston (2004) estimate models for Australia, Canada and New Zealand. They compare various specifications for small open economy models including habit, pricing choice and price indexation. Adolfson et al. (2007) also incorporate rich features that could bring financial frictions into the model. They estimate a model with price and wage rigidities, capital utilization, capital adjustment cost and incomplete exchange rate pass-through. Liu (2006) develops a small open economy model for New Zealand and also applied the Bayesian estimation. These studies show that the Bayesian approach is able to work with a model incorporated with various structural features.

A few researchers try to find the regime of policies by fitting the data into policy functions. Lubik and Schorfheide (2007) estimate models for Australia, Canada, New Zealand and the UK with a view to detecting the responses of their central banks to exchange rate movements. They prove that the Bayesian approach is able to distinguish different policies adopted by different economies. Similar with their work, Best (2011) provides a study of Mexico and evaluates the extent to which the monetary policy of Mexico reacts to the exchange rate. Rabaral and Tuesta (2006) depart from previous studies in that they set up a two-country large open economy model and estimate it by the data of the US and the EA. They try different specifications and evaluate which can better explain the volatility of the real and nominal exchange rates. These researchers provide a large group of studies based on Bayesian estimation of NOEM and DSGE models and this approach can be adopted for analysis of different policies.

With this growing literature, the Chinese economy is becoming one of the focuses of the field. Mehrotra, Nuutilainen, and Pääkkönen (2011) develop and simulate a closed economy DSGE model for China. They evaluate the effects of different shocks on China and the dynamics in the process of adjusting from investment-led to consumption-led growth. Huang (2009) simulates an open economy model based on Betts and Devereux (2000) to analyze the level of exchange rate pass-through for China. Huang argues that the necessary condition to ensure an effective surplus reduction by appreciation is that the majority of firms use producer currency pricing. Estimation studies on China mostly focus on monetary and fiscal policies adopted by the government. Liu (2008) estimates a small open economy DSGE model for China using the Bayesian approach to derive the monetary policy adopted by the central bank. On the other hand, Jian (2011) estimates a model based on Gali and Moneacelli (2005) and focuses on the examination of the multiplier of government spending. Following the above studies, our model contains common features of NOEM models including monopolistic competition, nominal rigidity and structural shocks. Also, we arrive at findings about the structural features and policies of China and other economies with posteriors of Bayesian estimation.

Our model is different from most studies developed in the literature in several respects. Firstly, our work is one of the earliest multi-country studies which include China. As shown in the review above, most researchers base their analysis on two-country modelling. However, estimation results demonstrate the necessity of a multi-country framework for analyzing interactions between major economies. In order to examine China's interaction with other economies of the world, we separate the foreign economies into the United States, the Euro Area and a block representing the Rest of the World. Chudik (2007) criticizes the small open economy structure. Grouping the foreign economies as one 'foreign' block implicitly assumes away the exogeneity of these foreign economies. Such an assumption should be justified before adopting the framework. There is also a large group of studies that uses the multi-country structure in their modelling (Jacquinot and Straub 2008; Breuss and Fornero 2009; Haberis et al. 2011; Markovic and Povoledo 2011). Asia, as an emerging block, is also within the consideration of these researchers. However, there are very few studies that describe the role of China specifically while focusing on her interactions with major foreign partners.

We use the Bayesian approach to estimate the system with macro data of these four economies. This approach benefits our analysis with better identification for the model. Estimation models for China often face difficulties such as small sample size and lack of sample variables. In addition to the information from data, Bayesian inference considers the prior distributions of parameters, which reflect the expectation of parameter value according to theoretical and empirical evidence. The Bayesian approach also overcomes the problem of maximum likelihood estimation in that the priors give reasonable information about the posteriors.

We base our analysis on the estimation results from a different perspective. Most open economy studies simplify the framework by assuming large symmetry between countries. However, cross-country heterogeneity is emphasized by a school of researchers (De Grauwe and Piskorski 2001; Corsetti 2006; Kolasa 2008; Jondeau and Sahuc 2008). Although starting from symmetric structural parameters for the priors, we examine the heterogeneity of these economies based on the posteriors. Our estimation updates the symmetric priors with information from data to arrive at heterogeneous posteriors. This methodology generates heterogeneity from the data of these different economies and can tell whether it is necessary to separate the foreign economies and use a multi-country structure, rather than assuming away the exogeneity ex ante.

In particular, we consider important differences between the Chinese regime and other economies. The monetary policy of China lies in a regime that follows both a quantity rule with credit limit and an interest rate policy that regulates the savings rate (He and Wang 2011). To characterize this regime, we estimate two versions of the model, one with the quantity rule and the other with the interest rate rule. By considering quantity rule for China and interest rate rule for other economies, we differ from other studies in that heterogeneity could also be introduced by different policy functions. To test the sensitivity of the estimation to the priors, we change the value of priors and re-estimate our model based on lower priors and higher settings than the baseline. Our sensitivity tests support that the main findings of our estimation are consistent with different sets of priors. Also, the scale of our model is appropriate to limit the problem of identification that often appears in empirical analysis of large scale models.

Our estimation finds large discrepancies in the parameter values and policy functions of these economies. China and the US are found to have a moderate persistency to consumption and moderate degrees of nominal rigidity, while the EA has lower consumption habit and higher price stickiness. Thereby the EA is more distorted in the production while China and the US are slow in consumption adjustment. Based on the estimation results using the interest rate or the money quantity rule for China, we conclude that both equations could be used for modelling China, but that different parameterization should be used. In the comparison of monetary policies for the blocks, China and the US are concerned more with growth, while the EA targets stabilization of inflation more strictly. We also find that the productivity shocks to these economies capture the magnitude and the persistency of the recession in the financial crisis. In the sensitivity tests, our model demonstrates general robustness with different prior means. The model is sensible and practical for examination of the Chinese economy in an open economy context.

This chapter is structured as follows. We introduce the linearized model in Section 4.2. Section 4.3 summarizes the Bayesian approach and the estimated form of the model. In Section 4.4, we perform the estimation and generate the results. The robustness of the model is examined in Section 4.5. Section 4.6 summarizes this chapter.

4.2. The Linearized Structural Model

The linearized structural model includes equations describing three sectors: households, firms and the government. These equations consist of optimal decisions of the participants, conditions of market clearing, and processes to gauge innovations. There are four economies in the model: China, the US, the EA, and the ROW. They are represented by subscript or superscript from one to four, respectively. All the structural equations are linearized from the NOEM model constructed in Chapter 3. In what follows, variables with subscript or superscript j are defined with respect to country $j \in J = \{1, 2, 3, 4\}$. Without further notification, variables are expressed as their percentage deviations from steady state levels.

Optimal intertemporal choices of households in two countries are linked together to derive the international risk sharing condition:

$$\widehat{\lambda}_t^j - \widehat{\lambda}_t^{j'} = -\widehat{\mathcal{E}}_{j,t}^{j'}, \tag{4.1}$$

where $\widehat{\lambda}_t^j$ is the marginal utility of consumption and $\widehat{\mathcal{E}}_{j,t}^{j'}$ is the exchange rate. Changes in the relative level of the marginal utilities between two countries are captured by the changes in the exchange rate. In fact, under uncovered interest parity, movements of the current exchange rate reflect the interest rate differential and future exchange rate under uncovered interest parity. Intertemporal choices of two countries are affected by their interest rates and expectation about the future exchange rate. Marginal utility is defined as:

$$\widehat{\lambda}_t^j = -\widehat{P}_t^j - \frac{\sigma_C^j}{1 - h^j\overline{A}^j}\widehat{C}_t^j + \frac{\sigma_C^j h^j \overline{A}^j}{1 - h^j\overline{A}^j}\widehat{C}_{t-1}^j + \left(\sigma_C^j - 1\right)\widehat{A}_t^j, \tag{4.2}$$

where $\widehat{P}_t^j$ is the consumer price index, $\widehat{C}_t^j$ the consumption, and $\widehat{A}_t^j$ the process linking the error term in productivity. σ_C^j is the elasticity of consumption in the utility function, h^j the degree of consumption habit, $\overline{A}^j$ the steady state growth rate of productivity. Equation (4.2) is derived from the optimal consumption choice of households. Optimal choice with respect to money leads to the following condition:

$$\sigma_M^j \widehat{M}_t^j = \left(\sigma_M^j - 1\right)\widehat{P}_t^j - \widehat{\lambda}_t^j - \frac{\left(\beta^j\right)^2}{1 - \beta^j}\widehat{i}_t^j, \tag{4.3}$$

where $\widehat{M}_t^j$ is the demand for money and $\widehat{i}_t^j$ the interest rate (changes of the interest rate). σ_M^j is the elasticity of money in the utility function and β^j is the intertemporal discount factor. Similarly, the condition with respect to optimal labour supply is:

$$\widehat{W}_t^j = \sigma_L^j \widehat{L}_t^j - \widehat{\lambda}_t^j + \widehat{\zeta}_{L,t}^j, \tag{4.4}$$

where $\widehat{W}_t^j$ is the wage level, $\widehat{L}_t^j$ the labour supply, and $\widehat{\zeta}_{L,t}^j$ the weight of working effort in the utility function.

In order to reduce the dimension of the model for estimation, we assume a linear production function. The capital labour ratio is implicit in the productivity process:

$$\widehat{Y}_t^j = \widehat{A}_t^j + \widehat{L}_t^j, \tag{4.5}$$

where $\widehat{Y}_t^j$ is the output. The marginal cost of the firm $\widehat{MC}_t^j$ is positively related to the wage level and negatively related to productivity:

$$\widehat{MC}_t^j = \widehat{W}_t^j - \widehat{A}_t^j. \tag{4.6}$$

We use the Calvo type pricing to incorporate nominal rigidity into our model. The producer price index $\widehat{P}_{j,t}^j$ is defined as:

$$\widehat{P}_{j,t}^j = \frac{\theta^j}{1+\beta^j\left(\theta^j\right)^2}\widehat{P}_{j,t-1}^j + \frac{\beta^j\theta^j}{1+\beta^j\left(\theta^j\right)^2}E_t\{\widehat{P}_{j,t+1}^j\} + \frac{\left(1-\theta^j\right)\left(1-\beta^j\theta^j\right)}{1+\beta^j\left(\theta^j\right)^2}\widehat{MC}_t^j + \widehat{\zeta}_{P,t}^j, \tag{4.7}$$

where $\widehat{\zeta}^{j}_{P,t}$ is the argument to evaluate the mark-up of the PPI on marginal cost. θ^{j} is the fraction of firms that have fixed price in the current period. The average duration for the firms to change price is $1/(1-\theta^{j})$. Our optimal pricing condition demonstrates that PPI combines effects from two sources: stickiness and changes in the marginal cost. Marginal cost positively affects PPI. At the same time, the previous level and expectation of future PPI have a bearing on price setting of firms who can change prices in the current period.

Households face budget constraints, which is converted to the resource constraint for each economy:

$$\widehat{P}^{j}_{j,t} + \widehat{Y}^{j}_{t} = \widehat{\zeta}^{j}_{G,t} + \zeta^{j}_{G}\widehat{P}^{j}_{j,t} + \zeta^{j}_{G}\widehat{Y}^{j}_{t} + \zeta^{j}_{C}\widehat{P}^{j}_{t} + \zeta^{j}_{C}\widehat{C}^{j}_{t}, \tag{4.8}$$

where $\widehat{\zeta}^{j}_{G,t}$ is the change in the ratio of government spending to output. We define that the fiscal policy controls the government spending sharing in the total output of the country. $\widehat{\zeta}^{j}_{G,t}$ is an AR(1) process with a shock to the government spending share in the total output. ζ^{j}_{G} is the steady state ratio of government spending to output. ζ^{j}_{C} is the share of consumption. CPI is the weighted average of PPIs of domestic goods and foreign goods:

$$\widehat{P}^{j}_{t} = \sum_{j' \in J} \left(a^{j}_{C,j'}\widehat{P}^{j'}_{j',t}\right) + \sum_{j' \in J} \left(a^{j}_{C,j'}\widehat{\mathcal{E}}^{j'}_{j,t}\right). \tag{4.9}$$

In addition, goods produced by each country should satisfy the market clearing condition:

$$\left(1-\zeta_G^j\right)\widehat{Y}_t^j = \widehat{\zeta}_{G,t}^j + \frac{1}{n^j}\sum_{j'\in J}\left(n^{j'}a_{C,j}^{j'}\zeta_C^{j'}\zeta_{Y,j}^{j'}\widehat{C}_t^{j'} - n^{j'}a_{C,j}^{j'}\zeta_C^{j'}\zeta_{Y,j}^{j'}\eta^{j'}\widehat{P}_{j,t}^j \right.$$
$$\left. - n^{j'}a_{C,j}^{j'}\zeta_C^{j'}\zeta_{Y,j}^{j'}\eta^{j'}\widehat{\mathcal{E}}_{j',t}^j + n^{j'}a_{C,j}^{j'}\zeta_C^{j'}\zeta_{Y,j}^{j'}\eta^{j'}\widehat{P}_t^{j'}\right), \quad (4.10)$$

where n^j is the share of the country in the world population and η^j is the trade elasticity between domestic and foreign goods in consumption.

Monetary policies in the US, the EA and ROW are all assumed to follow the general Taylor rule:

$$\widehat{i}_t^j = \rho_{i,1}^j\widehat{i}_{t-1}^j + \left(1-\rho_{i,1}^j\right)\rho_{i,2}^j\widehat{P}_t^j + \left(1-\rho_{i,1}^j\right)\rho_{i,3}^j\widehat{Y}_t^j + \epsilon_{i,t}^j, \quad (4.11)$$

where $\rho_{i,1}^j$ is the parameter representing the degree of inertia of the interest rate. $\rho_{i,2}^j$ and $\rho_{i,3}^j$ measure the response of monetary policy to inflation and output, respectively. $\epsilon_{i,t}^j$ is the shock to the interest rate. China adopts both credit limit and savings rate regulation for the monetary policy (He and Wang 2011). Our model has two versions which correspond to these two policies respectively. In the first version, China's policy is described by a standard Taylor rule (equation 4.11) similar as other economies. The second version of the model uses a quantity rule:

$$\widehat{M}_t^1 = \rho_{M,1}^1\widehat{M}_{t-1}^1 + \left(1-\rho_{M,1}^1\right)\rho_{M,2}^1\widehat{P}_t^1 + \left(1-\rho_{M,1}^1\right)\rho_{M,3}^1\widehat{Y}_t^1 + \epsilon_{M,t}^1. \quad (4.12)$$

The quantity rule is assumed to have a similar structure with the interest rate rule so that we can compare the values of the estimated parameters of these two versions of policy functions.

Except for the interest rate or money shock, other shocks are all incorporated into the system by the AR(1) processes:

$$\widehat{A}_t^j = \rho_A^j \widehat{A}_{t-1}^j + \epsilon_{A,t}^j, \tag{4.13}$$

$$\widehat{\zeta}_{G,t}^j = \rho_G^j \widehat{\zeta}_{G,t-1}^j + \epsilon_{G,t}^j, \tag{4.14}$$

$$\widehat{\zeta}_{P,t}^j = \rho_P^j \widehat{\zeta}_{P,t-1}^j + \epsilon_{P,t}^j, \tag{4.15}$$

$$\widehat{\zeta}_{L,t}^j = \rho_L^j \widehat{\zeta}_{L,t-1}^j + \epsilon_{L,t}^j. \tag{4.16}$$

In total, the system consists of 62 equations with 62 endogenous variables and 20 exogenous variables for the four-country model.

4.3. The Bayesian Approach for Estimation

The Bayesian approach derives the posterior distributions of the parameters by updating their prior distributions with the density of the sample conditional on the parameters. It serves as a means of resolving the problems of misspecification of structural models. When the data are not informative enough, it also provides better identification than other approaches such as maximum likelihood (Lubik and Schorfheide 2006). Prior distributions define meaningful expectations about the parameters so that the posteriors can be more credible than other approaches. In the case where the sample is short in period or lacks observables, the Bayesian approach provides a way to obtain estimation based on the priors. The steps of applying this approach include solution of the model, linking the model with observables, choosing priors and reaching posteriors for the parameters (Adjemian 2010).

The NOEM model developed in the previous section can be expressed in the structural form Φ:

$$E_t\left[\Phi\left(X_{t+1}, X_t, X_{t-1}, \varepsilon_t\right)\right] = 0, \tag{4.17}$$

where X_t is the vector of endogenous variables and ε_t is the vector of structural shocks. A solution to the model requires expressing the model by state equations Ψ:

$$X_t = \Psi\left(X_{t-1}, \varepsilon_t\right). \tag{4.18}$$

The endogenous variables are in the function of their first lag and the shocks in the current period. In most cases, equation (4.18) could not be solved explicitly. The equations are approximated around the deterministic steady state by Taylor expansion. The steady state of the endogenous variables $\overline{X}$ satisfies:

$$E_t\left[\Phi\left(\overline{X}, \overline{X}, \overline{X}, 0\right)\right] = 0. \tag{4.19}$$

The first-order approximation of equation (4.18) around the steady state derives at the following condition:

$$\Phi\left(\overline{X},\overline{X},\overline{X},0\right)+\frac{\partial\Phi}{\partial X_{t+1}}\left\{\frac{\partial\Psi}{\partial X_{t-1}}\left[\frac{\partial\Psi}{\partial X_{t-1}}\left(X_{t-1}-\overline{X}\right)+\frac{\partial\Psi}{\partial\varepsilon_t}\varepsilon_t\right]\right.$$
$$\left.+\frac{\partial\Psi}{\partial\varepsilon_t}\varepsilon_{t+1}\right\}+\frac{\partial\Phi}{\partial X_t}\left[\frac{\partial\Psi}{\partial X_{t-1}}\left(X_{t-1}-\overline{X}\right)+\frac{\partial\Psi}{\partial\varepsilon_t}\varepsilon_t\right]$$
$$+\frac{\partial\Phi}{\partial X_{t-1}}\left(X_{t-1}-\overline{X}\right)+\frac{\partial\Phi}{\partial\varepsilon_t}\varepsilon_t=0. \qquad (4.20)$$

After adopting expectation on both sides of equation (4.20), the condition reduces to:

$$\left(\frac{\partial\Phi}{\partial X_{t+1}}\frac{\partial\Psi}{\partial X_{t-1}}\frac{\partial\Psi}{\partial X_{t-1}}+\frac{\partial\Phi}{\partial X_t}\frac{\partial\Psi}{\partial X_{t-1}}+\frac{\partial\Phi}{\partial X_{t-1}}\right)\left(X_{t-1}-\overline{X}\right)$$
$$+\left(\frac{\partial\Phi}{\partial X_{t+1}}\frac{\partial\Psi}{\partial X_{t-1}}\frac{\partial\Psi}{\partial\varepsilon_t}+\frac{\partial\Phi}{\partial X_t}\frac{\partial\Psi}{\partial\varepsilon_t}+\frac{\partial\Phi}{\partial\varepsilon_t}\right)\varepsilon_t=0. \qquad (4.21)$$

The above condition holds for any value of X_{t-1} and ε_t. $\partial\Phi/\partial X_{t+1}$, $\partial\Phi/\partial X_t$, $\partial\Phi/\partial X_{t-1}$ and $\partial\Phi/\partial\varepsilon_t$ are given by the structural equations. The two unknowns are $\partial\Psi/\partial X_{t-1}$ and $\partial\Psi/\partial\varepsilon_t$. A unique solution for $\partial\Psi/\partial X_{t-1}$ exists when the Blanchard-Kahn condition is satisfied. This condition states that the solution is unique if the number of eigenvalues larger than one is equal to the number of forward looking variables (control variables) in the system. The approximation of the state equations can be expressed as:

$$X_t=\overline{X}+\frac{\partial\Psi}{\partial X_{t-1}}\left(X_{t-1}-\overline{X}\right)+\frac{\partial\Psi}{\partial\varepsilon_t}\varepsilon_t. \qquad (4.22)$$

The state equations of the model are solved out with equation (4.22).

Meanwhile a subgroup of the endogenous variables is linked to the observations by measurement equations:

$$X_t^* = \Gamma X_t + \nu_t. \tag{4.23}$$

ν_t are the measurement errors that could be added to the system. The subgroup of the parameters to be estimated is supposed to be Ξ. It can be seen that equations (4.22) and (4.23) are linking the distributions of endogenous variables in the current period with their distributions in the previous period. With Bayes' theorem, the posterior distributions of the parameters are expressed as:

$$p_1(\Xi|X^*) = \frac{p_0(\Xi)p(X^*|\Xi)}{p(X^*)}, \tag{4.24}$$

where $p_1(\Xi|X^*)$ is the density of posterior distributions and $p_0(\Xi)$ is the density of prior distributions. $p(X^*|\Xi)$ is the probability density function of the sample conditional on the parameters, which is also defined as the likelihood. Except for a constant term, the posterior density is proportional to the product of the prior density and the likelihood:

$$p_1(\Xi|X^*) \propto p_0(\Xi)p(X^*|\Xi). \tag{4.25}$$

Equation (4.25) demonstrates how the prior distributions affect the posteriors. When the likelihood function is flat with the choice of parameter values, it is possible that identification with maximum likelihood estimation is difficult and the estimates are far from credible. In that case, priors enter to help decide the posteriors.

The Bayesian approach reduces to calibration when the values of the parameters are certain with deterministic priors. On the other hand, one can estimate with non-informative priors. For example, if the distributions of the priors are assumed to be uniform, then the posterior distributions are only dependent on the likelihood. There are different means to choose the priors. Subjective choice includes setting the priors based on previous empirical evidence or the values according to a subgroup of the sample. Objective choice includes 'Minnesota' priors. Practically, types of the distributions of the priors are set to be consistent with the domains of the parameters. In order to evaluate to what extent Bayesian overcomes the problem of identification and misspecification, the sensitivity test could be performed by choosing different sets of priors or using more general assumptions. Generally, the posterior distributions of the parameters cannot be derived explicitly. The distributions are usually simulated by creating draws from the posteriors using the Metropolis-Hastings algorithm (Griffoli 2008).

4.4. Estimation

The four-country NOEM model provides the foundation for the analyzing interactions between China and other major economies in the world economy. In order to derive the potential heterogeneous structural features of China and other economies, we estimate our linearized model in this section using the Bayesian approach. We investigate the structural features implied by the posteriors of the parameters and compare those values between China and the other three blocks to identify the heterogeneity implied by the information inhabited in the data.

4.4.1. Observables, Calibrated Parameters and Priors

Observables for our estimation include $\widehat{Y}_t^1$, $\widehat{Y}_t^2$, $\widehat{Y}_t^3$, $\widehat{Y}_t^4$, $\widehat{P}_t^1$, $\widehat{P}_t^2$, $\widehat{P}_t^3$, $\widehat{P}_t^4$, $\widehat{P}_{1,t}^1$, $\widehat{P}_{2,t}^2$, $\widehat{P}_{3,t}^3$, $\widehat{P}_{4,t}^4$, $\widehat{\mathcal{E}}_{1,t}^2$, $\widehat{\mathcal{E}}_{2,t}^3$, $\widehat{M}_t^1$, $\widehat{i}_t^1$, $\widehat{i}_t^2$ and $\widehat{i}_t^3$. Estimation is based on quarterly data from 2000Q1 to 2010Q4. The data are de-trended using the Hodrick-Prescott (HP) filtered series with a smoothing factor of 1600 which is consistent with quarterly data.

By the definition of the ROW, we should exclude China, the United States and the Euro Area from the data of the Rest of the World, for example, using GDP excluding these three blocks. However, the dataset here is using the world average series for the ROW. The possible problem of this approach is to cause some degree of multicollinearity. We provide the correlations matrix for these variables in Table 4.1. Practically, we find that this approach does not cause larger correlations of these economies with the Rest of the World. For example, the average correlation of the GDPs of the three economies with the Rest of the World is 0.58, while the average correlation of the GDPs between these three economies is 0.55. We can find even lower correlations between these economies and the ROW for CPI and PPI. Secondly, the net trade balance data for ROW with other blocks is excluding these three blocks,

Table 4.1 Correlation matrix

		Money	Interest rate		
		China	China	US	EA
Money	China	1.00	-0.63	-0.50	-0.67
Interest rate	China		1.00	0.28	0.59
	US			1.00	0.67
	EA				1.00

	Exchange rate	
	RMB / USD	USD / Euro
RMB / USD	1.00	-0.21
USD / Euro		1.00

CPI	China	US	EA	ROW
China	1.00	0.21	0.33	0.70
US		1.00	0.60	0.10
EA			1.00	0.23
ROW				1.00

PPI	China	US	EA	ROW
China	1.00	0.35	0.68	0.84
US		1.00	0.78	0.18
EA			1.00	0.57
ROW				1.00

GDP	China	US	EA	ROW
China	1.00	0.41	0.61	0.73
US		1.00	0.62	0.36
EA			1.00	0.63
ROW				1.00

Net trade (home country / foreign country)	China / US	China / EA	China / ROW	US / EA	US / ROW	EA / ROW
China / US	1.00	0.33	0.30	-0.36	-0.55	0.06
China / EA		1.00	0.31	0.07	-0.18	-0.40
China / ROW			1.00	-0.50	-0.42	0.52
US / EA				1.00	0.80	-0.64
US / ROW					1.00	-0.31
EA / ROW						1.00

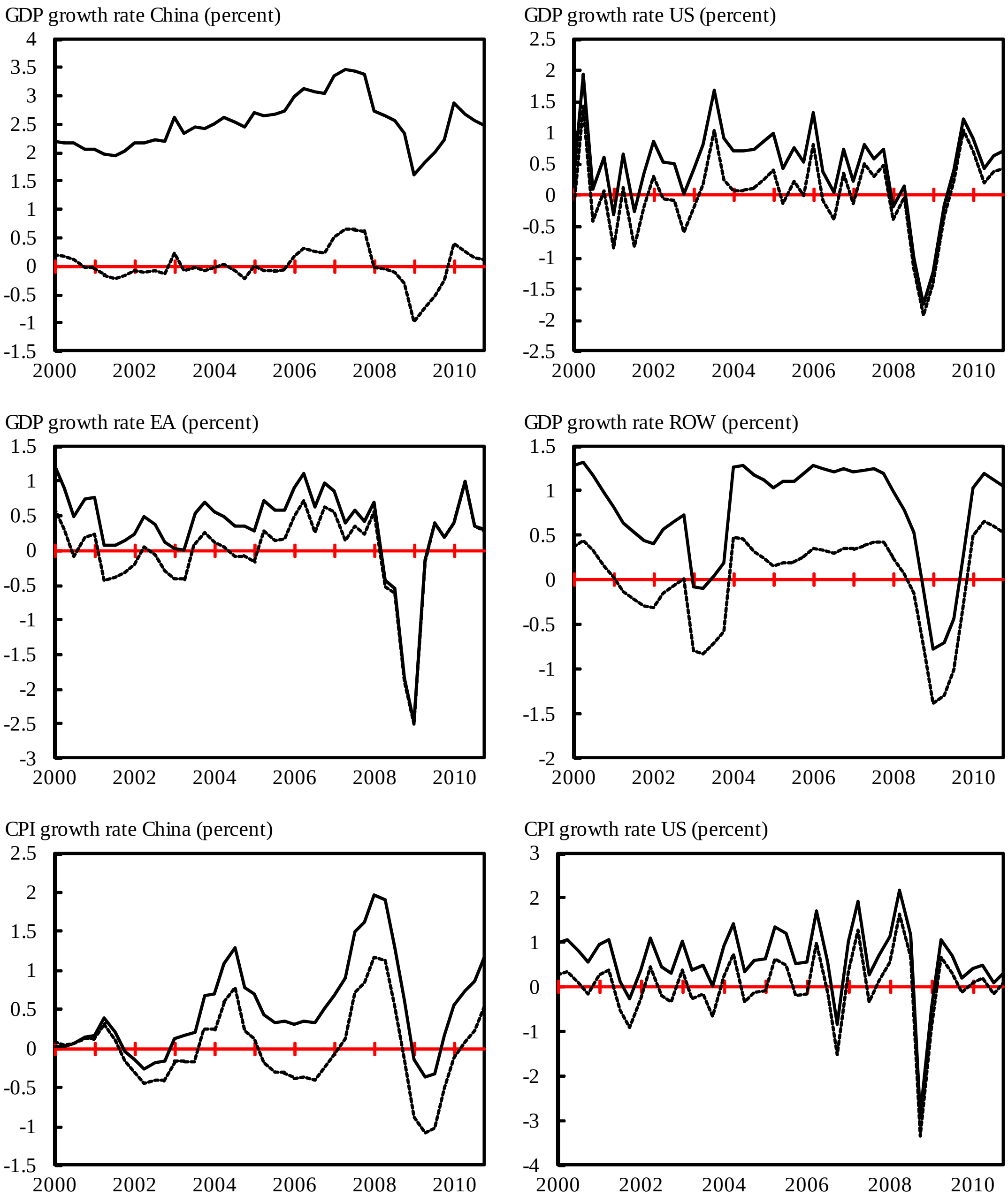
which is a true representing of the ROW. Lastly, only three world average series enter the dataset, which are CPI, PPI and GDP. For the other three economies, they also include monetary policy, and exchange rates. Thereby we confirm the degree of multicollinearity and the problem it may bring is not seriously increased by our approach.

The sample period is from 2000Q1 to 2010Q4. This period is chosen according to the longest available series for quarterly data, and also the adoption of the euro. Although the convergence of the Euro Area could be traced back to early 1990s and there is also research synthesizing data for this area before 1999 (Fagan, Henry, and Mestre 2005), the period after adoption provides a few benefits. This period covers the use of one single currency by all member countries in the EA. Since the exchange rate is a crucial variable in the evaluation of international interdependence in open economy modelling, a single currency with market price facilitates the model setting and also provides empirical precision. In addition, the integration within the Euro Area is observed to be stronger after 2000 than before. De Hann, Inklaar, and Jong-A-Pin (2008) examines the integration of business cycles within the EA and this provides the basis for our aggregation the countries within. A sample size of 44 is usually not enough for empirical approaches such as standard VAR estimation. However, we use the Bayesian approach, which has no restriction on the sample size. As we discuss in Section 4.3, one benefit of Bayesian is by setting up the priors, the estimation updates the distributions to get posteriors using information in the data, which even works with very short time series.

Figure 4.1 depicts the original series (solid line) and the de-trended data (dashed line). $\widehat{Y}_t^1$, $\widehat{Y}_t^2$, $\widehat{Y}_t^3$ and $\widehat{Y}_t^4$ are quarterly real GDP growth rates of the four blocks. Growth rates for China are calculated from quarterly publications of annualized GDP growth rates by the National Bureau of Statistics (NBS). US real GDP growth is the 'GDPC96' series from the Bureau of Economic Analysis (BEA). For Euro Area GDP, we use the data generated by the AWM and the series is 'ESA.Q.I6.Y.0000.B1QG00.1000. TTTT.L.U.A'. World real GDP growth rates are the percentage changes of GDP volume published by International Financial Statistics (IFS) of IMF. The plots of the GDP growth rates show consistently high trending growth for China. The Rest of the World stands the second for the trend growth, which implies high real growth of the world economy since 2000. We can also observe very small trends for the two developed economies.

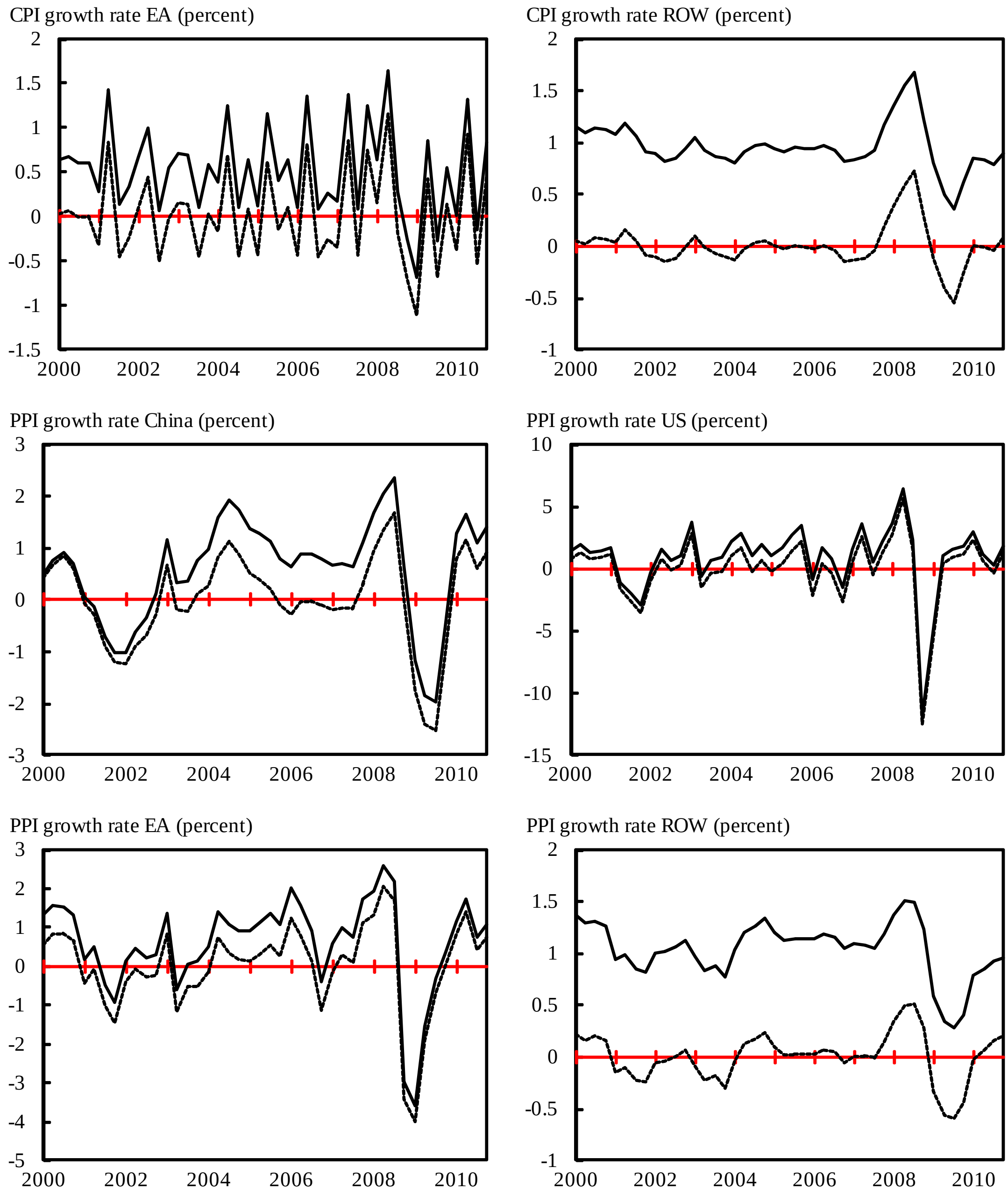
$\widehat{P}_t^1$, $\widehat{P}_t^2$, $\widehat{P}_t^3$ and $\widehat{P}_t^4$ are quarterly CPI growth rates. The data series for China and ROW are '64..XZF' and those for the US and the EA are '64…ZF', all from the IMF IFS. In Figure 4.1, CPIs of China and the ROW display different style with the US and the EA. The former two economies have more persistent fluctuations, while the later two are more often mean reverting. This suggests the two developed economies have more strict inflation targets and better monetary policy instruments. $\widehat{P}_{1,t}^1$, $\widehat{P}_{2,t}^2$, $\widehat{P}_{3,t}^3$ and $\widehat{P}_{4,t}^4$ are PPI growth rates. We use '63..XZF' for China and '63…ZF' for the US and the EA from IMF IFS. PPI growth rates of the world are not published by the

Figure 4.1 Graphs of the observables



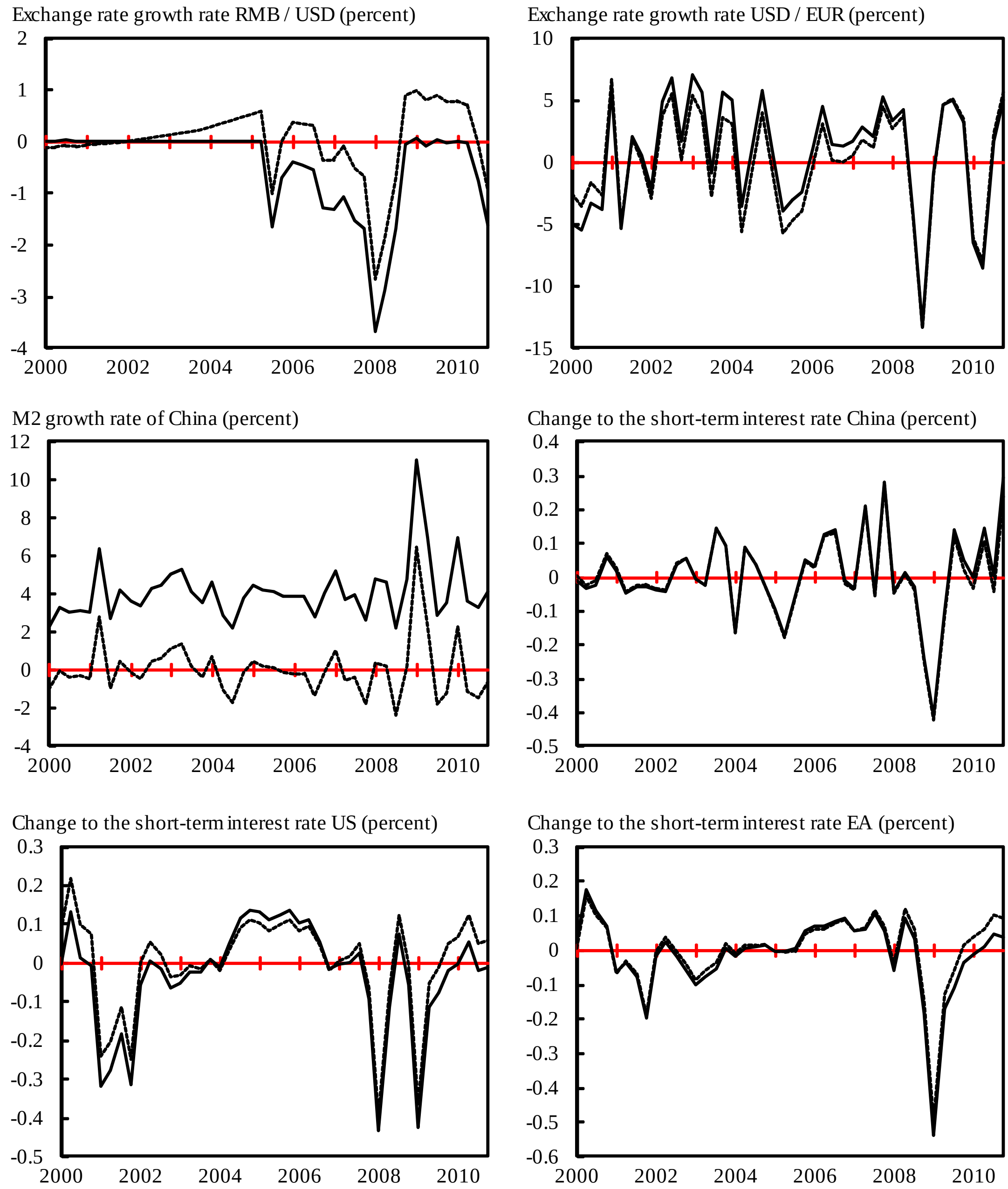
Solid line: original series; Dashed line: HP de-trended series

Figure 4.1 (continued) Graphs of the observables



Solid line: original series; Dashed line: HP de-trended series

Figure 4.1 (continued) Graphs of the observables



Solid line: original series; Dashed line: HP de-trended series

IMF, and the GDP deflator '99BIX8F' is used to proxy them. PPIs display similar styles as CPIs for these economies.

$\widehat{\mathcal{E}}_{1,t}^{2}$ and $\widehat{\mathcal{E}}_{2,t}^{3}$ are quarterly exchange rates growth rates for China and the EA, calculated from the Main Economic Indicators (MEI) of the Organization of Economic Co-operation and Development (OECD). Figure 4.1 displays strong evidence of China's management of the exchange rate, before 2005 and during financial crisis. Monetary supply of China $\widehat{M}_t^1$ is captured by M2 '59MB.ZF' from IMF IFS. $\widehat{i}_t^1$, $\widehat{i}_t^2$ and $\widehat{i}_t^3$ are interest rates for China, the US and the EA, respectively, and they are obtained from the short-term interest rates of the MEI of the OECD. All interest rates are taken first-order difference to match the definition, which is the change to the interest rates in the model.

Table 4.2 illustrates the descriptive statistics for observables. The GDP of China ranks the first in the average growth with a quarterly rate of 2.5 percent and smallest standard deviation. The US and the EA both have similar fluctuations, but the EA has much smaller average GDP growth. The ROW growth is between the fast growing China and the developed economies. China, the US and the EA all have smaller inflation and PPI than the ROW, showing better functioning monetary policy of these three economies. Both renminbi (RMB) and euro appreciate quarterly by 0.49 percent

Table 4.2 Descriptive statistics for observables

Series	Market	Mean	Median	Standard deviation
GDP	China	2.50	2.49	0.44
	US	0.44	0.55	0.67
	EA	0.32	0.40	0.66
	ROW	0.76	1.03	0.57
CPI	China	0.49	0.34	0.58
	US	0.60	0.58	0.79
	EA	0.52	0.56	0.51
	ROW	0.95	0.92	0.23
PPI	China	0.57	0.74	1.00
	US	0.87	1.34	2.73
	EA	0.60	0.90	1.21
	ROW	1.03	1.07	0.27
Exchange rate	RMB / USD	-0.49	0.00	0.85
	USD / EUR	0.61	1.53	4.61
Money	China	4.09	3.87	1.54
Interest rate	China	0.01	-0.01	0.12
	US	-0.03	-0.01	0.14
	EA	-0.01	0.00	0.11

Interest rate: deviations from previous period; Other series: growth rates

and 0.61 percent, respectively. China's smaller appreciation rate than the euro is probably due to the exchange rate policy.

We use the Bayesian approach to infer posterior distributions for the parameters of elasticities, habit, degrees of rigidity, shock persistency and monetary policy reaction. Before that, we set the values for the calibrated parameters and the prior means and types of distribution for the estimated parameters. Besides the potential to resolve misspecification and provide identification, Bayesian also practically benefits the user by fixing part of the parameters while estimating the others.

The calibrated parameters include the population share n^j, intertemporal discount factor β^j, relative output between countries $\zeta_{Y,j}^{j'}$, share of goods from different countries in the consumption basket $a_j^{j'}$, ratio of government spending to output ζ_G^j, and ratio of consumption to output ζ_C^j. Table 4.3 exhibits the values of the calibrated parameters. n^j are the three year average from 2008 to 2010 of the population shares of China, the US and the EA in the world. Population data are from 'SP.POP.TOTL' of the World Development Indicators (WDI) of the World Bank. Among these blocks, the ROW has the largest population share, which is about 70.2 percent, and China with about 20.2 percent standing the second. The intertemporal discount factor β^j is set to be 0.995, corresponding to a steady state interest rate level of two percent. The output ratios $\zeta_{Y,j}^{j'}$ are defined as relative per capita real GDP between two blocks. The per capita GDP of China is the real GDP data 'NY.GDP.MKTP.KD' of 2010 divided by the population, both from the WDI. One feature of the Chinese economy is the low per capita output. Per capita outputs of the United States, the Euro Area and the Rest of the World are 10.742, 8.356, and 2.098 times that of China. Even with larger population than the US and the EA, China still consists of smaller weight in the world GDP. To c3alculate the share of goods from each country in the consumption basket $a_j^{j'}$, we first obtain the degree of openness which is the ratio of total imports to

Table 4.3 Values for calibrated parameters

n^j	**Share in world population**			
	China	US	EA	ROW
	0.202	0.046	0.050	0.702

β^j	**Intertemporal discount factor**
	0.995

$\zeta_{Y,j}^{j'}$	**Relative output of the country j' to country j**			
j \ j'	China	US	EA	ROW
China		10.742	8.356	2.098
US	0.093		0.778	0.195
EA	0.120	1.285		0.251
ROW	0.477	5.128	3.984	

$a_{C,j}^{j'}$	**Share of intermediate goods produced by country j in final goods production in country j'**			
j \ j'	China	US	EA	ROW
China	0.771	0.018	0.016	0.052
US	0.017	0.866	0.014	0.045
EA	0.023	0.018	0.686	0.147
ROW	0.189	0.098	0.284	0.756

ζ_G^j	**Ratio of government spending to output**			
	China	US	EA	ROW
	0.144	0.158	0.205	0.173

ζ_C^j	**Ratio of consumption to output**			
	China	US	EA	ROW
	0.856	0.842	0.795	0.827

GDP. Total imports are the aggregated level provided by IMF Direction of Trade Statistics (DOTS) and GDP is the nominal level from 'NY.GDP.MKTP.CD' in WDI. The domestic goods share in consumption is then derived by using one minus the degree of openness. The degree of openness is distributed into each foreign partner by the weight of import from that area in the country's total imports. The data of volume of imports from a specific partner are also from IMF DOTS. Finally, these shares are averaged for the three years from 2008 to 2010. Our calibration shows the US has the least open goods markets, with 86.6 percent of the consumption from home produced goods. On the other hand, the EA is most open, with the lowest degree of openness 68.6 percent. China has similar average level as the ROW. ζ_G^j is the government consumption expenditure obtained directly from the WDI and is also three years' average. ζ_C^j is derived by the steady state condition $\zeta_C^j = 1 - \zeta_G^j$. China has the least government spending ratio, while the EA has the largest one, which is over 20.5 percent.

Instead of setting asymmetry priors for parameters to be estimated for these four blocks, we use symmetric priors. After we update these priors using information from data, we aim to evaluate how the posteriors of the parameters are different between the economies. By controlling the priors, we can attribute all the asymmetry reflected by the posteriors to the information of data. Selection of values for the prior means follows theoretical and empirical evidence in the literature. We do not use a subsample to derive priors since data regarding China has small sample size and all observations are used for the estimation to provide better identification. Table 4.4 displays our settings for the prior means, distributions and standard deviations.

Table 4.4 Prior distributions for estimated parameters

		Prior mean	Prior distribution	Standard deviation			Prior mean	Prior distribution	Standard deviation
σ_C	CN	1.50	Gamma	0.20	ρ_A	CN	0.20	Beta	0.10
	US	1.50	Gamma	0.20		US	0.20	Beta	0.10
	EA	1.50	Gamma	0.20		EA	0.20	Beta	0.10
	ROW	1.50	Gamma	0.20		ROW	0.20	Beta	0.10
σ_M	CN	1.50	Gamma	0.20	ρ_G	CN	0.20	Beta	0.10
	US	1.50	Gamma	0.20		US	0.20	Beta	0.10
	EA	1.50	Gamma	0.20		EA	0.20	Beta	0.10
	ROW	1.50	Gamma	0.20		ROW	0.20	Beta	0.10
σ_L	CN	1.50	Gamma	0.20	ρ_P	CN	0.20	Beta	0.10
	US	1.50	Gamma	0.20		US	0.20	Beta	0.10
	EA	1.50	Gamma	0.20		EA	0.20	Beta	0.10
	ROW	1.50	Gamma	0.20		ROW	0.20	Beta	0.10
η_C	CN	2.00	Gamma	0.20	ρ_L	CN	0.20	Beta	0.10
	US	2.00	Gamma	0.20		US	0.20	Beta	0.10
	EA	2.00	Gamma	0.20		EA	0.20	Beta	0.10
	ROW	2.00	Gamma	0.20		ROW	0.20	Beta	0.10
h	CN	0.50	Beta	0.10	ϵ_i	CN	0.50	Inverse gamma	0.25
	US	0.50	Beta	0.10		US	0.50	Inverse gamma	0.25
	EA	0.50	Beta	0.10		EA	0.50	Inverse gamma	0.25
	ROW	0.50	Beta	0.10		ROW	0.50	Inverse gamma	0.25
θ_P	CN	0.75	Beta	0.10	ϵ_A	CN	0.50	Inverse gamma	0.25
	US	0.75	Beta	0.10		US	0.50	Inverse gamma	0.25
	EA	0.75	Beta	0.10		EA	0.50	Inverse gamma	0.25
	ROW	0.75	Beta	0.10		ROW	0.50	Inverse gamma	0.25
$\rho_{i,1}$	CN	0.50	Beta	0.10	ϵ_G	CN	0.50	Inverse gamma	0.25
	US	0.50	Beta	0.10		US	0.50	Inverse gamma	0.25
	EA	0.50	Beta	0.10		EA	0.50	Inverse gamma	0.25
	ROW	0.50	Beta	0.10		ROW	0.50	Inverse gamma	0.25
$\rho_{i,2}$	CN	1.50	Gamma	0.20	ϵ_P	CN	0.50	Inverse gamma	0.25
	US	1.50	Gamma	0.20		US	0.50	Inverse gamma	0.25
	EA	1.50	Gamma	0.20		EA	0.50	Inverse gamma	0.25
	ROW	1.50	Gamma	0.20		ROW	0.50	Inverse gamma	0.25
$\rho_{i,3}$	CN	0.50	Gamma	0.20	ϵ_L	CN	0.50	Inverse gamma	0.25
	US	0.50	Gamma	0.20		US	0.50	Inverse gamma	0.25
	EA	0.50	Gamma	0.20		EA	0.50	Inverse gamma	0.25
	ROW	0.50	Gamma	0.20		ROW	0.50	Inverse gamma	0.25

The elasticity of consumption σ_C^j, which is also known as the risk aversion coefficient, is set to have a mean value of 1.5. Evidence on this parameter usually falls within the range from 1.0 to 2.0. A large proportion of the literature uses 1.0 for the ease of log-utility for consumption, such as Smets and Wouters (2007), Gali and Monacelli (2005) for the US and Smets and Wouters (2003) for the EA. Zhang (2009) and Plasmans, Michalak, and Fornero (2006) take a value of 2.0 for China and the Netherlands, respectively. We use a reasonable value within this range. We also set the elasticity of money σ_M^j and the elasticity of labour σ_L^j to be 1.5. Sargent and Surico (2011) use the value 4.0 and it is close to 3.13 by Zhang's (2009) estimation. Coenen, McAdam and Straub (2008) apply a value of 2.0 for the inverse Fisher elasticity for labour both in the US and Europe. Smets and Wouters (2003) apply a similar value for Europe and the US level by Gali and Monacelli (2005) is 3.0. The values are the same as the elasticity of consumption to examine their differences after estimation. Bodenstein (2011) discusses extensively the value of elasticity of intermediate goods from different countries η^j, which is called trade elasticity. Higher elasticity can be found in the studies with more aggregated data. We follow this thinking and set the prior of international trade elasticity to be 2.0.

The coefficients on habit persistence h^j stay within the range of zero to one, and we set the prior value to be 0.5 with a beta distribution and a standard deviation of 0.1. The coefficient that controls the degree of rigidity θ^j is the share of the companies that can only use the previously set price. Our value is 0.75, which corresponds to an average length of changing contract in four quarters. These parameters are the two major coefficients to describe the different inertia of the economies.

Monetary policy contains three parameters. Interest rate (or money supply) inertia coefficient $\rho^j_{i,1}$ (or $\rho^j_{M,1}$) has a mean of 0.5. Reaction coefficients to inflation $\rho^j_{i,2}$ (or $\rho^j_{M,2}$) and to output $\rho^j_{i,3}$ (or $\rho^j_{M,3}$) are 1.5 and 0.5, respectively. These values are consistent with standard settings in the literature of monetary policy (Lubik and Schorfheide 2006). We set the same value for the AR(1) coefficient on shocks ρ^j_A, ρ^j_L, ρ^j_P and ρ^j_G, which is 0.2. The means for the standard deviations ϵ_i, ϵ_A, ϵ_L, ϵ_P and ϵ_G are all 0.5. This value is at a similar level as the standard deviations of the observables.

The type of probability density function of each parameter is determined according to the domain of the parameter. Parameters with domain $(0,1)$ are assumed to have beta distributions and those with domain $(0,\infty)$ are of gamma distributions. The distributions of standard deviations are all inverse gamma. Correspondingly, we set the standard deviation to be 0.1 for beta distributions, 0.2 for gamma distributions and 0.25 for inverse gamma distributed parameters.

4.4.2. Estimation Results

In this section, we illustrate our estimation findings about the posterior means of the parameters. Since we estimate two versions of the model with different policy function for China, we first introduce the findings with estimation using the interest rate rule. Then we compare the difference of estimation results between these two versions.

We estimate our model based on symmetric priors for the structural parameters excluding the calibrated parameters introduced above. Not surprisingly, after updating priors with data, the posterior distributions for the parameters of these four blocks imply a large amount of cross-country heterogeneity. Table 4.5 presents our priors and posteriors for the structural parameters. We estimate our model based on different monetary policies for China, either based on interest rate rule or quantity rule, whose estimation results are indicated by column 'I' and 'II', respectively. Generally, estimation results based on these two rules are similar. Both the interest rule and quantity rule identify the responses of the monetary policy to inflation and output gap. In what follows, we first focus on the results based on the estimation using the interest rate rule, and then we introduce the difference between these two estimations.

Table 4.5 Prior and posterior distributions for estimated parameters

		Prior mean	Posterior mean I	Posterior mean II	Confidence interval (90 percent) I	I	II	II	Prior distribution	Standard deviation
σ_C	China	1.50	1.73	2.42	1.60	1.87	2.20	2.65	Gamma	0.20
	US	1.50	1.97	2.60	1.85	2.11	2.54	2.67	Gamma	0.20
	EA	1.50	2.09	2.11	1.97	2.18	1.98	2.24	Gamma	0.20
	ROW	1.50	1.41	1.34	1.34	1.48	1.23	1.45	Gamma	0.20
σ_M	China	1.50	1.40	0.93	1.26	1.53	0.83	1.00	Gamma	0.20
	US	1.50	1.67	1.22	1.48	1.87	1.10	1.36	Gamma	0.20
	EA	1.50	1.61	1.28	1.47	1.76	1.18	1.38	Gamma	0.20
	ROW	1.50	1.40	1.17	1.20	1.64	1.06	1.29	Gamma	0.20
σ_L	China	1.50	1.08	1.13	0.95	1.22	0.99	1.27	Gamma	0.20
	US	1.50	1.72	1.50	1.54	1.88	1.30	1.71	Gamma	0.20
	EA	1.50	1.49	1.10	1.33	1.65	1.03	1.18	Gamma	0.20
	ROW	1.50	1.15	1.00	1.00	1.33	0.90	1.13	Gamma	0.20
η_C	China	2.00	1.07	0.99	0.98	1.16	0.98	1.02	Gamma	0.20
	US	2.00	1.05	1.02	0.98	1.09	0.99	1.05	Gamma	0.20
	EA	2.00	1.00	0.98	0.98	1.02	0.98	0.99	Gamma	0.20
	ROW	2.00	0.98	0.98	0.98	0.99	0.98	0.98	Gamma	0.20
h	China	0.50	0.57	0.26	0.49	0.63	0.22	0.31	Beta	0.10
	US	0.50	0.45	0.56	0.40	0.49	0.50	0.62	Beta	0.10
	EA	0.50	0.13	0.08	0.09	0.17	0.05	0.10	Beta	0.10
	ROW	0.50	0.32	0.27	0.28	0.35	0.19	0.35	Beta	0.10
θ_P	China	0.75	0.72	0.66	0.66	0.77	0.63	0.69	Beta	0.10
	US	0.75	0.69	0.65	0.66	0.72	0.61	0.69	Beta	0.10
	EA	0.75	0.87	0.94	0.82	0.92	0.90	0.97	Beta	0.10
	ROW	0.75	0.66	0.82	0.56	0.75	0.75	0.90	Beta	0.10
$\rho_{i,1}$	China	0.50	0.82	0.61	0.77	0.88	0.57	0.67	Beta	0.10
	US	0.50	0.92	0.90	0.89	0.94	0.87	0.93	Beta	0.10
	EA	0.50	0.90	0.63	0.87	0.93	0.57	0.69	Beta	0.10
	ROW	0.50	0.49	0.13	0.41	0.56	0.09	0.16	Beta	0.10
$\rho_{i,2}$	China	1.50	1.16	1.34	1.01	1.29	1.28	1.39	Gamma	0.20
	US	1.50	1.11	0.92	0.98	1.24	0.82	1.01	Gamma	0.20
	EA	1.50	1.83	1.78	1.70	1.95	1.68	1.88	Gamma	0.20
	ROW	1.50	1.46	1.42	1.37	1.58	1.30	1.55	Gamma	0.20
$\rho_{i,3}$	China	0.50	0.31	0.10	0.18	0.44	0.04	0.15	Gamma	0.20
	US	0.50	1.28	1.37	1.03	1.54	1.28	1.46	Gamma	0.20
	EA	0.50	0.22	0.25	0.11	0.29	0.15	0.35	Gamma	0.20
	ROW	0.50	0.39	0.86	0.24	0.51	0.81	0.92	Gamma	0.20

Model I: estimated with interest rate rule for monetary policy of China; Model II: estimated with quantity rule for monetary policy of China

Table 4.5 (continued) Prior and posterior distributions for estimated parameters

		Prior mean	Posterior mean I	Posterior mean II	Confidence interval (90 percent) I	I	II	II	Prior distribution	Standard deviation
ρ_A	China	0.20	0.10	0.13	0.03	0.17	0.06	0.18	Beta	0.10
	US	0.20	0.13	0.14	0.04	0.20	0.05	0.23	Beta	0.10
	EA	0.20	0.27	0.41	0.21	0.34	0.36	0.47	Beta	0.10
	ROW	0.20	0.16	0.72	0.10	0.23	0.68	0.78	Beta	0.10
ρ_G	China	0.20	0.50	0.34	0.44	0.57	0.27	0.40	Beta	0.10
	US	0.20	0.58	0.65	0.53	0.65	0.60	0.71	Beta	0.10
	EA	0.20	0.13	0.11	0.08	0.18	0.07	0.15	Beta	0.10
	ROW	0.20	0.49	0.28	0.32	0.66	0.23	0.33	Beta	0.10
ρ_P	China	0.20	0.17	0.05	0.11	0.24	0.02	0.08	Beta	0.10
	US	0.20	0.09	0.24	0.04	0.13	0.19	0.30	Beta	0.10
	EA	0.20	0.16	0.15	0.10	0.21	0.07	0.23	Beta	0.10
	ROW	0.20	0.12	0.12	0.05	0.18	0.08	0.15	Beta	0.10
ρ_L	China	0.20	0.08	0.33	0.03	0.12	0.29	0.38	Beta	0.10
	US	0.20	0.15	0.12	0.06	0.24	0.08	0.15	Beta	0.10
	EA	0.20	0.08	0.36	0.02	0.13	0.31	0.41	Beta	0.10
	ROW	0.20	0.09	0.11	0.04	0.14	0.08	0.15	Beta	0.10
ϵ_i	China	0.50	0.21	1.65	0.17	0.24	1.49	1.81	Inverse gamma	0.25
	US	0.50	0.18	0.19	0.15	0.21	0.15	0.23	Inverse gamma	0.25
	EA	0.50	0.16	0.40	0.13	0.19	0.30	0.48	Inverse gamma	0.25
	ROW	0.50	0.64	1.13	0.27	0.97	1.06	1.21	Inverse gamma	0.25
ϵ_A	China	0.50	1.43	1.34	1.09	1.74	1.24	1.45	Inverse gamma	0.25
	US	0.50	2.75	2.46	2.48	3.01	2.34	2.58	Inverse gamma	0.25
	EA	0.50	4.88	3.30	4.67	5.05	3.14	3.45	Inverse gamma	0.25
	ROW	0.50	0.31	0.31	0.22	0.40	0.19	0.42	Inverse gamma	0.25
ϵ_G	China	0.50	0.28	0.99	0.20	0.36	0.90	1.09	Inverse gamma	0.25
	US	0.50	1.25	0.84	1.11	1.42	0.68	1.01	Inverse gamma	0.25
	EA	0.50	3.89	3.29	3.63	4.16	3.07	3.47	Inverse gamma	0.25
	ROW	0.50	1.61	1.65	1.42	1.81	1.46	1.84	Inverse gamma	0.25
ϵ_P	China	0.50	0.22	0.27	0.17	0.26	0.20	0.34	Inverse gamma	0.25
	US	0.50	0.31	0.24	0.24	0.37	0.19	0.29	Inverse gamma	0.25
	EA	0.50	1.22	1.86	1.05	1.43	1.68	2.08	Inverse gamma	0.25
	ROW	0.50	0.64	0.72	0.52	0.78	0.63	0.81	Inverse gamma	0.25
ϵ_L	China	0.50	0.22	0.27	0.17	0.26	0.20	0.34	Inverse gamma	0.25
	US	0.50	0.31	0.24	0.24	0.37	0.19	0.29	Inverse gamma	0.25
	EA	0.50	1.22	1.86	1.05	1.43	1.68	2.08	Inverse gamma	0.25
	ROW	0.50	0.64	0.72	0.52	0.78	0.63	0.81	Inverse gamma	0.25

Model I: estimated with interest rate rule for monetary policy of China; Model II: estimated with quantity rule for monetary policy of China

Among the four economies, the developed economies generally have higher elasticities in the utility function. The elasticities of consumption σ_C^j in the utility function for the US and the EA are 1.97 and 2.09, respectively. These values are higher than the level of China, 1.73, and much higher than ROW, 1.41. From equation (4.2), the elasticity determines the magnitude of the response of consumption to the change in the marginal utility. The US and the EA have more volatile consumption than China and ROW facing the same change in the marginal utility. Our estimation is consistent with the literature. Lubik and Schorfheide (2006) estimates a two-country model for the US and the EA and finds the elasticity to be 2.81 and 3.01, respectively. Smets and Wouters (2003) concludes the parameter to have a mean of 1.391 and Jondeau and Sahuc (2008) finds a median of 2.078. Huang (2009) uses 2.00 to calibrate a China model, and Liu (2008) estimates the value for China to be 2.10. A few studies use the value two in their calibrations for these economies (Jacquinot and Straub 2008; Mehrotra, Nuutilainen, and Pääkkönen 2011).

The situation is similar for the elasticity of substitution of money σ_M^j. The US and the EA have higher levels at 1.67 and 1.61, respectively. China and ROW have the same degree at 1.40. This parameter is usually calibrated to have a value of one and induce log utility for money (Jian, Li, and Lu 2011; Breuss and Fornero 2009). Among the three elasticities, the labour elasticity σ_L^j shows the largest difference between these economies. The US has a value of 1.72 and China has the lowest level at 1.08. The literature on labour elasticity displays mixed results. For example, Lubik and Schorfheide (2006) set log utility for the US and the EA, while Haberis et al. (2011) use 10. Estimated values are generally around two, for example, 2.503 for the EA in Smets and Wouters (2003), 2.078 for the EA and 2.384 for the US in Breuss and Fornero (2009), and 1.934 for the EA in Jonheau and Sahuc (2008). Our estimation implies that the US labour market responds more to the change in marginal utility than does the Chinese labour market. If there is a shock originating from foreign countries and transmitted through international risk sharing, the responses of China and ROW are probably smaller than those of the US and the EA.

The trade elasticity η^j measures the preference between domestic and foreign goods in consumption. We find that the elasticity values are considerably different from the prior means, which is the evidence of good identification. Moreover, the values for the four blocks are all close to unity. The largest is China with 1.07; ROW has the smallest value at 0.98. Calibrated value for trade elasticity in the literature is usually one. Lubik and Schorfheide (2006) finds the value to be 0.43 for the US and the EA, and Breuss and Fornero (2009) derives 0.367, 0.365 and 0.413 for Austria, the US and the EA, respectively. Our findings conclude that the elasticity is about the same level for these economies, even if the values are different from the studies above. Since we set the international financial market to be complete, there is no trade surplus or deficit implied by this assumption. Complete market setting is consistent with the assumption of unity of trade elasticity, since unit elasticity also leads to proportional change of world distribution and thus balanced trade. This finding regarding trade elasticity confirms the soundness of our estimates.

The consumption habit h^j shows a large discrepancy between these four economies. The EA has the smallest habit persistency at 0.13 as shown in the consumption habit estimates. China and the US are relatively high at 0.57 and 0.45, respectively. Higher habit coefficient implies a slower adjustment process toward the long-run consumption level when the expectation of households changes. Our estimation finds greatest flexibility for households in the EA and more lagged consumption adjustment for China and the US. Our estimation using heterogeneous open economy model finds different values between these economies. Most studies find the habit persistent for the EA around 0.6 in closed economy or small open economy estimation, for example, 0.592 in Smets and Wouters (2003), 0.694 in Adolfson et al. (2007), and 0.63 in Jondeau and Sahuc (2008). Lubik and Schorfheide (2006) estimates 0.41 for the US and the EA in a symmetric model. Mehrotra, Nuutilainen, and Pääkkönen (2011) calibrate for China with a value of 0.76. These studies have inconsistent findings with each other and motive our approach.

Another distortion to the economy is price rigidity in the production sector in terms of coefficient θ^j. Although the EA has the greatest flexibility in consumption, it is the most distorted in price adjustment. The EA has the highest value at 0.87. China has a value close to the prior at 0.72. The US has a value of 0.69 and is similar to the degree of ROW, which is 0.66. Since the average length of contract is $1/(1-\theta^j)$, the EA has an average length of over 7.5 quarters, China about 3.5 quarters, and the US and the world about 3 quarters. Our estimation implies a high degree of inflexibility of the firms in the EA. This is confirmed by Lubik and Schorfheide (2006), which finds 0.62 and 0.90 for the US and the EA, respectively. Also, 0.905 in Smets and Wouters (2003) and 0.895 in Adolfson et al. (2007) reveals high stickiness of the EA.

Estimation I assumes a general Taylor rules adopted by monetary authorities of these four economies. China, the US and the EA all have higher inertia coefficients of their interest rate policy, which are 0.82, 0.92 and 0.90, respectively. A high level of inertia implies a long and persistent interest rate cycle. The reaction of interest rate policy to inflation is greater than 1.0 for all these four economies, so the monetary policies are all putting significant weight on stabilizing inflation. In particular, the Euro Area has the reaction parameter with respect to inflation of about 1.83, showing that inflation is of most concern for the monetary authorities in the EA. We also find stimulus features in monetary policies adopted by these economies. However, the degree of the reaction of interest rate policy to output growth is different between them. We identify the US as having the highest value in this regard at 1.28, and the EA to have the lowest at 0.22. Our evidence suggests that US monetary policy reacts more strongly to revert the trend while the EA has smaller policy responses. Even if most studies adopt Taylor rule, they estimate different forms of functions, leading to different parameters and values. Lubik and Schorfheide (2006) use deviations of output growth from mean in the central bank's response. Smets and Wouters (2003) use deviations of lagged inflation from objective and lagged output gap. Adolfson et al. (2007) add real exchange rate to the monetary policy function. Our estimation pursuits simple form of Taylor rule and thereby introduce deviations of output and inflation in the function.

The Bayesian approach provides information about the persistency of the innovations in the economies. Moreover, it estimates standard deviations of these shocks. Since we use GDP growth as one observable and the data are directly linked with productivity shocks through the production function, our estimation could provide critical evidence about productivity improvements. We identify that the EA has the highest persistency of productivity shock at 0.27, and the US and China have smaller values at 0.13 and 0.10, respectively. Not only does the EA have greater persistent productivity shock, but the magnitude of the shock is also the largest. The posterior means of the standard deviation of productivity shocks for the EA, the US and China are 4.88, 2.75, and 1.43, respectively. Persistency of world productivity improvement is about the average of the three economies. The standard deviation of ROW is 0.31

and much smaller than the other three economies. This should be the effect of aggregation because country-specific shocks are diversified away. Since our sample period covers the global financial crisis from 2007, the persistency and large shock of the EA are from the adverse effect of the crisis on its growth. We can also observe large volatility of the EA in the figure of the GDP growth for these economies (Figure 4.1). China's high growth is more characterized by the trend growth, and her growth is fluctuating within a small band after being de-trended. The US and the EA both have a smaller trend growth rate, but the EA growth is much more volatile.

Fiscal policies for these economies consist of another dimension of heterogeneity. The persistency coefficients on government spending shocks are 0.50, 0.58, 0.13 and 0.49 for China, the US, the EA and ROW, respectively. The sizes of government spending shocks are 0.28, 1.25, 3.89 and 1.61 in terms of standard deviation for these economies. The policy of the EA can be characterized as the largest in size, but is not as persistent as the others. Although shock to stimulus spending is smaller for China, her policy is more long-lasting. Combining monetary and fiscal policies, the EA uses interest rate policy more often to boost growth, while being relatively conservative in government spending. China and the US have similar features, which are the reverse to the EA. Mark-up shocks have a lower persistency for the four economies, but the EA is identified as having much greater price shock. The preference shocks are small in terms of both persistency and standard deviations for all blocks. We also provide 90 percent confidence intervals for the posteriors in Table 4.5.

In estimation II, we substitute the monetary policy in China with a quantity rule and estimate with money quantity as an observable in the model. Column II of Table 4.5 demonstrates our posteriors based on this estimation. We find that both the interest rate and the money quantity capture the monetary regulation's responses to inflation and output gap. However, these two instruments have different degrees of responses. According to the quantity rule, the inertia of money quantity is 0.61, smaller than evaluated by the interest rate rule. At the same time, the quantity rule finds a higher response to inflation and a lower magnitude of reaction to the output gap by the policy authority. $\rho^j_{i,2}$ increases from 1.16 to 1.34 and $\rho^j_{i,3}$ decreases from 0.31 to 0.10. The quantity rule implies that China targets more at inflation stabilization while leaving flexibility to the productivity improvement. Zhang (2009) also describes the Chinese economy using quantity rule. They are different with us in the function form and also they use calibration. Other parameters of the estimation with quantity rule are generally comparable with the estimation with the interest rate rule.

In summary, our estimation results provide evidence of the distinct behaviours of the four economies and support our four-country framework for analysis. The heterogeneity among China, the US and the EA falls in both the structure of the economies and the value of a variety of parameters that reflect different intertemporal dynamics. The monetary policy of China is described by both interest rate rule and money quantity. Interest rate is set to response more to output gap, while money quantity is linking more closely with inflation. In order to further examine the specification in our model and the identification by the estimation, we perform robustness tests in the following section.

4.5. Robustness of the Model

The Bayesian approach is considered to be an approach that can overcome the shortcomings of empirical NOEM models such as misspecification and identification. It can be viewed as a combination of calibration using parameters based on evidence from micro-level analysis and updating prior distributions with data. Prior distributions provide presumptions on the parameters and have effects on the value of the posterior means. The sensitivity of the model depends on the extent to which the values of priors affect the posteriors. On the other hand, the Bayesian approach is criticized for being unable to update a few parameters and the posteriors having values close to the priors (Lubik and Schorfheide 2006). With regard to these two challenges, we perform sensitivity tests to evaluate the effects of different priors on the estimation results of our model to examine the robustness of our estimation. We estimate our model based on two other sets of priors besides the baseline estimation in the previous section. One set of priors for the re-estimation uses prior means lower than the baseline settings and the other uses higher values. The mean values for the priors and posteriors of these two auxiliary estimations are presented in Table 4.6.

Estimation results of the auxiliary estimations lend strong support for the observed heterogeneity in the baseline estimation. Generally, the posteriors updated from both lower and higher priors are compatible with the baseline estimation. The elasticities in the utility function are similar to that in the baseline and these values are different from the priors, which reflects the information from the observations. Although the trade elasticities are slightly different from the baseline, these values are still close to unity. In particular, the parameters describing the distortion of the economy are largely confirmed by the robustness test. Even starting from different priors, estimations of habit h^j and stickiness θ^j are about the same as the baseline estimation. Also, the Euro Area is still the lowest in habit and highest in price rigidity by estimation with lower priors.

However, auxiliary estimations find a small number of parameters showing instability. Specifically, the posterior means from estimation with higher priors and the interest rule are largely different from other estimations. For example, the rigidity coefficients of this estimation are all greater than 0.9, which is not consistent with evidence from

Table 4.6 Prior and posterior means in sensitivity tests

		Baseline			**Low priors**			**High priors**		
		Prior mean	**Posterior mean I**	**Posterior mean II**	**Prior mean**	**Posterior mean I**	**Posterior mean II**	**Prior mean**	**Posterior mean I**	**Posterior mean II**
σ_C	China	1.50	1.73	2.42	1.40	2.03	1.82	1.60	0.97	1.08
	US	1.50	1.97	2.60	1.40	1.94	2.12	1.60	1.77	1.81
	EA	1.50	2.09	2.11	1.40	1.56	1.65	1.60	1.82	2.03
	ROW	1.50	1.41	1.34	1.40	1.40	1.82	1.60	2.47	2.58
σ_M	China	1.50	1.40	0.93	1.40	1.35	1.44	1.60	1.89	1.31
	US	1.50	1.67	1.22	1.40	1.22	1.42	1.60	1.56	1.80
	EA	1.50	1.61	1.28	1.40	1.48	1.43	1.60	1.43	1.33
	ROW	1.50	1.40	1.17	1.40	1.45	1.24	1.60	1.71	1.46
σ_L	China	1.50	1.08	1.13	1.40	1.37	1.28	1.60	1.12	1.45
	US	1.50	1.72	1.50	1.40	1.46	1.36	1.60	1.53	1.62
	EA	1.50	1.49	1.10	1.40	1.36	1.34	1.60	1.22	1.62
	ROW	1.50	1.15	1.00	1.40	1.37	1.49	1.60	1.30	1.98
η_C	China	2.00	1.07	0.99	1.80	1.32	0.93	2.20	1.38	1.28
	US	2.00	1.05	1.02	1.80	1.19	0.84	2.20	1.27	1.28
	EA	2.00	1.00	0.98	1.80	1.08	1.13	2.20	1.18	1.18
	ROW	2.00	0.98	0.98	1.80	0.87	0.81	2.20	1.16	1.16
h	China	0.50	0.57	0.26	0.45	0.53	0.34	0.55	0.26	0.23
	US	0.50	0.45	0.56	0.45	0.47	0.71	0.55	0.23	0.23
	EA	0.50	0.13	0.08	0.45	0.17	0.18	0.55	0.92	0.92
	ROW	0.50	0.32	0.27	0.45	0.32	0.32	0.55	0.28	0.30
θ_P	China	0.75	0.72	0.66	0.70	0.61	0.78	0.80	0.96	0.96
	US	0.75	0.69	0.65	0.70	0.68	0.81	0.80	0.94	0.92
	EA	0.75	0.87	0.94	0.70	0.90	0.89	0.80	0.90	0.92
	ROW	0.75	0.66	0.82	0.70	0.81	0.90	0.80	0.96	0.96
$\rho_{i,1}$	China	0.50	0.82	0.61	0.45	0.79	0.36	0.55	0.90	0.65
	US	0.50	0.92	0.90	0.45	0.88	0.85	0.55	0.90	0.92
	EA	0.50	0.90	0.63	0.45	0.85	0.81	0.55	0.88	0.89
	ROW	0.50	0.49	0.13	0.45	0.41	0.44	0.55	0.58	0.72
$\rho_{i,2}$	China	1.50	1.16	1.34	1.40	1.03	1.24	1.60	1.47	1.93
	US	1.50	1.11	0.92	1.40	1.17	0.91	1.60	1.30	1.72
	EA	1.50	1.83	1.78	1.40	1.17	0.97	1.60	1.58	1.88
	ROW	1.50	1.46	1.42	1.40	1.37	1.14	1.60	1.48	1.37
$\rho_{i,3}$	China	0.50	0.31	0.10	0.45	0.27	0.29	0.55	0.38	0.49
	US	0.50	1.28	1.37	0.45	0.42	0.35	0.55	0.48	0.67
	EA	0.50	0.22	0.25	0.45	0.19	0.13	0.55	0.40	0.32
	ROW	0.50	0.39	0.86	0.45	0.37	0.51	0.55	0.99	0.99

Model I: estimated with interest rate rule for monetary policy of China; Model II: estimated with quantity rule for monetary policy of China

Table 4.6 (continued) Prior and posterior means in sensitivity tests

		Baseline			Low priors			High priors		
		Prior mean	Posterior mean I	Posterior mean II	Prior mean	Posterior mean I	Posterior mean II	Prior mean	Posterior mean I	Posterior mean II
ρ_A	China	0.20	0.10	0.13	0.15	0.15	0.16	0.25	0.14	0.36
	US	0.20	0.13	0.14	0.15	0.07	0.25	0.25	0.30	0.35
	EA	0.20	0.27	0.41	0.15	0.46	0.46	0.25	0.12	0.18
	ROW	0.20	0.16	0.72	0.15	0.14	0.40	0.25	0.29	0.14
ρ_G	China	0.20	0.50	0.34	0.15	0.43	0.30	0.25	0.41	0.50
	US	0.20	0.58	0.65	0.15	0.53	0.15	0.25	0.27	0.28
	EA	0.20	0.13	0.11	0.15	0.11	0.17	0.25	0.33	0.25
	ROW	0.20	0.49	0.28	0.15	0.52	0.22	0.25	0.17	0.21
ρ_P	China	0.20	0.17	0.05	0.15	0.07	0.06	0.25	0.13	0.30
	US	0.20	0.09	0.24	0.15	0.10	0.06	0.25	0.10	0.17
	EA	0.20	0.16	0.15	0.15	0.08	0.07	0.25	0.19	0.12
	ROW	0.20	0.12	0.12	0.15	0.07	0.06	0.25	0.11	0.08
ρ_L	China	0.20	0.08	0.33	0.15	0.11	0.10	0.25	0.16	0.23
	US	0.20	0.15	0.12	0.15	0.10	0.12	0.25	0.18	0.10
	EA	0.20	0.08	0.36	0.15	0.12	0.08	0.25	0.30	0.27
	ROW	0.20	0.09	0.11	0.15	0.10	0.22	0.25	0.32	0.13
ϵ_i	China	0.50	0.21	1.65	0.45	0.21	1.35	0.55	0.22	1.76
	US	0.50	0.18	0.19	0.45	0.17	0.17	0.55	0.19	0.20
	EA	0.50	0.16	0.40	0.45	0.14	0.14	0.55	0.18	0.18
	ROW	0.50	0.64	1.13	0.45	0.53	0.39	0.55	0.97	0.54
ϵ_A	China	0.50	1.43	1.34	0.45	0.29	2.82	0.55	0.45	1.88
	US	0.50	2.75	2.46	0.45	3.31	0.43	0.55	2.87	2.91
	EA	0.50	4.88	3.30	0.45	6.91	4.80	0.55	0.89	0.90
	ROW	0.50	0.31	0.31	0.45	0.42	1.23	0.55	2.09	2.57
ϵ_G	China	0.50	0.28	0.99	0.45	0.26	1.41	0.55	5.30	4.74
	US	0.50	1.25	0.84	0.45	1.36	0.40	0.55	3.31	3.58
	EA	0.50	3.89	3.29	0.45	5.71	3.73	0.55	1.76	1.76
	ROW	0.50	1.61	1.65	0.45	1.77	1.52	0.55	3.39	2.56
ϵ_P	China	0.50	0.22	0.27	0.45	0.18	0.18	0.55	0.29	0.24
	US	0.50	0.31	0.24	0.45	0.30	0.53	0.55	0.54	0.52
	EA	0.50	1.22	1.86	0.45	1.40	1.46	0.55	1.29	1.30
	ROW	0.50	0.64	0.72	0.45	0.65	0.73	0.55	0.68	0.70
ϵ_L	China	0.50	0.39	0.38	0.45	0.38	0.42	0.55	1.20	0.79
	US	0.50	0.37	0.64	0.45	0.50	0.39	0.55	0.77	0.43
	EA	0.50	0.54	0.86	0.45	0.36	0.35	0.55	0.37	0.50
	ROW	0.50	0.48	0.24	0.45	0.37	0.36	0.55	1.07	0.42

Model I: estimated with interest rate rule for monetary policy of China; Model II: estimated with quantity rule for monetary policy of China

micro studies. To some extent, Bayesian may also suffer an identification problem and the posteriors may be sensitive to the choice of priors. Thereby estimations with different priors are called for to demonstrate the robustness. More important, the sensitivity to the priors is lower in a larger sample. Due to the short sample period for the model of the Chinese economy, it is unavoidable that the model suffers an identification problem to some degree. However, this problem will be resolved with a larger sample size, since the posteriors are approaching their true values with the increase of the number of observations.

4.6. Summary

The field of NOEM modelling is developing from establishing general models that can be applied to a wide group of countries sharing similar features to specific models designed for a particular country, which incorporates the country's heterogeneity with the other countries. Distinct structural features between countries and different policies applied by the governments could lead to major misinterpretation if analyzed based on a general model. In this chapter, we set up a model which is designed for the Chinese economy. Apart from the standard two-country model with one home and one foreign country, the model separates two of her major international partners, the US and the EA, from the rest of the world block and these three blocks work as foreign economies with regard to China. Also, we allow for heterogeneous structural parameters and monetary policies between China and other economies. We propose that such a model is not only appropriate but also necessary in order to analyze the role of China in the global economy.

The model is estimated based on the priors and data for the four economies using the Bayesian approach. Estimation starts with priors that are symmetric among the four blocks, but the updated posteriors confirm large discrepancies between China, the US and the EA. These heterogeneities include different habit towards consumption and degree of nominal rigidity described by the coefficient in the Calvo pricing. Policy regime applied by the government is also different and could lead to different effects of monetary policy on the economy. In terms of monetary policy, authority in the Euro Area is concerned more with inflation and reacts less to boost growth. The fiscal policy of the EA is more one-off while the other economies have more persistent policies. China and the US have similar policies and are the reverse of the EA. In addition, the sensitivity test confirms our conclusions and similar heterogeneous patterns between pairs of countries appear even with changing priors. Overall, the model has an appropriate scale and good identification. All these demonstrate the importance of designing a heterogeneous model for specific country analysis and using a general model could lead to major misspecification. However, we also call for a larger sample for estimating the Chinese economy, so that the posteriors can be less sensitive and closer to the true values.

Chapter 5

China in a World with Heterogeneous International Investment

5.1. Introduction

The recent decades see the rise of cross-country asset and liability positions and the size of these positions can reach multiples of GDP (Devereux and Sutherland 2011). For example, at the end of 2010, the external liabilities of the United States arrived at 156 percent of its GDP, and the ratio after netting the external assets was almost 17 percent (IMF IFS). Caballero, Farhi, and Gourinchas (2008) consider the increase in the demand for US assets in global portfolio to be contradictory to conventional perspectives. The net borrowers also include the Euro Area, whose net IIP amounts 14 percent of its GDP. The other side of these phenomena are the debtors in the international financial markets. Among these lenders, China is the largest country with a net external asset position of 1,790 billion dollars, which exceeds 30 percent of its GDP. The asymmetry between the external positions of these creditor and debtor countries calls for a global perspective (Lane and Milesi-Ferretti 2007b). The heterogeneity in external asset and liability positions raises new challenges for macroeconomic research, as listed by Devereux and Sutherland (2011).

The evolution of external asset and liability positions has been investigated by a few studies. One group of views cast their eyes on the structure of international financial markets. Blanchard, Giavazzi, and Sa (2005) find that imperfect substitutability between US and foreign assets is a cause of the shift in relative demand for assets. Caballero, Farhi, and Gourinchas (2008) prove that the rising demand for US assets is an equilibrium under different capacity of different regions to generate financial assets. Lane and Milesi-Ferretti (2007a) evaluate the role of financial flows, valuation gains and residual adjustments in the forming of US external asset positions. They also give possible sources of the residual adjustments and reject attribution the total of the residuals to valuation effects. There are also views focusing on the role of policies. Tille (2003) conclude the indebtness of the US to be the effects of persistently strong performance of dollar in 1990s and early 2000s

The macroeconomic influences of the external asset and liability positions are also in the list of questions. Lane and Milesi-Ferretti (2007b) suggest a global perspective to extend the conventional models. The asymmetric external positions prove necessity of their perspective in understanding the interdependence between creditor and debtor countries. They strengthen that the heterogeneity between the international investments of these countries is important even when the net balances are zero. They perform an empirical analysis for G7 countries and conclude that accumulation of dollar assets is not going to be persistent when the external demand is tightening.

However, their analysis ignores China which is the largest debtor country. Devereux and Sutherland (2011) also propose that equilibrium financial asset portfolios are a possible extension to NOEM modelling. They point out that one problem of the existing models is ignoring the distinction between assets and liabilities when netting foreign assets.

We follow these studies and analyze macro interdependence of a multiple of countries including China in a NOEM framework. Two particular issues about international welfare transfer catch our concern. The first one is the interdependence of consumptions and productions between countries. In NOEM models with complete financial markets, perfect risk sharing ensures perfect international risk sharing and zero net asset positions for the participating countries. This chapter considers the heterogeneity in international investments under incomplete financial markets and can drive conclusions about the influences of external assets and liabilities on the correlations of consumptions and productions between countries. Corsetti, Dedola, and Leduc (2008) reconcile international business cycle models to match the empirical evidence of imperfect risk sharing. We follow their agenda and further incorporate heterogeneous international investments. In addition, another channel that brings about valuation effects is evaluated in this paper. Lane and Milesi-Ferretti (2007a) and Tille (2003) both emphasize the role of valuation effects in the forming and evolution of the US indebtness. Our study addresses this issue in a multi-country context rather than a specific investigation of the US only.

For the above purposes, we modify the multi-country NOEM model in Chapter 4. The model still has four blocks: China, the United States, the Euro Area, and the Rest of the World. Besides all the sectors already in the framework, we enrich the financial markets by adding financial intermediates who supply internationally traded bonds to domestic and foreign buyers. However, in this model, the financial intermediates no longer provide a complete set of financial assets for households. To overcome the problem of non-stationarity brought about by incomplete financial markets, we introduce quadratic bond adjustment costs. Our model contributes a mechanism to NOEM modelling to capture heterogeneous cross-country investment. When netting the external assets and liabilities, the model can evaluate the net IIP of a country.

After linearizing the model, we derive at a few analytical findings. We find that the extent of international risk sharing between two countries is decided by their IIPs. Zero initial IIPs are sufficient to lead to perfect international risk sharing. Heterogeneous international investments of two countries cause imperfect international risk sharing between them. We also conclude that heterogeneous international investment opens the valuation channel. Large IIPs provide bases for value changes due to interest rate differentials and exchange rate movements. Further, interest rates differentials account more proportion in the valuation channel than do exchange rate movements.

In addition to the analytical properties of our model, we extract findings of the model through simulations. First, the steady state of the four economies is calibrated using the data about their populations, outputs, weights in international trade and investment, etc. We calculate the external liabilities to GDP ratios for the countries to get their steady state ratios of IIPs to output. The heterogeneous IIPs split the four blocks into two groups. China and the ROW have relative fewer external liabilities than the US and the EA. Thereby China and the ROW have positive net IIPs while the other two countries have negative ones. Then we examine the dynamics of these economies in four scenarios. In each scenario, a country is facing one percent productivity improvement. We collect cumulative deviations of the variables from the steady state. We pick up different periods after the shock to capture the short- and long-run equilibriums. Also, IRFs are plotted to capture the evolvement of the economies from short run to long run.

Our simulation finds that productivity improvement in a country generally increases the welfare of its households by increasing consumption and decreasing labour. The

IIP of the country facing improvement also increases. However, the heterogeneity of the four economies leads to large distinction of the dynamics between shocks in different areas. Except the EA, the other three blocks expand their monetary policies facing productivity shocks in them. The shocks in the US and the EA have larger spillovers to other economies than the shock in China. Given the readily large share of exports in the output, the surplus of trade of China in productivity shock is almost neglectable. Similarly, the IIPs of China and the ROW grow very slightly, provided that they have large positive IIPs in the steady state. A US shock can bring significant surplus to the US and help it to accumulate external assets. The valuation effects are decided by the heterogeneous IIPs in the steady state and the interest rate differentials. Shocks in China and the ROW cause very small value changes to the international investments, mainly due to the small external liabilities of these two areas. The US shock leads to large increase in the value of the net IIP of the US, but the shock in the EA makes adverse effects on the net IIP of the EA. The contradictory valuation effects of these two economies are because of the different monetary policy responses of them.

This chapter is structured as follows. In Section 5.2, we improve the model established in Chapter 4. Section 5.3 provides an analysis of the steady states of the economies, and the methodology for simulating the model. In Section 5.4, we investigate the main findings from the four scenarios in our simulation. Section 5.5, 5.6 and 5.7 are detailed analyses of the implications of the model for the trade and valuation channels and the international investment, respectively. We give our summary of this chapter in Section 5.8.

5.2. A Model with Heterogeneous International Investment

In this section, we enrich international financial markets of the multi-country framework in Chapter 4. The model in this chapter contains a new sector for financial intermediates, but the set of financial assets are no longer a complete set of contingent bonds. By this setting, we allow countries in the model hold heterogeneous international investment positions. In Section 3.3.1, we proved that perfect international risk sharing leads to zero net IIP at all times. In this section, we express international risk sharing between two countries in the function of the IIPs of them. From this function, we derive at that zero initial IIPs are sufficient to bring about perfect international risk sharing. Imperfect risk sharing is a result of heterogeneous IIPs of the regarding economies. Also, heterogeneous IIP for participating countries enrich the properties of our multi-country model. With large gross investment positions, exchange rate movements and interest rate differentials can cause significant welfare transfers. Such valuation effects are analytically reflected by our model in this section.

Sequentially, we introduce the model settings of the international investment sector and evaluate the valuation channel in 5.2.1, and then in 5.2.2 we discuss how the levels of external assets positions affect international risk sharing.

5.2.1. International Financial Sector

We work out a method to model the cross-country heterogeneous holdings of international financial assets and derive its implications to international risk sharing. We assume that in each country there are financial intermediates issuing internationally traded bonds. Households buy bonds issued by these intermediates. The budget constraint for the representative household in country j is:

$$\begin{aligned}(1+\Gamma^{j}_{C,t})P^{j}_{t}C^{j}_{t}+P^{j}_{I,t}I^{j}_{t}+M^{j}_{t}+T^{j}_{t}+\frac{1}{n^{j}}\sum_{j'\in J/\{j\}}\frac{\mathcal{E}^{j'}_{j,t}B^{j}_{j',t}(1+\Gamma^{j}_{B,j',t})}{1+i^{j'}_{t}}\\ +\frac{1}{n^{j}}\frac{B^{j}_{j,t}}{1+i^{j}_{t}}=Pr^{j}_{B,t}+W^{j}_{t}L^{j}_{t}+r^{j}_{t}K^{j}_{t}+Pr^{j}_{Y,t}+\frac{1}{n^{j}}B^{j}_{j,t-1}\\ +\frac{1}{n^{j}}\sum_{j'\in J/\{j\}}\left(\mathcal{E}^{j'}_{j,t}B^{j}_{j',t-1}\right)+M^{j}_{t-1},\quad (5.1)\end{aligned}$$

where $\Gamma^{j}_{C,t}$ is the adjustment cost due to changes in consumption, P^{j}_{t} the consumption price index, C^{j}_{t} the per capita consumption, $P^{j}_{I,t}$ the price for investment final goods, I^{j}_{t} the investment of the household, M^{j}_{t} the balance of money, T^{j}_{t} the tax paid or transfer received, n^{j} the population share of country j in the world, $\mathcal{E}^{j'}_{j,t}$ the exchange rate which is defined as the units of currency of country j per unit of currency of country j’, W^{j}_{t} the wage level, L^{j}_{t} the labour of the household or working effort per capita, r_t^j the rental income of the capital, K_t^j the level of capital stocks, and $Pr_{Y,t}^j$ the profit received from domestic firms.

$B_{j,t}^j$ and $B_{j',t}^j$ in equation (5.1) are the discount bonds issued by country j and j', respectively. They are all held by households in country j. From the perspective of country j, foreign issued bonds are denominated in the currency of the issuer and thereby home households evaluate them by multiplying the exchange rates. $\Gamma_{B,j',t}^j$ is the adjustment cost that home households paid to foreign intermediates for changing the positions of their holdings. Households have full ownership over domestic financial intermediates, and we assume that the intermediates transfer all their proceeds to the households. $Pr_{B,t}^j$ is the amount of the proceeds by issuing internationally traded bonds in the current period:

$$\begin{aligned} Pr_{B,t}^j &= \frac{1}{n^j}\sum_{j'\in J}\frac{B_{j,t}^{j'}}{1+i_t^j} - \frac{1}{n^j}\sum_{j'\in J}B_{j,t-1}^j \\ &= \frac{1}{n^j}\frac{B_{j,t}^j}{1+i_t^j} - \frac{1}{n^j}B_{j,t-1}^j + \frac{1}{n^j}\sum_{j'\in J/\{j\}}\frac{B_{j,t}^{j'}}{1+i_t^j} - \frac{1}{n^j}\sum_{j'\in J/\{j\}}B_{j,t-1}^{j'}, \end{aligned} \quad (5.2)$$

where i_t^j is the interest rate of the bond. Equation (5.2) expresses the proceeds of issuing bonds as the difference of the amounts received for selling bonds by the intermediates and the principal paid for bonds issued in the previous period, and the second line of equation (5.2) separately expresses the incomes from home and foreign buyers.

If we substitute the domestic holdings of home issued assets in equation (5.1) by equation (5.2), we can derive the aggregate budget constraint for all households:

$$\begin{aligned}&\left(1+\Gamma_{C,t}^{j}\right)P_{C,t}^{j}C_{t}^{j}+P_{I,t}^{j}I_{t}^{j}+\zeta_{G,t}^{j}Y_{t}^{j}-\frac{1}{n^{j}}\sum_{j'\in J/\{j\}}\frac{B_{j,t}^{j'}}{1+i_{t}^{j}}\\&+\frac{1}{n^{j}}\sum_{j'\in J/\{j\}}\frac{\mathcal{E}_{j,t}^{j'}B_{j',t}^{j}\left(1+\Gamma_{B,j',t}^{j}\right)}{1+i_{t}^{j'}}=P_{j,t}^{j}Y_{t}^{j}-\Gamma_{W,t}^{j}W_{t}^{j}L_{t}^{j}\\&-\frac{1}{n^{j}}\sum_{j'\in J/\{j\}}B_{j,t-1}^{j'}+\frac{1}{n^{j}}\sum_{j'\in J/\{j\}}\left(\mathcal{E}_{j,t}^{j'}B_{j',t-1}^{j}\right).\end{aligned}\tag{5.3}$$

From equation (5.3), we can observe that a country’s trade surplus or deficit will be transmitted into domestic holdings of foreign bonds $B_{j',t}^{j}$ or foreign holdings of domestic bonds $B_{j,t}^{j'}$.

In addition, the holding costs of foreign assets $\Gamma_{B,j',t}^{j}$ are:

$$\Gamma_{B,j',t}^{j}=\frac{\phi_{B,j'}^{j}}{2}\left(\frac{B_{j',t}^{j}}{n^{j'}P_{j',t}^{j'}Y_{t}^{j'}}-b_{j'}^{j}\right)^{2}.\tag{5.4}$$

The costs are a quadratic function of the difference between the ratios of current holding of foreign bonds to foreign output level and the steady state ratio of that $b_{j'}^{j}$. $\phi_{B,j'}^{j}$ is the coefficient that affects the overall magnitude of the costs. Although the adjustment costs could be described by other functional forms, the important thing is that the second-order deviation is positive around the steady state and the cost is accelerating if the position of foreign bonds deviates from the steady state level considerably. Technically, the purpose of inducing quadratic adjustment costs for international assets is to create a stationary model. Bodenstein (2011) and Schmitt-Grohe and Uribe (2003) introduce several approaches to eliminate unit root for non-stationarity in large and SOE models, respectively. We further expand this family with our design. The advantage of our method is that the quadratic cost can be interpreted as a premium afforded by the demand side, while we do not require an endogenous discount factor or debt-elastic premium. Also, the cost is paid if the level deviates from the steady state level, rather than the zero position assumed by research in their field.

The Euler equation with bond adjustment cost is derived at by taking the first-order derivation of the Hamiltonian function of the dynamic programming problem:

$$\lambda_t^j \left[1 + \Gamma^j_{B,j',t} + \phi^j_{B,j'} \frac{B^j_{j',t}}{n^{j'} P^{j'}_{j,t} Y^{j'}_t} \left(\frac{B^j_{j',t}}{n^{j'} P^{j'}_{j',t} Y^{j'}_t} - b^j_{j'} \right) \right] = \beta^j \left(1 + i^{j'}_t\right) \mathrm{E}_t \left\{ \frac{\mathcal{E}^{j'}_{j,t+1}}{\mathcal{E}^{j'}_{j,t}} \lambda^j_{t+1} \right\}, \quad (5.5)$$

where λ_t^j is the Lagrangian multiplier which equals the marginal utility of consumption. We find that the adjustment cost of external assets enters the intertemporal decision of households.

Without further notice, we define the linearization of a variable $\widehat{X}$ as the percentage deviation of the variable from the steady state $\widehat{X} = \mathrm{d}X/\overline{X}$, where $\overline{X}$ represents the steady state level of the variable. Log-linearization of equation (5.5) leads to the following equation:

$$\widehat{\lambda}_t^j + \phi_{B,j'}^j b_{j'}^j \widehat{B}_{j',t}^j - \phi_{B,j'}^j \left(b_{j'}^j\right)^2 \widehat{P}_{j',t}^{j'} - \phi_{B,j'}^j \left(b_{j'}^j\right)^2 \widehat{Y}_t^{j'} = \beta^j \widehat{i}_t^{j'} \\ + \mathrm{E}_t\left\{\widehat{\mathcal{E}}_{j,t+1}^{j'}\right\} - \widehat{\mathcal{E}}_{j,t}^{j'} + \mathrm{E}_t\left\{\widehat{\lambda}_{t+1}^{j'}\right\}. \quad (5.6)$$

$\widehat{B}_{j',t}^j$ is defined as the change of the ratio of bond position to the output of country j', $\widehat{B}_{j',t}^j = \mathrm{d}B_{j',t}^j/(n^{j'}\overline{P}_{j'}^{j'}\overline{Y}^{j'})$. The equation of international risk sharing is obtained by combining the Euler equations of two economies. If we define the change of the net asset position of country j with respect to country j' as:

$$\widehat{NA}_{j,t}^{j'} = \frac{n^{j'}}{n^j}\zeta_{Y,j}^{j'}\widehat{B}_{j',t}^j - \widehat{B}_{j,t}^{j'}. \quad (5.7)$$

$\widehat{NA}_{j,t}^{j'}$ is the change of the ratio of the net asset position between country j and j' to the output of country j. The change of net asset position to output of a country with all its international partners is the sum of the changes to each foreign economy, respectively:

$$\widehat{NA}_{j,t} = \sum_{j' \in J\{j\}} \widehat{NA}_{j,t}^{j'}. \quad (5.8)$$

The international risk sharing can be derived by substituting $\widehat{B}_{j',t}^j$ and $\widehat{B}_{j,t}^{j'}$ in equation (5.7) by equation (5.6):

$$
\begin{aligned}
&n^j \phi_{B,j}^{j'} b_j^{j'} \phi_{B,j'}^j b_{j'}^j \widehat{NA}_{j,t}^{j'} = n^j \phi_{B,j'}^j b_{j'}^j \widehat{\lambda}_t^{j'} - n^{j'} \zeta_{Y,j}^{j'} \phi_{B,j}^{j'} b_j^{j'} \widehat{\lambda}_t^j \\
&- n^j \phi_{B,j'}^j b_{j'}^j \mathrm{E}_t\{\widehat{\lambda}_{t+1}^{j'}\} + n^{j'} \zeta_{Y,j}^{j'} \phi_{B,j}^{j'} b_j^{j'} \mathrm{E}_t\{\widehat{\lambda}_{t+1}^j\} - \beta^j n^j \phi_{B,j'}^j b_{j'}^j \widehat{i}_t^j \\
&+ \beta^j n^{j'} \zeta_{Y,j}^{j'} \phi_{B,j}^{j'} b_j^{j'} \widehat{i}_t^{j'} - \left(n^j \phi_{B,j'}^j b_{j'}^j + n^{j'} \zeta_{Y,j}^{j'} \phi_{B,j}^{j'} b_j^{j'}\right) \widehat{\mathcal{E}}_{j,t}^{j'} \\
&+ \left(n^j \phi_{B,j'}^j b_{j'}^j + n^{j'} \zeta_{Y,j}^{j'} \phi_{B,j}^{j'} b_j^{j'}\right) \mathrm{E}_t\{\widehat{\mathcal{E}}_{j,t+1}^{j'}\} - n^j b_j^{j'} \phi_{B,j}^{j'} b_j^{j'} \phi_{B,j'}^j b_{j'}^j \widehat{P}_{j,t}^j \\
&- n^j b_j^{j'} \phi_{B,j}^{j'} b_j^{j'} \phi_{B,j'}^j b_{j'}^j \widehat{Y}_t^j + n^{j'} \zeta_{Y,j}^{j'} b_{j'}^j \phi_{B,j}^{j'} b_j^{j'} \phi_{B,j'}^j b_{j'}^j \widehat{P}_{j',t}^{j'} \\
&+ n^{j'} \zeta_{Y,j}^{j'} b_{j'}^j \phi_{B,j}^{j'} b_j^{j'} \phi_{B,j'}^j b_{j'}^j \widehat{Y}_t^{j'} \qquad . \qquad (5.9)
\end{aligned}
$$

We compare the international risk sharing under incomplete markets with that of perfect correlation under complete market described by Equation (3.39). The marginal utilities $\widehat{\lambda}_t^j$ and $\widehat{\lambda}_t^{j'}$ do not move together, since $\widehat{NA}_{j,t}^{j'}$ enters Equation (5.9). Heterogeneous IIPs and net IIP movements break down the perfect risk sharing between the two countries.

According to the definition of the net asset position (5.7), the resource constraint (5.3) can be linearized as:

$$
\begin{aligned}
&\widehat{P}_{j,t}^j + \widehat{Y}_t^j - \sum_{j' \in J/\{j\}} \left[\beta^j \widehat{NA}_{j,t}^{j'} - \widehat{NA}_{j,t-1}^{j'} - \frac{n^{j'}}{n^j} \left(\beta^j\right)^2 \zeta_{Y,j}^{j'} b_{j'}^j \widehat{i}_t^{j'} \right. \\
&\left. + \left(\beta^j\right)^2 b_j^{j'} \widehat{i}_t^j + \frac{n^{j'}}{n^j} \zeta_{Y,j}^{j'} \beta^j b_{j'}^j \widehat{\mathcal{E}}_{j,t}^{j'} - \frac{n^{j'}}{n^j} \zeta_{Y,j}^{j'} b_{j'}^j \widehat{\mathcal{E}}_{j,t}^{j'} \right] = \widehat{\zeta}_{G,t}^j + \zeta_G^j \widehat{P}_{j,t}^j \\
&+ \zeta_G^j \widehat{Y}_t^j + \zeta_C^j \widehat{P}_{C,t}^j + \zeta_C^j \widehat{C}_t^j + \zeta_I^j \widehat{P}_{I,t}^j + \zeta_I^j \widehat{I}_t^j. \qquad (5.10)
\end{aligned}
$$

We find that change to the net holdings of international assets by one economy is partly financed by international trade. Other financing channels including home and foreign interest rate changes $\widehat{i}_t^j$ and $\widehat{i}_t^{j'}$. Exchange rate movements $\widehat{\mathcal{E}}_{j,t}^{j'}$ could also affect the external asset position of an economy. These effects of international welfare transfer resulting from changes in asset price and currency exchange rate are defined by Gourinchas and Rey (2007) as the valuation effects. In the budget constraint (5.10), changes due to interest rate differentials $\widehat{i}_t^{j}$ and $\widehat{i}_t^{j'}$ are the effects of changes in the asset prices, since the interest rate decides the price of the bond. We express the valuation effect as the change of the ratio of the budget to the output due to the movements of exchange rates and interest rates:

$$\widehat{VC}_{j,t}^{j'} = \left(\beta^j\right)^2 b_j^{j'} \widehat{i}_t^{j} - \left(\beta^j\right)^2 \frac{n^{j'}}{n^j} \zeta_{Y,j}^{j'} b_{j'}^{j} \widehat{i}_t^{j'} + \left(\beta^j - 1\right) \frac{n^{j'}}{n^j} \zeta_{Y,j}^{j'} b_{j'}^{j} \widehat{\mathcal{E}}_{j,t}^{j'}. \tag{5.11}$$

The valuation effects of a country with the other three economies can be summarized as the overall effect that the country encounters:

$$\widehat{VC}_{j,t} = \sum_{j' \in J/\{j\}} \widehat{VC}_{j,t}^{j'}. \tag{5.12}$$

Importantly, equation (5.11) delivers that the valuation effects due to exchange rate movement are much smaller than the effects from changes in asset prices, since $\beta^j - 1$ is close to zero and much smaller than $\left(\beta^j\right)^2$. For the interest rate changes, the principal for calculation of the effects is the gross position as a whole. However, the exchange rate drives the gross position of the current and previous periods moving together. The basis for the calculation of the effects from exchange rate movements is the difference between the gross positions of the two periods. In particular, the interests could approximate the basis if the gross position is not far from the steady state level. When the household perceives that the gross position has a steady state level, the value of the assets facing the volatile exchange rate is the interest on the gross position. We conclude that in a rational expectation framework, valuation effects from the asset prices are more significant than the effects brought by the exchange rate.

5.2.2. International Risk Sharing under Heterogeneous International Investment Positions

A critical contribution of our model is that it enables us to find which factor breaks down perfect international risk sharing under incomplete financial markets. In what follows, we start from the international risk sharing condition in the previous section and examine the findings if the initial steady state levels of the IIPs are zero.

Equation (5.9) links the intertemporal choices of households in two economies. In fact, we can rewrite equation (5.9) into the following form:

$$\frac{1}{\phi_{B,j}^{j'} b_j^{j'}}\left(\widehat{\lambda}_t^{j'} - E_t\{\widehat{\lambda}_{t+1}^{j'}\} - \beta^j \widehat{i}_t^j - \widehat{\mathcal{E}}_{j,t}^{j'} + E_t\{\widehat{\mathcal{E}}_{j,t+1}^{j'}\}\right)$$
$$-\frac{n^{j'}\zeta_{Y,j}^{j'}}{n^j \phi_{B,j'}^{j} b_{j'}^{j}}\left(\widehat{\lambda}_t^{j} - E_t\{\widehat{\lambda}_{t+1}^{j}\} - \beta^j \widehat{i}_t^{j'} + \widehat{\mathcal{E}}_{j,t}^{j'} - E_t\{\widehat{\mathcal{E}}_{j,t+1}^{j'}\}\right)$$
$$= \widehat{NA}_{j,t}^{j'} + b_j^{j'}\left(\widehat{P}_{j,t}^{j} + \widehat{Y}_t^{j}\right) - \frac{n^{j'}\zeta_{Y,j}^{j'} b_{j'}^{j}}{n^j}\left(\widehat{P}_{j',t}^{j'} + \widehat{Y}_t^{j'}\right). \qquad (5.13)$$

The left-hand side of equation (5.13) exhibits the relation between the intertemporal choices of households in two economies. The right-hand side of the equation is the change in the ratio of net asset position to output. Intuitively, if the right-hand side of the equation equals zero, which means that the net IIP does not change relative to the size of the output, the marginal utility of two countries changes proportionally with each other. In that case, if the home country changes the optimal path of decisions, the foreign households react correspondingly by changing their paths. Below, we prove that zero initial net IIP leads to perfect international risk sharing and this scenario is equivalent to the case under complete financial markets.

Firstly, we assume that the steady state level of bonds of country j' held by country j is zero $b^{j}_{j'} = 0$. Equation (5.9) becomes:

$$\widehat{\lambda}^{j'}_t - E_t\{\widehat{\lambda}^{j'}_{t+1}\} - \beta^j \widehat{i}^j_t - \widehat{\mathcal{E}}^{j'}_{j,t} + E_t\{\widehat{\mathcal{E}}^{j'}_{j,t+1}\} = 0. \tag{5.14}$$

Similarly, if we assume that the steady state level of bonds of country j held by country j' is zero $b^{j'}_{j} = 0$, equation (5.9) turns into:

$$\widehat{\lambda}^{j}_t - E_t\{\widehat{\lambda}^{j}_{t+1}\} - \beta^j \widehat{i^{j'}_t} + \widehat{\mathcal{E}}^{j'}_{j,t} - E_t\{\widehat{\mathcal{E}}^{j'}_{j,t+1}\} = 0. \tag{5.15}$$

Equations (5.14) and (5.15) already confirm the proportional change of the marginal utility of the two countries. If we combine these two equations:

$$\widehat{\lambda}^{j'}_t - E_t\{\widehat{\lambda}^{j'}_{t+1}\} - \beta^j \widehat{i}^j_t - \widehat{\mathcal{E}}^{j'}_{j,t} + E_t\{\widehat{\mathcal{E}}^{j'}_{j,t+1}\} = \widehat{\lambda}^{j}_t - E_t\{\widehat{\lambda}^{j}_{t+1}\} - \beta^j \widehat{i^{j'}_t} + \widehat{\mathcal{E}}^{j'}_{j,t} - E_t\{\widehat{\mathcal{E}}^{j'}_{j,t+1}\}. \tag{5.16}$$

Using the uncovered interest rate parity:

$$\widehat{\mathcal{E}}^{j'}_{j,t} = \mathrm{E}_t\{\widehat{\mathcal{E}}^{j'}_{j,t+1}\} - \beta^j \widehat{i}^j_t + \beta^j \widehat{i}^{j'}_t, \tag{5.17}$$

we can derive at the condition between the optimal decision path of the two countries:

$$\widehat{\lambda}^j_t - \mathrm{E}_t\{\widehat{\lambda}^j_{t+1}\} = \widehat{\lambda}^{j'}_t - \mathrm{E}_t\{\widehat{\lambda}^{j'}_{t+1}\} + \widehat{\mathcal{E}}^{j'}_{j,t} - E_t\{\widehat{\mathcal{E}}^{j'}_{j,t+1}\}. \tag{5.18}$$

When solved backward, equation (5.18) is equivalent to equation (3.39). We conclude that in our model with incomplete markets, international risk sharing is perfect when the steady state levels of the IIPs of the two countries are zero.

5.3. Parameterization and Methodology

The purpose of this section is to demonstrate how we calibrate the steady states for four heterogeneous economies based on empirical analysis. The steady state for each economy shows large differences in the role that each country plays in the world economy. This distinctive steady state has the potential to provide a basis for the different dynamics of the economies when there is a shock to the world. Also, we set the values for other parameters in our model according to literature or our estimation results in Chapter 4.

In Section 5.3.1, we explain in detail how we calculate the steady states of the four economies based on the data about the real economy. For the structural coefficients that are not determined by the steady states, we provide the parameterization of them in Section 5.3.2. We introduce the simulation methodology and justify our choice according to our motivation in Section 5.3.3.

5.3.1. Steady State Analysis

We now calibrate the steady state of the model and this can also provide values of parameters for our later simulation. Steady state analysis reveals heterogeneous structures and different roles of the blocks in the world economy. Table 5.1 displays values of the relevant parameters in the steady state.

The relative size n^j is defined as the population share of a country with respect to the world. The calculation is based on the average of the shares from 2000 to 2010. Population data is from the total population SP.POP.TOTL of the WDI published by the World Bank in September 2011. China's population accounts for 20.2% of the world's population. The US and the EA have shares similar to each other: 4.6% and 5%, respectively. The rest, 70.2%, belongs to the ROW block. Since we evaluate variables in per capita form, we can expect that economic size will affect international transmission of shocks to different countries.

The relative output $\zeta_{Y,j}^{j'}$ is the ratio of per capita output of country j' to that of country j:

Table 5.1 Steady state

n^j	Share in world population			
China	US	EA	ROW	
0.202	0.046	0.050	0.702	

$\zeta_{Y,j}^{j'}$	Relative output of the country j' to country j			
j \ j'	China	US	EA	ROW
China		10.742	8.356	2.098
US	0.093		0.778	0.195
EA	0.120	1.285		0.251
ROW	0.477	5.128	3.984	

$a_{C,j}^{j'}$ $a_{I,j}^{j'}$	Share of intermediate goods produced by country j in final goods production in country j'			
j \ j'	China	US	EA	ROW
China	0.771	0.018	0.016	0.052
US	0.017	0.866	0.014	0.045
EA	0.023	0.018	0.686	0.147
ROW	0.189	0.098	0.284	0.756

$b_j^{j'}$	Ratio of liabilities to output of country j held by country j'			
j \ j'	China	US	EA	ROW
China		0.021	0.023	0.320
US	0.285		0.070	0.990
EA	0.353	0.080		1.226
ROW	0.491	0.112	0.122	

ζ_G^j	Ratio of government spending to output			
China	US	EA	ROW	
0.144	0.158	0.205	0.173	

ζ_C^j	Ratio of consumption to output			
China	US	EA	ROW	
0.542	0.831	0.769	0.769	

ζ_I^j	Ratio of investment to output			
China	US	EA	ROW	
0.337	0.006	0.020	0.058	

$$\zeta_{Y,j}^{j'} = \frac{\overline{\mathcal{E}}_j^{j'} \overline{P}_{j'}^{j'} \overline{Y}_{j'}^{j'}}{\overline{P}_j^j \overline{Y}_j^j}. \tag{5.19}$$

We calculate per capita output as the real GDP volume divided by the population of a country. The real GDP volume is the GDP denominated in 2000's US dollar NY.GDP.MKTP.KD series, which is published by the World Bank WDI. Our results are the average of the annual ratios from 2000 to 2010. China has the lowest per capita GDP, and the relative sizes of US, EA and ROW per capita GDP to China are 10.742, 8.356, and 2.098, respectively. Among these four blocks, the US has the highest per capita output, and the second efficient region is the EA, which is 0.778 times of the output of the US. The ROW has average per capita output much less than the US, but still higher than China. However, given China's large population, China is catching up with the EA in terms of aggregate output and also has an economic size that is about half that of the US.

$a_{C,j}^{j'}$ and $a_{I,j}^{j'}$ are the weights of intermediate goods produced by country j in the consumption and investment final goods of country j'. Since it is difficult to proxy the composition of investment final goods, we set the weights of these two kinds of final goods equal for one country. To calibrate the value, we first calculate the degree of openness, which is the share of foreign goods in the consumption and investment $1 - a_{C,j}^{j}$. The value is the ratio of total imports of a country to its GDP. NY.GDP.MKTP.CD is the GDP in current value of US dollars from the World Bank

WDI. Then we attribute the degree of openness to the three foreign trade partners of the country by their relative imports. All bilateral and aggregate trade data are from DOTS published by IMF in November 2011. We then average the shares from 2008 to 2010 to get the parameter values. Our results show large differences between countries. Overall, the US has the highest home bias with 86.6% of their consumption and investment in domestic goods.

The steady state external asset position $b^j_{j'}$ is a measurement of cross-country heterogeneous international investment:

$$b^j_{j'} = \frac{\overline{B}^j_{j'}}{\overline{P}^{j'}_{j'}\overline{Y}^{j'}}. \tag{5.20}$$

$b^j_{j'}$ is the ratio of the liabilities to the output of the issuer country. To calculate this ratio, we divide the gross liabilities of country j' to its GDP, and then distribute this ratio by the populations of the three foreign counterparts of j'. Gross liabilities are from the series 8995D. in the Balance of Payments Statistics (BOPS) published by the IMF. GDP is the nominal value measured by the local currency published by the World Bank WDI. Since the gross liability data are denominated in US dollars, we convert the series using the conversion rate provided by IMF BOPS. As it is difficult to aggregate the gross liabilities for the ROW block, we further assume that the ROW has a zero net IIP:

$$\frac{\overline{B}_1^4}{\overline{\mathcal{E}}_1^4} + \frac{\overline{B}_2^4}{\overline{\mathcal{E}}_2^4} + \frac{\overline{B}_3^4}{\overline{\mathcal{E}}_3^4} = \overline{B}_4^1 + \overline{B}_4^2 + \overline{B}_4^3. \tag{5.21}$$

The level of the liabilities issued by ROW can then be derived using equation (5.21) and the assets held by ROW calculated previously.

According to our calculation, China has the lowest level of foreign liabilities. Liabilities to the US, the EA and ROW account for 2.1%, 2.3% and 32% of her GDP, respectively. The US has a relatively high level of foreign liabilities. The US liabilities held by China, EA and ROW are 28.5%, 7%, and 99% of US output, respectively. On aggregate, these account for overall liabilities of about 135% of US output. The liabilities of the EA to China, the US and ROW are 35.3%, 8%, and 122.6% of its output, respectively. The Euro Area's external indebtedness is even worse than the US. Besides the attractiveness of lending to the EA, EA's high liability to output ratios are also due to its relatively lower output compared to that of the US. The parameterization of $b_{j'}^{j}$ enables us to model the cross-country heterogeneity in NOEM models.

The consumption and government spending to output ratios ζ_C^j and ζ_G^j are the shares of consumption and government expenditure to GDP, respectively. Consumption share in GDP is from the NE.CON.TETC.ZS series, and government expenditure share is from the NE.CON.GOVT.ZS series of the World Bank WDI. The ratios are the average values from 2000 to 2010. The capital investment shares of the economies are then derived by the steady state resource constraint:

$$\zeta_I^j = 1 - \zeta_G^j - \zeta_C^j - \frac{\beta^j - 1}{n^j} \sum_{j' \in J/\{j\}} \left(n^{j'} b_{j'}^j \zeta_{Y,j}^{j'} - n^j b_j^{j'} \right). \tag{5.22}$$

We find that China has the highest derived value of investment to output ratio, which is about 33.7%. Capital investment is perceived to be the most important driving force behind China's persistently high growth.

Our quantitative analysis of the steady state of the four regions reveals large heterogeneity between them in the long-term level of IIPs. We gather evidence of large discrepancies among countries in the role of the global economy and this steady state could serve as a base for further analysis of transmission of shocks. Other parameters whose values have not been set in the calibration of the steady states are introduced in the following section.

5.3.2. Model Parameters

Before calibration, it is necessary to introduce values of the parameters of the model and the possible influences that are brought about by these settings. One critique of the NOEM models concerns the problems in specification, part of which can be attributed to the possibility of inappropriate values of coefficients. From the perspective that misspecification exists in non-data generating models, the problem turns to the extent to which the model is robustness to coefficient values. In this section, we demonstrate our parameter generating process and justify our choice of values according to sound evidence including estimation and those commonly acknowledged in the literature. Table 5.2 exhibits our settings of the parameters that are not yet decided in the steady state analysis.

According to our estimation in Chapter 4, the parameters of the NOEM model demonstrate large heterogeneity across countries. However, the extent to which we set the values differently depends on the focus of our study. In this chapter, we try to capture the different dynamics of the four economies given their roles in the world economy. In particular, we focus on the possible outcome due to different features in terms of population, size, share in international trade and IIP, etc. With these, we calibrate the steady state that is able to explain the heterogeneity in these features. In order to control for other factors and to better observe the effects brought about by these features, we set the other parameters the same values across the four economies under investigation. Structural differences are to be found in steady state and external assets and liabilities.

Table 5.2 Parameter values

China	US	EA	ROW	China	US	EA	ROW
β	**Discount rate**			h^j	**Consumption habit**		
0.995				0.300	0.300	0.300	0.300
$\overline{A}^j$	**Steady state growth rate**			$\phi^j_{C,1}$	**Consumption adjustment cost coefficient 1**		
1/0.995	1/0.995	1/0.995	1/0.995	0.029	0.029	0.029	0.029
δ^j	**Depreciation rate**			$\phi^j_{C,2}$	**Consumption adjustment cost coefficient 2**		
0.025	0.025	0.025	0.025	0.150	0.150	0.150	0.150
α^j	**Capital share in production**			ϕ^j_I	**Investment adjustment cost coefficient**		
0.330	0.330	0.330	0.330	4.000	4.000	4.000	4.000
σ^j_C	**Elasticity of consumption in utility**			θ^j	**Calvo coefficient**		
1.500	1.500	1.500	1.500	0.500	0.500	0.500	0.500
σ^j_M	**Elasticity of money in utility**			$\phi^{j'}_{B,j}$	**International investment adjustment cost coefficient**		
1.500	1.500	1.500	1.500	4.000			
σ^j_L	**Elasticity of labour in utility**			$\rho^j_{M,1}, \rho^j_{i,1}$	**Monetary policy persistence**		
2.000	2.000	2.000	2.000	0.500	0.500	0.500	0.500
η^j	**Elasticity of substitution between domestic and foreign goods**			$\rho^j_{M,2}, \rho^j_{i,2}$	**Monetary policy reflection to inflation**		
2.000	2.000	2.000	2.000	1.500	1.500	1.500	1.500
				$\rho^j_{M,3}, \rho^j_{i,3}$	**Monetary policy reflection to output**		
				0.500	0.500	0.500	0.500

The four blocks in our model have the same value, 0.995 for the discount rates β^j, which is equivalent to an annual discount rate of two percent. The steady state growth rates $\overline{A}^j$ are set to be compatible with the discount rate and have a value of 1/0.995. The depreciation rate δ^j has a value of 0.025 for the capital following a common setting in the literature, and this is equivalent to an annual depreciation rate of 10 percent. The capital shares α^j in the Cobb-Douglas production functions are all standard literature setting of 0.33. The elasticity of consumption in the utility function

σ_C^j is set to be 1.5 according to Smets and Wouters (2007). The elasticity of money σ_M^j has the same value. The elasticity of labour σ_L^j has the value of two. These imply that consumption and leisure (negative labour) are complements. A decrease in the consumption price or wage would level up both consumption and leisure, and decrease labour supply. The elasticity of substitution of intermediate goods from different countries in the consumption and investment final goods production η^j is set to have a value of two. The degree of habit in consumption h^j is 0.3 according to the prior set by Lubik and Schorfheide (2006). We use 0.029 and 0.15 for the two parameters $\phi_{C,1}^j$ and $\phi_{C,2}^j$ that decides the consumption transaction cost following the justification in Straub and Thimann (2010). The investment adjustment coefficients ϕ_I^j are 4.0 as in Smets and Wouters (2007). The adjustment coefficients $\phi_{B,j}^{j'}$ on international assets also have a comparable level to investment adjustment coefficients with the value of four. The Calvo coefficient that indicates the share of the firms that could change prices in each period θ^j is 0.5. In the model, the monetary policy of China is assumed to have different policy function from others. We assume that China's policy is described by a rule governing the money quantity and other blocks are using Taylor rule. These functions all have a persistency coefficient $\rho_{M,1}^j$ or $\rho_{i,1}^j$ of 0.5. The responses on the inflation $\rho_{M,2}^j$ or $\rho_{i,2}^j$ and output $\rho_{M,3}^j$ or $\rho_{i,3}^j$ are 1.5 and 0.5, respectively. These policy functions induce stabilization policies facing inflation and stimulus for production by controlling money quantity or short-term interest rate.

5.3.3. Methodology

We perform the simulation using Dynare 4.2.5. We simulate the model on a quarterly basis which means that each period corresponds to a quarter of the real economy. A one percent productivity shock is introduced at the beginning of the experiment period for each economy and these shocks stay permanent for the economies. To control for the difference in the level of shocks for these economies, we choose symmetric size for the shocks so that the standardized approach can provide a basis for comparison of the scenarios. In addition, because of the nature of the linearized model, our simulation should exhibit proportional movements of the variables when the shocks are increasing. Setting the size of the productivity shock as one percent does not compromise the generality of the findings.

We extract simulation results by computing a series of arguments to reveal the dynamics of the variables and compare these variables across the economies. We derive at impulse response functions of the variables for 40 periods, which corresponds to changes of the variables during in 10 years after the shock. The impulse response functions are collected and plotted so that we can compare the movements of the variables in different periods and between different countries. At the same time, the cumulative percentage changes of the variables after four periods and 40 periods are also calculated. These two arguments exhibit the cumulative effects of the productivity shock on the economies in one year and in 10 years, respectively. The immediate jump of the variables after the shock, together with the cumulative effects, reflects the short-, medium-, and long-term dynamics of the economies. Using 10 year to measure long-term effects captures major dynamics, because most impulses die out after 40 periods in the simulation.

To draw implications from the simulation results, we first discuss the results for each scenario where a shock is imposed on one of the economies in our model. We provide findings about output, consumption, price levels, the exchange rate, etc. for each economy. With these general findings, we then specifically analyze two channels that transmit the shocks to foreign countries and link the dynamics of these economies. They are the trade and the valuation channels, both measured by the variables defined in our model development section. We focus on the mechanisms of these two channels in balancing the economies towards their long-run equilibrium that are largely distinct from each other as described by their heterogeneous steady state.

5.4. Simulation of the Model

The purposes of the following sections are to understand the effects of productivity shocks to different economies on various variables, and the implications of these dynamics thereof. In each scenario, we introduce a permanent shock to one economy.

The analysis includes the responses of the domestic country under the shock and the transmission of the effects to foreign economies. This section is structured along the simulation results of the four scenarios, i.e. the shocks to China, the US, the EA, and the ROW, respectively.

Generally, we find that the dynamics of the four economies facing one percent productivity shocks in different areas are distinct. These distinctions could be attributed to the different roles of each in the world economy due to their population, relative size, share in world consumption, investment, etc. A multi-country framework is necessary to capture the dynamics of these variables.

5.4.1. Scenario 1: Productivity Shock in China

A productivity shock in China generally increases the utility of Chinese households. World output and consumption increases. China bears most changes and has limited effects on the other blocks. Table 5.3 exhibits the impulse responses of the variables immediately after the shock and the cumulative effects in 10 and 40 periods. Figure 5.1 in the Appendix displays the impulse response functions of the variables.

Our simulation generally captures the same direction of the variables as Mehrotra, Nuutilainen, and Pääkkönen (2011), which concludes increases in output,

Table 5.3 Impulse responses to a productivity shock in CN (percent)

Country j		China			US			EA			ROW		
Periods		**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Marginal utility		-0.47	-0.69	-0.58	0.01	-0.08	-0.04	0.06	-0.06	-0.01	-0.40	-0.01	-0.06
PPI		-0.28	-0.30	-0.47	0.03	0.02	-0.01	0.04	-	-0.03	0.11	-0.02	0.01
Output		0.74	0.83	1.01	0.03	-	0.03	0.08	-	0.06	0.03	0.04	0.01
CPI		-0.20	-0.27	-0.40	0.03	0.01	-0.01	0.06	-0.01	-0.03	0.07	-0.02	-0.01
Consumption		0.53	0.92	0.95	-0.03	0.02	0.04	-0.07	0.02	0.03	0.14	0.02	0.05
Labour		-0.39	-0.24	-0.20	0.05	-	0.01	0.11	-	0.04	0.04	0.05	0.05
Wage		-0.30	0.20	0.19	0.08	0.07	0.06	0.17	0.06	0.08	0.49	0.12	0.17
Marginal cost		-1.42	-0.87	-1.02	0.10	0.07	0.05	0.21	0.07	0.06	0.51	0.13	0.22
Capital		-	-0.02	0.42	-	-	0.06	-	-0.01	0.11	-	0.01	-0.09
Rental		-0.68	-0.02	-0.43	0.13	0.07	0.01	0.29	0.08	-	0.53	0.16	0.31
Investment		0.20	0.82	0.50	-	0.09	0.12	-0.01	0.15	0.19	0.03	-0.14	-0.12
Investment price		-0.20	-0.27	-0.40	0.03	0.01	-0.01	0.06	-0.01	-0.03	0.07	-0.02	-0.01
Money		-0.03	-0.04	0.09	-0.10	-0.08	0.04	-0.21	-0.07	0.03	0.01	-0.08	0.09
Interest rate		0.11	0.21	0.14	0.03	0.04	-0.01	0.06	0.02	-0.01	0.06	0.03	-0.02
Exchange rate w.r.t.	US	-0.08	-0.17	-0.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	EA	-0.05	-0.18	-0.15	0.03	-0.01	-	N/A	N/A	N/A	N/A	N/A	N/A
	ROW	-0.05	-0.18	-0.16	0.03	-0.01	-0.01	-	-	-0.01	N/A	N/A	N/A

consumption and investment, and decreases in inflation and labour. From the perspective of the production sector, a productivity shock should bring down marginal cost by one percent immediately. In the long run, the marginal cost decreases by 1.02 percent, which is similar as the size of the shock. Although wages become more expensive by 0.19 percent, the increase in rental for 0.43 percent offsets that in the marginal cost, and this is reason why the marginal cost changes proportionally with productivity. The 0.20 percent decrease in labour is compensated for by the raised capital of 0.42 percent, and thereby the output increases by 1.01 percent mainly due to productivity improvement. PPI decreases 0.47 percent with the marginal cost and leads to a 0.4 percent decrease of CPI.

For households, consumption has a rise of 0.95 percent mainly because consumption is a complement to leisure and an increase in CPI would increase both of them. Both consumption increase and labour decrease reflect an increase in the utility of Chinese households, which should be attributed to positive welfare effects of productivity improvements on the domestic economy. The investment side has a reduction of 0.4 percent in the price index and an increase in the level of investment by 0.5 percent, which contributes to the accumulated increase in capital.

Analytically, government should respond to the shock by tightening money supply. However, an increase in consumption also brings higher demand for money. The overall effect on money supply is a slight expansion of 0.09 percent in China. The 0.14 percent interest rate increase is due to both the tightening policy and an increase in demand for money in the short run. China's exchange rates with respect to the other three economies appreciate and the magnitude is decided by the differences of interest rates between them.

In the short run, companies who are able to change their contracts in the current period will reduce the prices of their products. Others face fixed price in the period of the shock. Aggregately, the PPI of China decreases by 0.28 percent immediately. Producers have smaller demand for labour since the productivity improvement increases the output per labour or capital input. Households reduce wage levels due to the decrease in the demand for labour. Similarly, capital rental reduces as well if we view rental as the price of the capital. The joint effect of a wage decrease of 0.3 percent and rental decrease of 0.68 percent further reduces marginal cost. This, together with the productivity improvement, leads to a 1.42 percent decrease of marginal cost. The output increased, but not by the level of the shock, since less inputs of production partly offset this improvement. From the demand side, PPI does not fully respond to the shock due to nominal rigidities. The output increases by 0.74 percent in the short run. Neither does consumption increase in the short run as much as in the long run, which attributes to a combined effect of CPI decrease and the movement of the exchange rates. China has a 0.53 percent increase in consumption after the shock. Structurally, this should be the due to the habit of households in refraining from increasing consumption to the long-term level immediately.

From the impulse response functions, we can observe generally consistent dynamics for most variables from the short run to the long run, though there are a few volatilities in the medium run. These can also be found from the consistent signs of changes of the variables immediately after the shock and those of the cumulative effects of 40 periods. Mehrotra, Nuutilainen, and Pääkkönen (2011) concludes deviations from the steady state of most key variables last about 25 quarters, and this is even shorter in their rebalanced calibration. The persistency we find in our scenario is due to the open economy features in our model. Mehrotra, Nuutilainen, and Pääkkönen (2011) is using a closed economy structure, but in our model, spillover effects transmit through the trade and valuation channels and build up international investment, leading to the permanent effects on welfare. The trade and valuation effects in this scenario will be discussion in Section 5.5, 5.6 and 5.7.

For the spillover effects of the productivity shock in CN, we find very small deviations of the foreign variables. Most foreign variables have a change less than 0.5 percent, both in the short and long run. This could be due to the small relative weight of China in the world economy, as we discussed in Section 5.3.1.

5.4.2. Scenario 2: Productivity Shock in the United States

The scenario of the US facing a domestic productivity shock is different from other scenarios that we described for a shock in China. The magnitude of the spillovers to foreign economies is much larger for the shock in the US than the shock in China. In addition, the wealth of the EA could be decreased given the US shock and the policy responses of the economies. Table 5.4 and Figure 5.2 (Appendix) provide the impulse response functions for this scenario.

Table 5.4 Impulse responses to a productivity shock in US (percent)

Country j		China			US			EA			ROW		
Periods		**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Marginal utility		-6.95	-15.35	-16.59	0.75	-0.91	-0.63	1.66	0.07	0.21	-6.33	-1.20	-1.90
PPI		2.50	4.88	3.42	-0.03	0.12	-0.06	0.83	0.31	0.26	1.97	0.41	1.11
Output		0.38	-1.80	0.82	1.31	1.01	1.42	1.50	0.45	1.17	0.59	0.66	0.10
CPI		2.21	3.26	2.22	0.34	0.37	0.25	1.21	0.55	0.64	1.70	0.67	1.13
Consumption		1.85	6.74	8.30	-0.39	0.16	0.28	-1.59	-1.23	-1.01	1.88	0.03	0.02
Labour		0.57	-2.50	-2.47	0.46	0.05	0.22	2.25	0.70	1.10	0.89	0.92	1.07
Wage		8.08	10.35	11.65	0.17	1.00	1.07	2.83	1.33	1.98	8.11	3.05	4.04
Marginal cost		8.27	9.65	8.36	-0.68	0.04	-0.12	3.57	1.58	1.91	8.40	3.31	5.00
Capital		-	-0.38	7.49	-	-0.05	0.82	-	-0.07	1.33	-	0.12	-1.87
Rental		8.65	8.23	1.69	0.62	1.11	0.47	5.08	2.10	1.75	8.99	3.85	6.97
Investment		2.02	11.83	10.87	-0.09	1.23	1.58	-0.48	1.26	2.39	0.51	-2.33	-2.84
Investment price		2.21	3.26	2.22	0.34	0.37	0.25	1.21	0.55	0.64	1.70	0.67	1.13
Money		-1.75	-4.42	-3.77	-1.94	-3.69	-2.99	-4.52	-5.88	-5.35	-0.98	-5.60	-4.48
Interest rate		1.81	4.49	4.45	0.58	1.31	1.09	1.28	1.62	1.55	1.42	1.96	1.75
Exchange rate w.r.t.	US	-1.22	-3.16	-3.34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	EA	-0.53	-2.85	-2.88	0.69	0.31	0.46	N/A	N/A	N/A	N/A	N/A	N/A
	ROW	-0.39	-2.51	-2.68	0.84	0.64	0.66	0.14	0.34	0.20	N/A	N/A	N/A

We find domestic effects of a US shock is expansionary, which is consistent with Lubik and Schorfheide (2006). In the long run, the US has a much higher output increase of 1.42 percent. Besides the productivity itself, labour and capital rise by 0.22 percent and 0.82 percent, respectively. Both capital and labour costs are higher due to higher demands for them, with 1.07 percent in wages and 0.47 percent in rental. For similar reasons, if we consider a reduction in marginal cost by 0.12 percent, then it is not reduced by the level of the productivity improvement. PPI reflects the small change in marginal cost and also decreases only by 0.06 percent. CPI does not benefit much from the PPI decrease and conversely increases by 0.25 percent with dollar depreciation. We attribute the 0.28 percent in consumption of the US generally to the increase in household income, of which a large part is from higher wages and labour. Similarly, both investment and investment price index increase by 1.58 and 0.25

percent, respectively. During this process, the US interest rate is raised by 1.09 percent and money decreases by 2.99 percent as a result of the contraction policy. We find that the contraction in monetary policy is not contradictory with the dollar depreciation, since the foreign response to US policy is even stronger. However, Lubik and Schorfheide (2006) derive negative transmission. The difference between our model and theirs is the international risk sharing which is assumed to be perfect in their case. The dollar depreciation and perfect risk sharing would shift production to higher productivity economy, and contracting the foreign economy. We illustrate the imperfect risk sharing feature of our model in Section 5.2.1, and our difference is based on this fact. We explain this in the later sections by analysis of the trade and valuation channels between economies.

Short-run effects are more persistent in our case. The responses are lasting more than 40 quarters. These effects are permanent due to international investment leads to asymmetry redistribution of welfare between these economies, which is observed in all four scenarios. In the symmetric calibration in Lubik and Schorfheide (2006), they find the dollar depreciation maintain relative price constant. This is consistent with our complete markets case in Section 3.3.2. In the short run, the marginal cost decreased as expected, but the magnitude is smaller than the improvement of productivity. The reason is that the productivity increase is partly offset by the increase in wages and rental. The US exchange rate depreciates with respect to all the other three blocks consistently from the short run to the long run. This makes goods from the US more competitive and the output of the US is raised by 1.31 percent in the short term, which is much larger than the 0.74 percent increase in output of China if the shock were on her. This extra response of output requires more labour and capital, which becomes the source of higher wages and rental prices. Consumption decreased in the short run as a complement to the decrease in leisure. Regardless of the cheaper price of domestic goods, the CPI still increases because the depreciation makes the imports more expensive for US households. The biggest difference between short-term and long-term US variables is consumption, which decreases by 0.39 percent in the short-run and is later reversed to increase. The increase in income for the US is largely becoming the accumulation of international assets. We will examine this phenomenon in detail in the sections below.

A US shock will affect foreign economies more than a shock in CN. We derive in Section 5.4.1 that the spillover effects of a productivity shock in CN are generally close to zero. However, a US shock has different implications. Facing it, CN and EA have increases in output by 0.82 and 1.17 percent, respectively. These two economies respond to the US shock with an expansion of about the same magnitude. In particular, China boosts consumption by 8.3 percent in 40 quarters, which shows the large potential of China's consumption rise if the shock is from the US. The EA responds to a US shock by contracting consumption for 1.01 percent in the long run. The aggregate effect of the US shock would suggest building up of net trade and investment position for the US and the EA, while adjusting trade surplus for China. This could be confirmed by the analysis of international trades in Section 5.5.

5.4.3. Scenario 3: Productivity Shock in the Euro Area

Generally, China and the US both have expansion in consumption and output when facing productivity shocks. Correspondingly, the monetary policies of their governments facing domestic productivity improvement are notable for contraction with regard to lower money issuance or higher interest rates. However, the Euro Area facing a similar shock is different from the previous two economies in that the EA has a contraction in production together with an expansionary interest rate policy in the long run. Table 5.5 and Figure 5.3 (Appendix) display the changes to the variables for the scenario of an EA shock.

We observe that in 40 periods after introducing the one percent permanent productivity shock in the Euro Area, the marginal cost decreases 3.08 percent, which is even stronger than that due to productivity improvement. Besides productivity, the other two components of marginal cost, which are wages and rental of capital, decrease by 2.07 and 2.12 percent, respectively. The decrease in labour demand for 1.13 percent should cause lower wages. Similarly, capital decreases by 1.07 percent.

Table 5.5 Impulse responses to a productivity shock in EA (percent)

Country j	China			US			EA			ROW		
Periods	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Marginal utility	6.95	15.02	14.67	-0.92	0.56	0.20	-1.74	-0.13	-0.19	6.54	1.09	1.61
PPI	-2.56	-4.79	-2.86	-0.40	-0.45	-0.31	-1.24	-0.69	-0.63	-2.03	-0.33	-0.92
Output	-0.51	1.71	-1.29	-0.69	-0.17	-0.40	-0.83	0.48	-0.11	-0.70	-0.70	-0.14
CPI	-2.30	-3.19	-1.84	-0.72	-0.65	-0.53	-1.52	-0.81	-0.85	-1.82	-0.66	-1.01
Consumption	-1.80	-6.59	-7.42	0.91	0.58	0.51	2.02	1.74	1.41	-1.90	0.06	0.05
Labour	-0.77	2.36	1.82	-1.02	-0.27	-0.43	-2.73	-0.81	-1.13	-1.04	-0.99	-1.15
Wage	-8.48	-10.30	-11.03	-1.13	-1.09	-1.06	-3.71	-1.49	-2.07	-8.62	-3.07	-3.92
Marginal cost	-8.73	-9.65	-7.92	-1.46	-1.19	-1.09	-5.61	-2.77	-3.08	-8.96	-3.36	-4.93
Capital	-	0.38	-7.60	-	0.04	-0.33	-	0.06	-1.07	-	-0.12	1.93
Rental	-9.24	-8.32	-1.61	-2.15	-1.40	-1.16	-6.44	-2.36	-2.12	-9.66	-3.94	-7.00
Investment	-2.02	-11.88	-10.67	0.23	-0.61	-0.92	0.56	-0.89	-2.22	-0.49	2.42	2.98
Investment price	-2.30	-3.19	-1.84	-0.72	-0.65	-0.53	-1.52	-0.81	-0.85	-1.82	-0.66	-1.01
Money	1.85	4.37	3.45	2.49	4.16	3.22	4.84	5.85	4.87	1.20	5.66	4.16
Interest rate	-1.86	-4.41	-3.96	-0.71	-1.32	-1.01	-1.35	-1.54	-1.34	-1.54	-1.95	-1.59
Exchange rate w.r.t. US	1.14	3.07	2.93	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exchange rate w.r.t. EA	0.51	2.86	2.60	-0.63	-0.22	-0.33	N/A	N/A	N/A	N/A	N/A	N/A
Exchange rate w.r.t. ROW	0.32	2.45	2.35	-0.82	-0.63	-0.58	-0.19	-0.41	-0.25	N/A	N/A	N/A

Accompanied by lower costs, prices set by producers of the Euro Area aggregately reduce by 0.63 percent. The output also has a cut of 0.11 percent in the long run, since the decrease in the factors of production, which are labour and capital, are more significant than the improvement of productivity.

In spite of the contraction in the production sector, the consumption of domestic households of the EA under a productivity shock is largely increased by 1.41 percent. On the one hand, the consumer price index is reduced by 0.85 percent, due to both a lower domestic goods price and the appreciation of the euro currency. The cheaper price should enhance consumption. On the other hand, this should be a complementary effect of reducing labour, since both wages and CPI decrease.

Investment is also smaller, and then the depreciation lowers the cumulated capital for the production sector.

The response of the EA governments to such effects is a decrease in interest rate of about 1.34 percent. Accordingly, the money quantity is increased by 4.87 percent. From the perspective of the definition of the utility function, the EA has an improvement in wealth, since consumption and money holding are increasing and labour is decreasing. The extent of this welfare improvement is even larger than China in a similar scenario, since both output increase and labour decrease are larger in this case.

The short-run responses of the variables are characterized by even larger movements than their long-run changes. For example, consumption increases by 2.02 percent and labour decreases by 2.73 percent immediately after the shock. However, after the stimulating monetary policy of the EA comes into effect, most variables are close to their long-run level in four periods.

Our findings with shock in the Euro Area are different from other EA models. We generally find contrationary response of the EA to the shock, while the other economies respond by even larger falling back. Smets and Wouters (2003) and Lubik and Schorfheide (2006) both conclude increase in output for the EA. Our consumption response is consistent with Smets and Wouters (2003) and Breuss and Fornero (2009). Our study differs from these studies in terms of imperfect risk sharing and multi-country heterogeneity. The distinct behaviour of the EA in our calibration is largely due to these features.

5.4.4. Scenario 4: Productivity Shock in the Rest of the World

Suppose a similar one percent permanent productivity increase is imposed on the block that represents the rest of the world, we find that the ROW as the home country has similar dynamics as China if the shock were on her. Table 5.6 and Figure 5.4 (Appendix) exhibit the impulse responses for the variables under investigation in this scenario.

In 40 periods after the introduction of the shock, one of the differences between the scenario of a shock to the EA and the scenario of China is that the wage level of the EA decreases by 0.61 percent rather than China's increase of 0.19 percent. Thereby, the marginal cost of the EA is reduced by 1.89 percent and is more than the extent of the productivity improvement. Rental also decreases by 1.45 percent and contributes to lowering marginal cost. The reduction of labour by 0.35 percent is largely offset by adding capital of 0.49 percent. They have an overall effect on the output of 0.93

Table 5.6 Impulse responses to a productivity shock in ROW (percent)

Country j	**China**			**US**			**EA**			**ROW**		
Periods	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Marginal utility	1.06	2.07	3.78	-0.13	0.11	-0.22	-0.33	-0.20	-0.87	0.33	-0.32	-0.08
PPI	-0.38	-0.54	-0.81	-0.07	-0.05	0.05	-0.10	0.08	0.14	-0.63	-0.40	-0.65
Output	-0.08	0.25	0.54	-0.11	-0.01	-0.12	-0.24	-0.07	-0.22	0.57	0.76	0.93
CPI	-0.40	-0.41	-0.60	-0.14	-0.10	-0.06	-0.25	-0.07	-0.12	-0.51	-0.34	-0.53
Consumption	-0.25	-0.93	-1.84	0.16	0.08	0.23	0.32	0.30	0.73	0.37	0.81	0.83
Labour	-0.13	0.36	0.92	-0.17	-0.03	-0.14	-0.36	-0.11	-0.38	-0.65	-0.35	-0.35
Wage	-1.32	-1.35	-1.94	-0.20	-0.16	-0.06	-0.39	-0.02	0.10	-1.62	-0.38	-0.61
Marginal cost	-1.36	-1.24	-1.57	-0.25	-0.17	-0.08	-0.51	-0.05	-0.06	-2.84	-1.48	-1.89
Capital	-	0.04	-0.22	-	0.01	-0.08	-	0.01	0.11	-	-0.03	0.49
Rental	-1.44	-1.03	-0.81	-0.36	-0.19	-0.12	-0.75	-0.13	-0.39	-2.27	-0.70	-1.45
Investment	-0.24	-1.13	-0.36	0.03	-0.20	0.03	0.10	-0.12	0.60	0.10	0.83	0.65
Investment price	-0.40	-0.41	-0.60	-0.14	-0.10	-0.06	-0.25	-0.07	-0.12	-0.51	-0.34	-0.53
Money	0.32	0.60	0.61	0.45	0.66	0.65	0.87	1.01	1.52	0.63	1.24	1.32
Interest rate	-0.30	-0.60	-0.95	-0.13	-0.21	-0.15	-0.25	-0.24	-0.28	-0.24	-0.24	-0.32
Exchange rate w.r.t. US	0.17	0.39	0.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exchange rate w.r.t. EA	0.05	0.36	0.66	-0.11	-0.03	-0.13	N/A	N/A	N/A	N/A	N/A	N/A
Exchange rate w.r.t. ROW	0.06	0.36	0.63	-0.11	-0.03	-0.17	0.01	-	-0.04	N/A	N/A	N/A

percent increase and the boost of the output is similar to the size of the productivity improvement. PPI decrease of 0.65 percent due to the savings on marginal cost enables the firms to charge less without affecting their profits. The PPI deflate not as much as the marginal cost, since a larger demand for ROW goods causes PPI to step up to the extent that the profits are increasing.

From the perspective of the households, consumption increases by 0.83 percent together with an increase in leisure (decrease in labour) in the long run. This is also because of a 0.53 percent deflation of CPI which leads to a cheaper consumer goods basket. Investment moves to the same direction of consumption by 0.65 percent and increases the capital for the production section. The investment goods price has the same decrease as CPI which is 0.53 percent. The interest rate is reduced by government policy for 0.32 percent. This features an expansionary policy, because the the interest rate policy responds more to deflation than output improvement. The money issue is increased by 1.32 percent.

In the short term, most variables have movements larger than the long-term changes. In the impulse response functions, we can observe a reverse of the changes in the medium term. For example, the marginal cost decreases by 2.84 percent, which is much larger than the 1.89 percent in 40 periods.

Shocks to the countries lead to different dynamics of domestic and foreign economies. The process of redistribution of world income relies on two channels: trade and valuation. We have defined these two channels in our model and calculated IRFs for them. Additionally, the outcomes of income and welfare redistribution are reflected in the holdings of international assets by each economy. In the next sections, we examine the trade, valuation and international asset changes in these simulations.

5.5. The Trade Channel

By imposing productivity shocks on each economy in the model, we can observe the net trade of each country when there is either a home or foreign productivity improvement. More importantly, our multi-country framework enables us to derive implications for the aggregate trade of each country, but also trade with each of its partners separately. With this mechanism, we find that the international income redistribution through international trades is decided by the weights of the economies in goods market. Specifically, these roles are characterized by the relative size of the economies and the shares of goods from different countries in the composition of final goods. The causes of this asymmetry in terms of surplus and deficit are the combining effects of the different changes in exports and imports. In the following part of this section, we examine findings from each scenario of our simulation. Table 5.7 displays the dynamics of trades between these economies in the four scenarios.

Scenario 1

International trade after a productivity shock in China does not see significant changes relative to the output of each country. China has a long-term trade surplus of only 0.04 percent of output, in which about 0.01 percent is with regards to the US, 0.03 percent to the ROW and changes in the net trade with EA is almost zero. The net trades are relatively larger in the short and medium runs, but still not compatible with the magnitude of the shock.

Table 5.7 Impulse responses of trades to productivity shocks (percent)

A. Productivity shock in CN

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	0.17	-0.14	0.04	0.04	-0.02	-0.01	0.11	-0.01	0.02	-0.07	0.02	-0.01
CN	N/A	N/A	N/A	-	-	-	-	0.01	-	-0.02	0.01	-0.01
US	0.01	-0.01	0.01	N/A	N/A	N/A	-	-	-	-0.01	0.01	-
EA	0.01	-0.01	-	-	-	-	N/A	N/A	N/A	-0.03	-	-
ROW	0.16	-0.12	0.03	0.04	-0.02	-	0.12	-0.02	0.02	N/A	N/A	N/A

B. Productivity shock in the US

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	-0.67	-6.89	-5.81	1.11	0.51	0.69	2.30	1.15	1.41	-0.93	0.41	0.12
CN	N/A	N/A	N/A	0.11	0.24	0.22	0.09	0.30	0.26	0.02	0.72	0.58
US	-0.28	-0.65	-0.60	N/A	N/A	N/A	-0.05	-	-0.02	-0.32	-0.09	-0.15
EA	-0.19	-0.64	-0.56	0.04	-	0.01	N/A	N/A	N/A	-0.63	-0.22	-0.32
ROW	-0.19	-5.60	-4.65	0.97	0.27	0.46	2.26	0.86	1.16	N/A	N/A	N/A

C. Productivity shock in the EA

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	0.54	6.80	5.12	-1.07	-0.47	-0.57	-2.25	-0.99	-1.08	0.92	-0.46	-0.16
CN	N/A	N/A	N/A	-0.10	-0.23	-0.19	-0.09	-0.29	-0.23	-0.01	-0.71	-0.52
US	0.27	0.64	0.52	N/A	N/A	N/A	0.05	-	0.02	0.30	0.07	0.12
EA	0.18	0.62	0.49	-0.04	-	-0.01	N/A	N/A	N/A	0.62	0.17	0.23
ROW	0.09	5.54	4.11	-0.93	-0.23	-0.37	-2.22	-0.70	-0.87	N/A	N/A	N/A

D. Productivity shock in the ROW

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	0.09	0.89	1.25	-0.16	-0.04	-0.19	-0.34	-0.14	-0.52	0.14	-0.06	0.05
CN	N/A	N/A	N/A	-0.01	-0.03	-0.05	-0.01	-0.04	-0.06	-	-0.09	-0.12
US	0.04	0.08	0.14	N/A	N/A	N/A	0.01	-	-	0.05	-	0.05
EA	0.03	0.08	0.13	-	-	-	N/A	N/A	N/A	0.10	0.03	0.13
ROW	0.03	0.73	0.98	-0.14	-0.01	-0.14	-0.34	-0.10	-0.46	N/A	N/A	N/A

Changes of net trade of country j with country j’ as percentage of the output of country j

In fact, in the steady state, China’s GDP is a relative small fraction of the world economy. Although the Chinese population accounts for 20.2 percent of the world total, the ratio of per capita output of the US, the EA and the ROW relative to that of China is 10.742, 8.356, and 2.098, respectively. This makes the productivity improvement in China only a fraction in terms of the world economic size. The foreign responses to China's shock are also moderate. Besides the size of the economy, China also has a small steady state net trade (Table 5.8). The net export of China is a surplus of 15.63 percent to her GDP. Counting the relative size of China in world production, we find that this surplus is relatively small. Therefore the international trade channel in the case of the shock in China has a limited role in international trade redistribution. The changes to the exports and imports of China due to home and foreign dynamics are small as reflected by our IRFs (Figure 5.1).

Scenario 2

Similarly to China in scenario 1, the US is also running a surplus after a domestic productivity shock. The aggregate surplus is 0.69 percent to US output, consisting of 0.22, 0.01, and 0.46 percent to China, the EA and the ROW, respectively. These surpluses are proportional to the net trade in the steady state in Table 5.8 as well.

In 40 periods after a productivity shock in the US, China runs aggregate trade deficits which are 5.81 percent of her GDP. We can observe from the IRFs that these deficits are mostly obtained during the first 10 periods after the shock, and the deficits are consistent from the short term to the long term. If we decompose the deficits into trade with the other three economies, China has deficits of 0.60, 0.56 and 4.65 percent

Table 5.8 Exports, imports and net trade balance to output ratios in steady state

Export of country j to j' (percentage of output of country j)					
j \ j'	Aggregate	China	US	EA	ROW
China	35.75		16.18	10.55	9.02
US	1.72	0.14		0.86	0.73
EA	5.23	0.24	1.94		3.05
ROW	139.26	7.92	42.06	89.27	
Import of country j from j' (percentage of output of country j)					
j \ j'	Aggregate	China	US	EA	ROW
China	20.13		1.49	2.02	16.61
US	11.22	1.51		1.51	8.20
EA	24.77	1.26	1.10		22.41
ROW	20.18	4.30	3.72	12.16	
Net trade of country j to j' (percentage of output of country j)					
j \ j'	Aggregate	China	US	EA	ROW
China	15.63		14.69	8.53	-7.59
US	-9.49	-1.37		-0.65	-7.48
EA	-19.54	-1.02	0.83		-19.36
ROW	119.08	3.62	38.34	77.12	

Implied exports, imports and the net trade balance to output ratios in the steady state (percent)

to her GDP, respectively. In these deficits with her partners, the ones with the ROW block are the largest, while those with the US and the EA are relatively small. For imports by China, intermediate goods from the ROW block consist of 18.9 percent in the basket of intermediate goods for final goods production of China, and these are the largest composites of foreign goods in China’s consumption and investment baskets. Therefore, the increase in China’s consumption and investment should lead to rising imports and the largest part of these from the ROW block. On the other hand, although China’s output has a larger share, 0.052 percent, in the consumption and investment of ROW than the shares in the final goods of the US or the EA, the magnitude is not as significant as the effects of the imports. Therefore, the net change of trades to the ROW is largely in deficits and the largest among the three foreign economies of China.

Scenario 3

The Euro Area has aggregate deficits in the long run facing a one percent productivity improvement. Different from the surpluses of China and US in the first two scenarios, the EA imports more because consumption increases much more than output decreases. On the other hand, the euro exchange rate is appreciating with regards to the RMB and the ROW. The ROW block is the largest fraction in trade with the EA implied by our steady state analysis in Table 5.8. This is confirmed by the impulse response of the deficit to the ROW block which is 0.87 percent to the output of the EA. The deficits of the EA are not the same among all its trade partners. The trade deficit to China is 0.23 percent and the EA has a small surplus to the US which is 0.02 percent. This is adverse to a US shock, but the magnitudes of the changes are similar in both scenarios. Also, the surplus to the US is consistent with the dollar appreciation of 0.33 percent to the euro in this case.

China's output decreases by 1.29 percent with the euro shock, but the consumption is reduced even further, by 7.42 percent, leading to the surplus of China in this case.

Again, the similarity of this scenario with the previous two is that the ROW block consists of the largest part of China's surplus.

Scenario 4

When there is an increase in the productivity of the ROW area, the overall effect on the net trade of the block is a surplus of 0.05 percent to the output. However, the elements of this surplus are distinct between different trade partners of the ROW. Specifically, the ROW runs surpluses of 0.05 and 0.13 percent to the US and the EA, while it has a deficit of 0.12 percent to China. As in our analysis of the steady state, the net trade of the ROW block is mainly due to the surpluses to the US and the EA, and China only contributes to 3.62 percent to the GDP of the ROW. This leads to the deficit of the ROW to China after the shock, when China responds to the shock with large decrease in consumption and a relatively small increase in output. Again, the net trade between the US and the EA is almost zero during all periods.

Overall, the dynamics of each country in response to a shock are different, as described by the four scenarios in the above analysis. Moreover, the behaviours of the foreign economies are not the same with respect to the home country. These complex dynamics between major economies can only be captured by a multi-country framework. Within this framework, the weights of each country in the world population, production, and trade determines the role of it in the world income distribution process.

5.6. The Valuation Channel

One contribution of our work to NOEM modelling is to explicitly express IIPs in a general equilibrium framework so that we can evaluate the valuation effects. In this section, we investigate the value changes of external assets due to asset price and exchange rate movements with respect to home and foreign shocks. The valuation channel between the two countries is affected by three variables: the interest rates of each country and the exchange rate. We find that the steady state IIP of each country is a base to calculate the magnitude of the changes of the value. Given a large initial external asset position, the valuation effects could be compatible with the trade channel in size. A traditional SOE model with incomplete market and netting off the cross-holdings between two countries underestimates the valuation effects. Due to the complexity of the gross positions in a multi-country framework, different countries may have different valuation effects facing a shock. The value changes can be positive or negative, and have distinct sizes. Table 5.9 displays the valuation channel in the shocks in these four economies.

Table 5.9 Impulse responses of valuation effects to productivity shocks (percent)

A. Productivity shock in CN

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	-0.25	-0.05	0.13	0.02	0.04	-	0.07	0.02	-0.01	0.01	-0.01	-0.01
CN	N/A	N/A	N/A	0.01	0.01	-	0.02	0.01	-	0.03	-	-0.01
US	-0.02	-0.02	0.01	N/A	N/A	N/A	-	-	-	-	-0.01	-
EA	-0.04	-0.01	0.01	-	-	-	N/A	N/A	N/A	-0.01	-0.01	-
ROW	-0.19	-0.02	0.11	0.01	0.03	-	0.05	0.02	-	N/A	N/A	N/A

B. Productivity shock in the US

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	-5.71	-7.34	-6.41	0.20	0.95	0.73	1.43	1.67	1.66	0.31	0.22	0.17
CN	N/A	N/A	N/A	0.15	0.33	0.27	0.43	0.52	0.49	0.61	0.76	0.66
US	-0.36	-0.80	-0.65	N/A	N/A	N/A	0.05	0.02	0.03	-0.03	-0.21	-0.16
EA	-0.88	-1.06	-1.01	-0.05	-0.02	-0.03	N/A	N/A	N/A	-0.27	-0.32	-0.32
ROW	-4.47	-5.48	-4.75	0.10	0.64	0.49	0.95	1.13	1.14	N/A	N/A	N/A

C. Productivity shock in the EA

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	6.24	7.27	5.83	-0.33	-0.97	-0.69	-1.48	-1.54	-1.40	-0.32	-0.25	-0.18
CN	N/A	N/A	N/A	-0.19	-0.33	-0.25	-0.45	-0.49	-0.43	-0.67	-0.76	-0.60
US	0.45	0.81	0.60	N/A	N/A	N/A	-0.05	-0.01	-0.02	0.06	0.22	0.15
EA	0.93	1.00	0.87	0.04	0.01	0.02	N/A	N/A	N/A	0.28	0.29	0.27
ROW	4.85	5.47	4.36	-0.19	-0.65	-0.46	-0.98	-1.03	-0.95	N/A	N/A	N/A

D. Productivity shock in the ROW

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	1.02	0.95	1.08	-0.08	-0.18	-0.07	-0.29	-0.27	-0.31	-0.03	0.01	-0.04
CN	N/A	N/A	N/A	-0.04	-0.05	-0.03	-0.08	-0.08	-0.09	-0.10	-0.09	-0.11
US	0.09	0.13	0.08	N/A	N/A	N/A	-0.01	-	-0.01	0.02	0.04	0.01
EA	0.17	0.16	0.18	0.01	-	0.01	N/A	N/A	N/A	0.06	0.05	0.06
ROW	0.76	0.66	0.82	-0.05	-0.13	-0.04	-0.20	-0.19	-0.21	N/A	N/A	N/A

Valuation effects of country j with country j’ as percentage of the output of country j

Scenario 1

Similar to the trade channel, the valuation effects of a productivity shock in China is small for the four economies. China has an overall increase in the value of external assets of 0.13 percent to her output, mainly due to a 0.11 percent increase in the value of investment with respect to the rest of the world. Although interest rate differentials exist between China and all the other three economies and the exchange rates of China appreciate with respect to all the other three blocks similarly, the ROW block has the largest amount of liabilities held by China. This makes the valuation effects with the ROW block more significant than with the other two blocks. In addition, the channels between other countries are also negligible.

Scenario 2

In the four scenarios, the productivity shock to the US leads to the greatest changes of the other economies through the valuation channels. In the long run, the deficits of China with the US, the EA and ROW due to valuation effects are 0.65, 1.01, and 4.75 percent of her output, respectively (Table 5.9). These aggregate to a deficit of about 6.41 percent of China's output, which is even larger than the trade deficit of 5.81 percent. The valuation effect is proportional to the gross position of a country, confirming our analytical findings. With regard to the liabilities of these three areas, the liability of the ROW block accounts for 49.1 percent of her output which is held by China in steady state. Considering that the ROW block is also the largest economy in aggregate output terms, the absolute level of liability of ROW to China is much higher than the US and the EA. Thereby the valuation effects of China attributed to ROW are the greatest among these three foreign economies.

Scenario 3

The productivity improvement in the Euro Area leads to similar size of international investment value changes, but the directions of these changes are exactly adverse to the effects of the shock in the US. For example, instead of a value decrease by 6.41 percent for China under the US shock, the EA shock causes an increase by 5.83 percent (Table 5.9). The reason is that the interest rate of China increases with regard to a US shock and it decreases when the shock is in the EA. However, since the liabilities of the US and the EA held by China are of similar size, the valuation changes are roughly the same in terms of absolute value in spite of the sign.

More interestingly, the major change in the value of China's investment is not with the EA. In fact, China has a surplus of 4.36 percent with the ROW though the shock is in the EA. While this is caused by the different responses of interest rates and exchange rates of China and the ROW. The holdings of ROW liabilities by China provide a large base for the values.

Scenario 4

Similarly to previous scenarios, a shock in the ROW leads to a large value increase of China, which is 0.82 percent of her output (Table 5.9), since the interest rate of China is reduced more than that of the ROW and the ROW has a large amount of liabilities held by China. The US and the EA have little benefits or losses due to interest rate changes or exchange rate movements.

When we compare the four scenarios, the shock in the EA brings about similar large effects on China to the shock in the US. However, the signs of the valuation effects on China in these two scenarios are adverse. This is because the distinct monetary policy of China in these two cases. China contracts the money supply with respect to a US shocks and expands the supply for an EA shock. For the shocks from China and the ROW, the valuation effects are much smaller globally. In particular, China's productivity improvement has by no means significant long-term effects on the other three blocks. The two variables governing valuation effects, which are the interest rates and the exchange rate, have only minor responses to the shock in China.

5.7. International Investment

The responses of international investment in our model are measured by ratios of the changes in the net asset position to the output of one country with respect to the other country. We base our analysis on the long-term deviations of the position from the steady state, which are reflected by the impulse responses in 40 periods after the shocks. A common phenomenon after a productivity improvement is that the domestic country under the shock accumulates net asset position over the foreign economies. Generally, a country having productivity improvement accumulates external assets and increase net IIP. Productivity improvements in the US and the EA will help these two economies to improve their external liabilities. Shocks in China and the ROW will raise the liabilities of the US and the EA, but the size is relatively small. Table 5.10 illustrates the deviations of the international investment positions.

Scenario 1

A productivity shock in China increases the aggregate net asset position of China to her output by 2.23 percent in 40 periods (Table 5.10). This net increase in IIP consists of 0.49, 0.38 and 1.36 percent to the US, the EA and the ROW, respectively. At the same time, both the US and the EA have deteriorating exposure with respect to China and the ROW, but the size of the changes only accounts for a very small proportion of their outputs. The ROW block has a decrease in the position with respect to China, while it has increases in its position with the US and the EA. The sum of these sub-accounts for the ROW is a net gain of 0.16 percent to its output.

Table 5.10 Impulse responses of net international investment positions to productivity shocks (percent)

A. Productivity shock in CN

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	0.48	1.49	2.23	0.02	-0.11	-0.67	-0.02	-0.17	-0.84	-0.07	-0.12	0.16
CN	N/A	N/A	N/A	0.07	0.06	-0.20	0.12	0.09	-0.18	-0.12	-0.25	-0.19
US	-0.18	-0.15	0.49	N/A	N/A	N/A	-0.02	0.05	-0.01	0.02	0.04	0.16
EA	-0.25	-0.18	0.38	0.02	-0.05	-	N/A	N/A	N/A	0.03	0.09	0.19
ROW	0.90	1.82	1.36	-0.07	-0.12	-0.48	-0.11	-0.32	-0.65	N/A	N/A	N/A

B. Productivity shock in the US

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	4.57	20.45	9.52	0.91	1.60	1.33	0.51	0.94	1.92	-1.08	-3.61	-2.29
CN	N/A	N/A	N/A	1.20	2.59	3.51	2.08	3.39	4.97	-1.62	-4.64	-3.89
US	-2.94	-6.35	-8.58	N/A	N/A	N/A	-0.88	0.50	0.22	0.35	0.20	0.67
EA	-4.31	-7.02	-10.29	0.75	-0.42	-0.18	N/A	N/A	N/A	0.20	0.84	0.93
ROW	11.83	33.81	28.39	-1.04	-0.58	-2.00	-0.69	-2.95	-3.27	N/A	N/A	N/A

C. Productivity shock in the EA

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	-5.21	-21.54	-20.06	-0.73	-0.84	2.81	-0.38	-0.50	1.89	1.07	3.38	1.27
CN	N/A	N/A	N/A	-1.12	-2.17	-0.95	-1.96	-3.08	-2.42	1.65	4.56	3.76
US	2.75	5.31	2.31	N/A	N/A	N/A	0.83	-0.46	-0.26	-0.37	-0.32	-1.19
EA	4.05	6.38	5.01	-0.71	0.39	0.22	N/A	N/A	N/A	-0.21	-0.86	-1.30
ROW	-12.01	-33.23	-27.38	1.10	0.95	3.53	0.74	3.04	4.57	N/A	N/A	N/A

D. Productivity shock in the ROW

Country j	CN			US			EA			ROW		
Country j'	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**	**0**	**0~4**	**0~40**
Aggregate	-0.85	-3.60	6.16	-0.08	0.17	-2.56	0.10	0.83	-1.34	0.12	0.20	0.39
CN	N/A	N/A	N/A	-0.08	-0.07	-2.02	-0.20	-0.03	-2.05	0.20	0.53	0.42
US	0.19	0.17	4.94	N/A	N/A	N/A	0.13	-0.02	0.38	-0.04	-0.08	0.08
EA	0.40	0.06	4.25	-0.11	0.01	-0.32	N/A	N/A	N/A	-0.05	-0.25	-0.10
ROW	-1.45	-3.83	-3.04	0.11	0.23	-0.22	0.17	0.87	0.34	N/A	N/A	N/A

Deviations of net international investment positions of country j with country j' as percentage of the output of country j

Scenario 2

When there is a productivity improvement in the US, the US also accumulates net IIP by 1.33 percent (Table 5.10), though the steady state position is negative. However, the dynamics between the US and her partners depends. The increase in the position comes from the 3.51 percent with respect to China, while the US decreases investment with the EA and the ROW by 0.18 and 2.0 percent, respectively. Similarly to international trade, the international assets of China are significantly affected by the US shock. Although the increase in the position of the US with China is a moderate proportion of the output of the US, it accounts for -8.58 percent of the output of China and is much larger due to the relatively small size of China's output. Adding up assets or cutting liabilities help both the US and the EA to gain positive movements of net positions to China, but China also obtains assets from the ROW.

Scenario 3

An increase in the productivity of the Euro Area leads to a decrease in the net IIP of China and an increase for the US. Similar to the shock to the US, the shock to the EA has the largest effect on China, with China losing 20.06 percent (Table 5.10) to output mainly attributed to the ROW. The US and the EA both have net gain in external assets from the ROW by 3.53 and 4.57 percent, respectively. These increases cover their decrease in the positions to China and bring about positive net accumulation in the aggregate exposures.

Scenario 4

The increase in productivity of the rest of the world leads to positive change of the net position of China by 6.16 percent and negative changes for that of the US by 2.56 percent and the EA by 1.34 percent (Table 5.10). The sizes of the changes caused by the shock in the ROW are moderate, compared to the US and EA shocks. The ROW mainly has net gains in external assets with respect to China, which causes China to have a 3.04 percent decrease in its position with the ROW. The dynamics of the scenario for the ROW block is similar to the scenario of China, in the sense that there is little change in the variables linking the US and the EA.

5.8. Summary

Today, NOEM models have been widely developed and used by researchers and policy makers to probe a wide variety of questions. Yet, the influences of heterogeneous external asset and liability positions remain relatively unexplored, probably due to the limited available techniques for the models to address the questions under this topic. We seek and succeed to provide a means to model the investment positions between economies in a multi-country model. By this instrument, the standard NOEM models could be equipped with variables than can reflect international trade, investment and the valuation effects in a cross-country analysis. We then apply our model in the investigation of the potential contribution of productivity development to the evolution of external positions and macro interdependence.

We first develop a four-country model for estimation of China, the US, the EA and the ROW. We introduce quadratic adjustment cost for international assets and induce stationarity to the model. Analytically, we explicitly express international trade and investment by linearization of the model. Also, we are able to decompose valuation effects and trade channel in international transmission. The valuation effects are attributed either to exchange rate movements or interest rate differentials. We prove that NOEM models with incomplete financial markets and symmetric steady state IIPs generate the same dynamics of international trade as models with complete financial markets. In this case, there is perfect risk sharing and balanced trade.

We then calibrate the steady state of the model based on the heterogeneous shares and weights of these economies in world output and international trade and investment. The model describes the Chinese economy as large in total output due to 20.2% in world population, but small in terms of per capita output. Both the US and the EA are over eight times larger in per capita output than China, and still larger in total output. We conclude that the US has the highest home bias with 86.6% of its consumption in domestic goods, and the EA is the most open block in trade. Our model calibrates the large gross positions of international investment between these economies, and the non-zero initial net IIPs. The US and the EA both have large foreign liabilities and the EA is worse than the US.

The model is simulated for four scenarios, in each of which there is a one percent productivity shock in one economy. We compare the short- and long-run dynamics of these economies and the transmission of shocks in each scenario. The shock in China can hardly affect foreign economies and foreign responses to it are almost zero. China has long-run consumption and output growths both about one percent. We are consistent with the literature in terms of signs of the deviations, but we find more persistent effects on China, which we attribute to the welfare changes caused by the deviations of net IIPs.

The shock in the US leads to world output expansion. Long-run output increases are 0.82, 1.42, 1.17 and 0.10 for China, the US, the EA and the ROW, respectively. The US shock has large spillover effects on the other economies. We are different from the literature that a US productivity improvement would contract foreign economies. Also, this world expansion is different from the simulation of the workhorse model. We attribute this to the imperfect international risk sharing brought by the asymmetric IIPs in incomplete financial markets. Adversely, the shock in the EA causes worldwide contraction. The size of the spillover effects is generally similar as that of the US, which is consistent with the steady state shares. Consistent with the US shock, the EA shock benefits the domestic economy most, which is recorded by the lowest production decrease among the four economies. The ROW shock is increasing the production of China and the ROW, while reducing that of the US and the EA, leading to a shift of world output from the developed economies to the developing ones.

We observe the dynamics of ethe trade and the valuation channels separately with the help of the decomposition of international transmissions in the modelling. We find equal importance of the trade channel and the valuation channel in transmission of shocks. The directions of these two channels are not necessarily the same, depending on the trade and investment shares in the steady state. The shock in China causes mixed effects and trade and valuation effects largely cancel. The US shock reduces both China's surplus and valuation magnificently. Also, shock origins generally increase investment positions, while foreign responses differ.

Our findings imply that the setting of incomplete financial markets is not sufficient to capture dynamics of trade and investment in the NOEM and heterogeneous investment positions are necessary. Heterogeneity between these economies is also reflected by their share in international trade and investment. Simulations of the shocks in these economies find distinctive dynamics of these economies. These differences are attributed to the imperfect international risk sharing due to heterogeneous IIPs. Dynamics of the valuation channel also reveals the importance of exchange rate movements and interest rate differentials to the value of IIPs. Our simulation calls for the use of heterogeneous multi-country model to describe dynamics between these economies.

Chapter 6

Conclusions

6.1. Summary of Findings

In this section, we present our conclusions and the implications from the thesis. We review the findings of each chapter and discuss how they link with the literature.

In Chapter 3, we establish a multi-country framework for open economy analysis of China. We base the model on the spirit of the NOEM and equip it with necessary components so that the model is of moderate scale for analytical and empirical analysis in the following chapters.

Besides the development of the workhorse model, Chapter 3 aims to explore how international risk sharing functions under complete financial markets. Analytically, we derive perfect international risk sharing between two countries in both the short and the long run, given a complete set of internationally traded contingent bonds. Our proof extends that of Corsetti and Pesenti (2005b) by weaker assumptions of the utility function and trade elasticity, which are argued to affect international transmission as well.

In addition, we calibrate the workhorse model under either productivity or interest rate shock to demonstrate international transmission under complete financial markets. We find balanced trade in both the short and the long run. The output and consumption of two countries co-move, and proportionally redistributed world income and consumption cause the budget of each country to be balanced.

Chapter 3 not only examines the features of the workhorse model under completeness, but also generates the following implications. Market completeness leads to constantly balanced trade, which is in conflict with the documented large and persistent trade surpluses of China with the US and the EA. Open economy models with this assumption ignore the reality of trade imbalances. From the perspective of the international business cycle, the empirically documented Backus-Kehoe-Kydland puzzle rejects perfect international risk sharing, and thus opens economy models with complete financial markets. Our demonstration calls for possible explanations to this imperfection and for appropriate models. This motivates our work in Chapters 4 and 5.

In Chapter 4, we estimate the model with data for China, the United States, the Euro Area and the Rest of the World using the Bayesian approach, by which we overcome the problems of estimation of a China model, including lack of observables and small sample size. By setting symmetric priors, we are able to identify heterogeneous structural parameters between these economies. Furthermore, we estimate the model with different types of monetary policy for China and other economies.

We find large discrepancies between many structural parameters of these four blocks. China and the US have similar Calvo pricing coefficient, at 0.72 and 0.69, respectively. The EA has a Calvo pricing coefficient of 0.87, and is much more rigid in price adjustment. China and the US both have strong habits of consumption, at 0.57 and 0.45, respectively. The EA household is less persistent in consumption and has a value of 0.13. These economies are also differentiated in terms of monetary policy. The US has the highest response to output deviation and the EA has the lowest. However, the EA reacts more to inflation. In addition, we capture the largest productivity persistency for the EA, and the lowest for China.

Our estimation findings are consistent with most closed economy estimations, but we capture the heterogeneity that is ignored in symmetric two-country estimations. China, the US and the EA are heterogeneous in that China and the US are more persistent in consumption and more flexible in price adjustment than the EA. Also, the EA is found to have the largest persistency in productivity shock, which implies the longer effect of the financial crisis on the EA than on China and the US.

After examination by sensitivity tests, our estimation results demonstrate robustness and identification of the model is moderately fine. We perform the sensitivity tests by changing the priors, and these tests find most posteriors to be stable with changes in the prior means. The Bayesian approach is concluded to be a better method for models with large scale, while the sample of estimation is considered less satisfactory than other approaches.

In Chapter 5, we calibrate four scenarios, each with a one percent productivity improvement in one block. Among these four scenarios, the shock in China is observed to have the smallest spillover effects, and shocks from the US and the EA both drive large responses of other economies. Due to the distinct steady state weights and shares of these economies, e.g. share in international trade and investment, shocks from different origins may bring either expansion or contraction. We document large output increases from all these economies if the shock is in the US. Shocks in China also lead to positive output responses, although small. However, shocks from the EA could cause small contractions of output for the US and the EA, and large reduction of output for China. We attribute these different effects from productivity improvements in different areas to the imperfect international risk sharing between these economies. This imperfect co-movement is proved to be the result of heterogeneous gross IIPs in the steady state and deviations of net IIPs.

We calibrate asymmetric gross IIPs for these economies and derive non-zero net IIPs in the steady state. This facilitates our decomposition of international transmissions into trade and valuation effects. Further, we attribute the valuation effects to either exchange rate movements or interest rate differentials. Our calibration finds the valuation channel and traditional trade channel to be of almost equal importance. Further, we examine the international transmissions in each scenario based on these channels and deviations of the net IIPs. Given the large share that China has already in international trade, there is little scope for productivity improvement in China to affect foreign economies through that channel. Also, the valuation effects, which depend on not only the exchange rates, but also the interest rate policies of China and its foreign partners, could cancel the trade surpluses or deficits. In addition, in each scenario, the valuation effects on China usually have different signs than the effects on the US and the EA. This is due to the initial large positive positions of China. A US shock could lead to a large welfare decrease for China through RMB appreciation and a larger response from China's interest rate policy.

Chapter 5 extends the literature in several aspects. Our incomplete financial markets model provides a mechanism for NOEM modelling to consider the heterogeneity in international investments across countries. The steady state of IIPs of the economies reflects their asymmetry in international investments and does not necessarily lead to zero net IIPs. Distinct external asset and liability positions are also proved to be a driving force for imperfect international risk sharing, and enlarge the family of possible explanations of the Backus-Smith effects. In addition, by separately considering the external assets and liabilities of the countries in the model, we are able to derive analytical expressions for the valuation effects, which enable us to evaluate key determinants of these effects. The simulation of the model finds richer dynamics for the economies with heterogeneous IIPs. The distinct roles of the economies in the steady state affect their short-term and long-term equilibriums.

6.2. Potential Areas for Future Research

The thesis also has some limitations. In Chapters 4 and 5, we use the Euro Area and the Rest of the World as two blocks in the estimation and simulation. Our methodology is developed based on the fact that the EA is one of the largest trade partners of China. Also, the stylized facts of China's trade and investment with the US and the EA are different. Our analysis features the heterogeneity between these economies. The ROW groups all other economies into one block, which is the approach usually adopted by the literature on open economy modelling. However, whichever approach is used, macroeconomic modelling suffers from the problem of specification. The model should be examined to prove its empirical rigour, using comparative approaches such as those proposed by Wieland et al. (2011). Comparison of our model with others calls for empirical testing of the fitness and forecast of the models to show how we can improve the findings of other studies.

Chapter 4 estimates the multi-country model with data of the four blocks. For ROW, we use world average data for GDP, CPI and PPI. A more precise way would be to exclude China, the US and the EA from the world aggregation. As we discussed in Section 4.4.1, including these blocks in the world average may lead to multicollinearity. Although we justify that our approach will not significantly increase the risk, using better measurements for the rest of the world would bring greater precision to the estimation and the implications drawn from that. Therefore, finding better proxies for the fourth block is on the agenda for future research.

The sample size for the Bayesian estimation in Chapter 4 is from 2000Q1 to 2010Q4. Although the Bayesian approach does not have a restriction on sample size, a larger sample would provide better estimation over the whole period by increasing the weight of the information from data relative to that from priors. As we discussed in Section 4.4.1, the benefit of using a single currency with market price for the EA is one motivation to select data within the window after the adoption of the euro. This thesis contains limited comparison between the output from a larger size and the current estimation. More estimations with different samples and proxies to the euro before 1999 will improve the sample size in future research.

This thesis raises some questions for potential future research. First, the model developed here can be compared with other macroeconomic models to evaluate the importance of using a heterogeneous multi-country framework. Wieland et al. (2011) emphasize the importance of using a systematic approach to compare macroeconomic models in order to generate robust policy recommendations. They develop an approach to standardize the common variables of a series of models and compare the impulse response functions generated by these models. Among other approaches to model evaluation, Schorfheide (2000) assesses the performance of models using loss functions that penalize the deviations of model predictions from actual observations. Our model can be compared with models with symmetric structural features or with small open economy models to confirm the importance of this framework in deriving model implications and in generating policy suggestions.

Our model can also be applied to drawing optimal policies for governments and central bankers. General equilibrium models have been used for policy suggestions because they can derive welfare-based optimal choices. Schmitt-Grohe and Uribe (2006) and Gali and Monacelli (2008) are two examples for finding the optimal monetary and fiscal policies. In addition, this thesis provides a multi-country framework suitable for the analysis of the international dimension of policies. Clarida, Galí, and Gertler (2002) and Corsetti and Pesenti (2005) explore international coordination of monetary policy. Devereux and Engel (1998) apply a model to the analysis of the optimal exchange rate regime. The model developed by this thesis can be used to find optimal policies for China considering foreign shocks and responses and the cooperation of China with others in economic policies.

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Appendix

Figure 5.1 Impulse response functions to a productivity shock in China (percent)

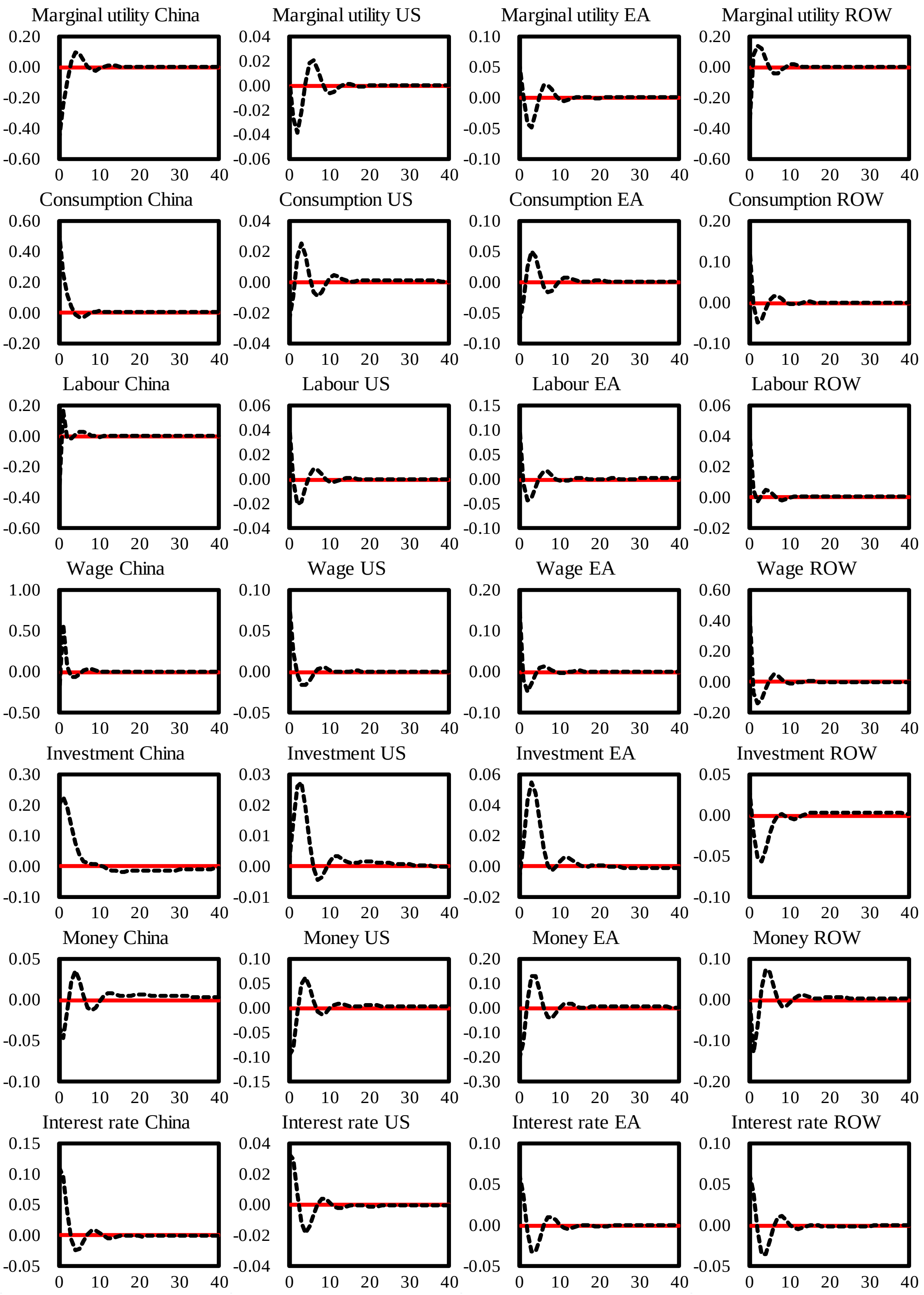

Figure 5.1 (continued) Impulse response functions to a productivity shock in China (percent)

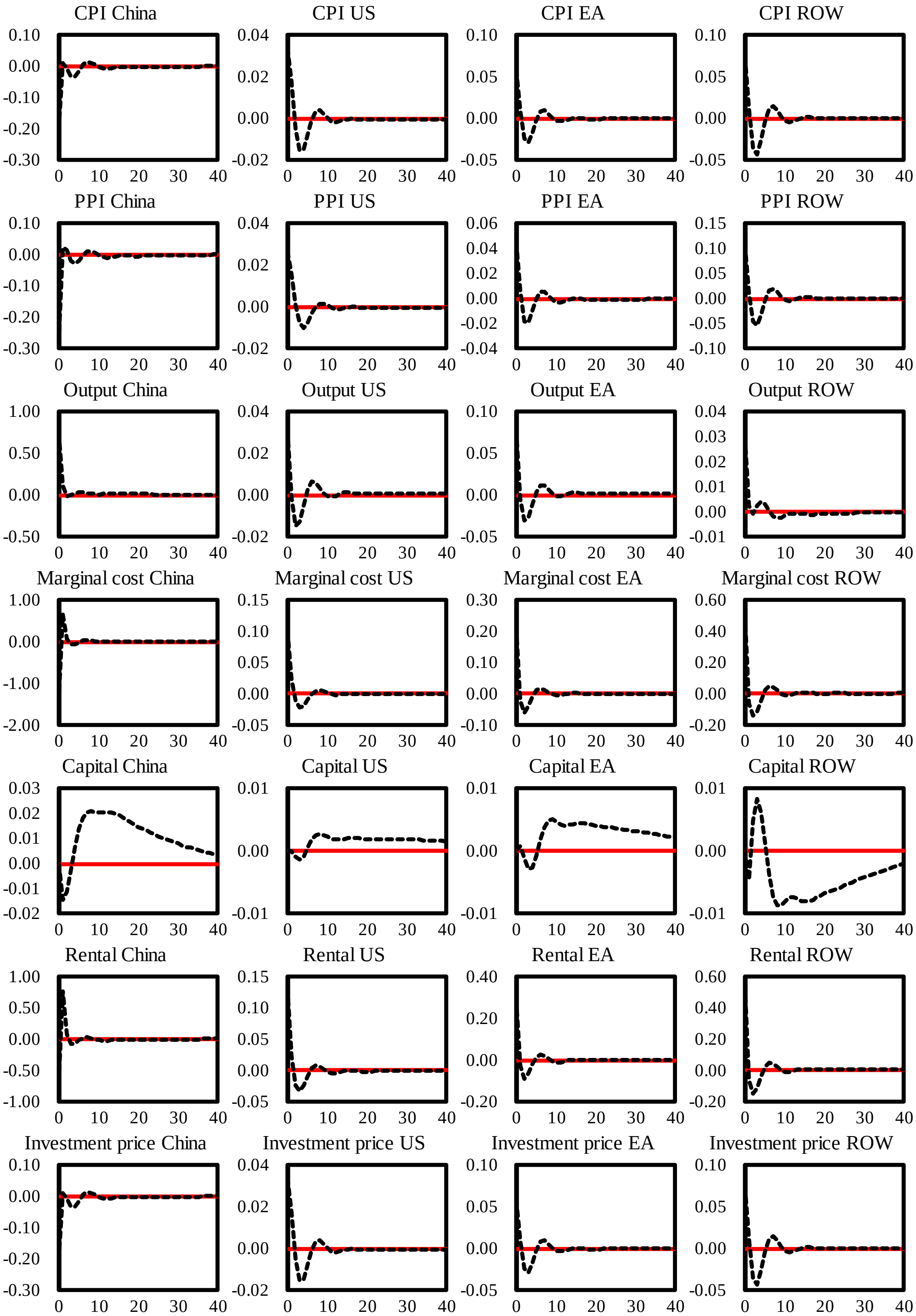

Figure 5.1 (continued) Impulse response functions to a productivity shock in China (percent)

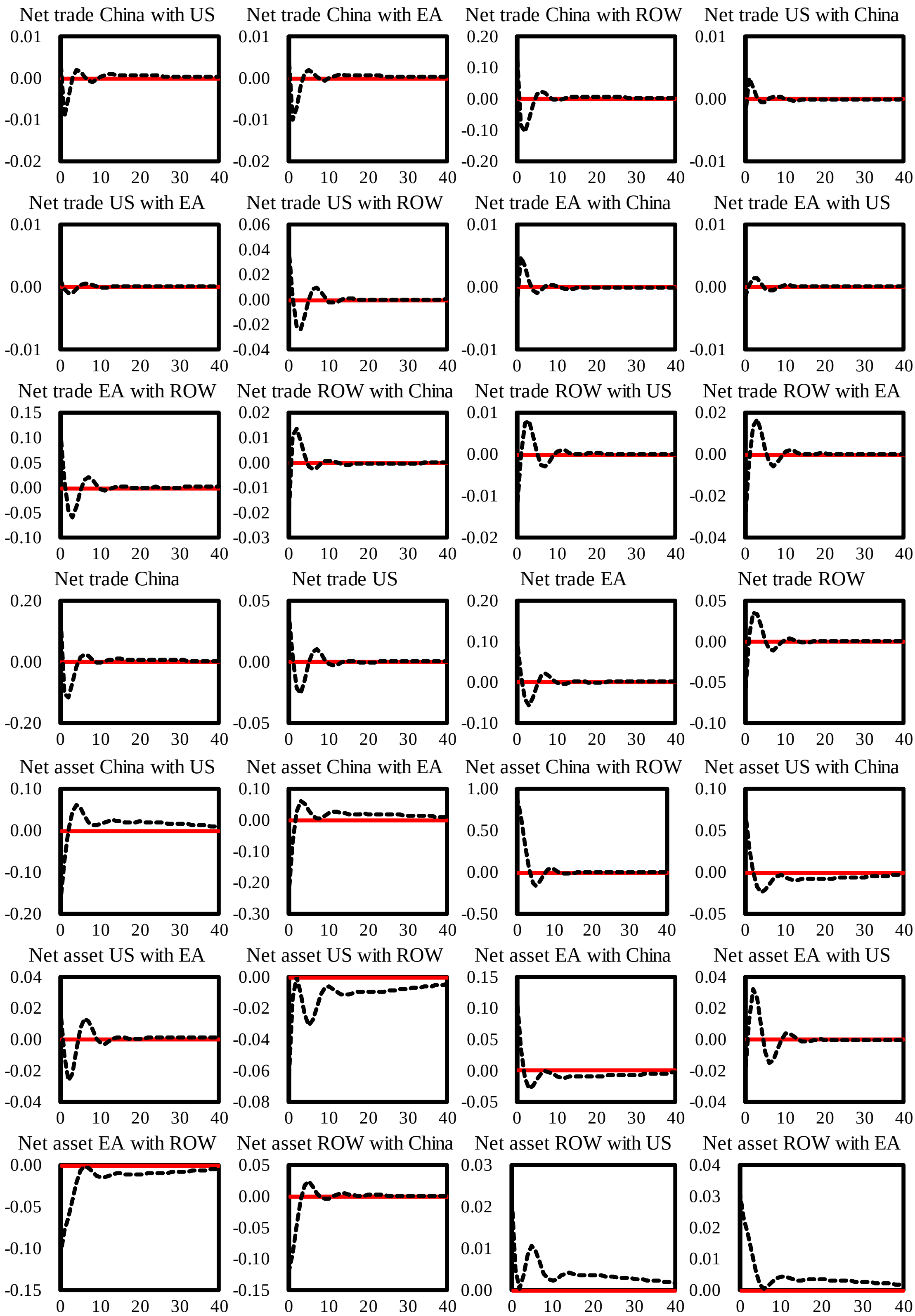

Figure 5.1 (continued) Impulse response functions to a productivity shock in China (percent)

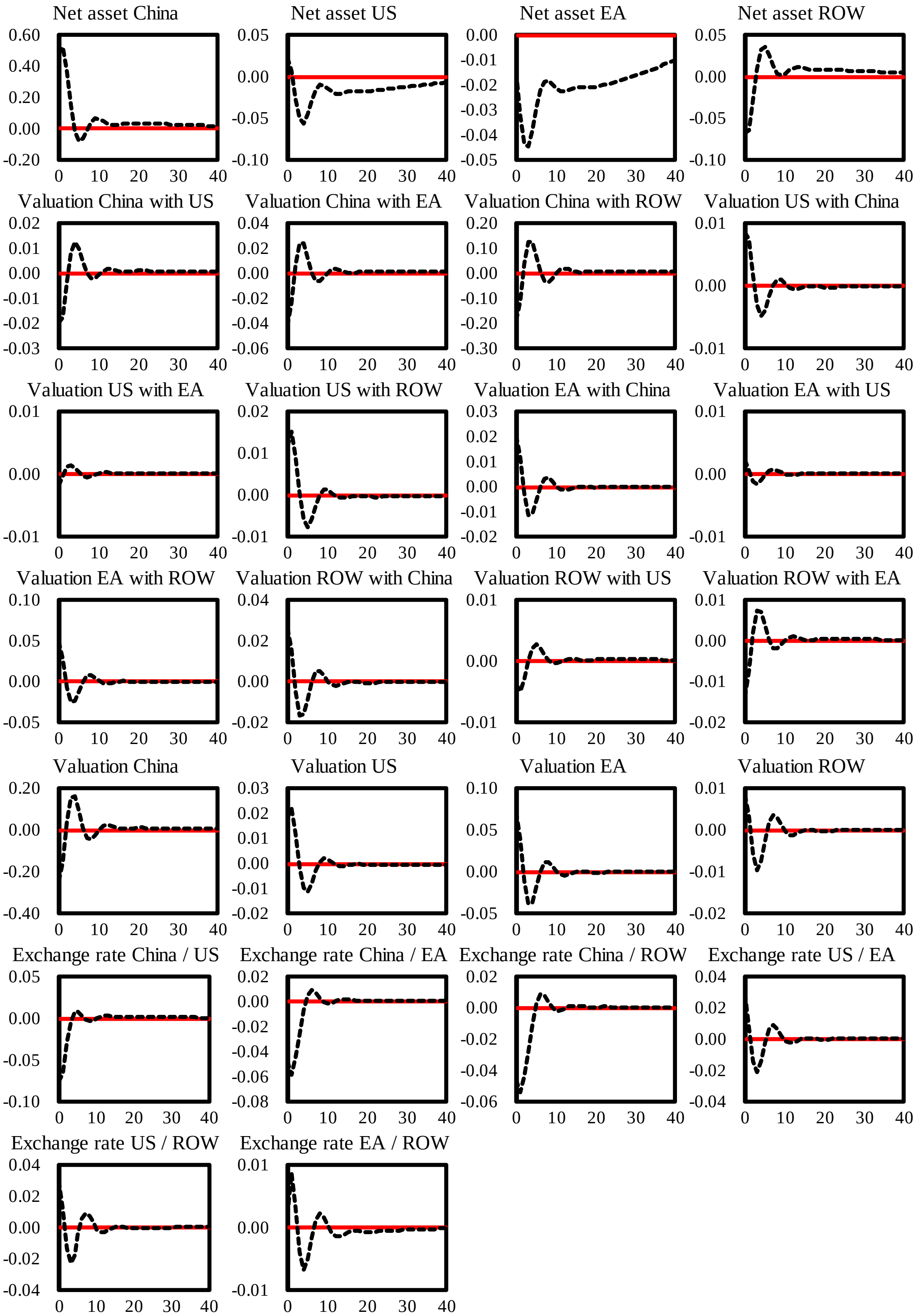

Figure 5.2 Impulse response functions to a productivity shock in US (percent)

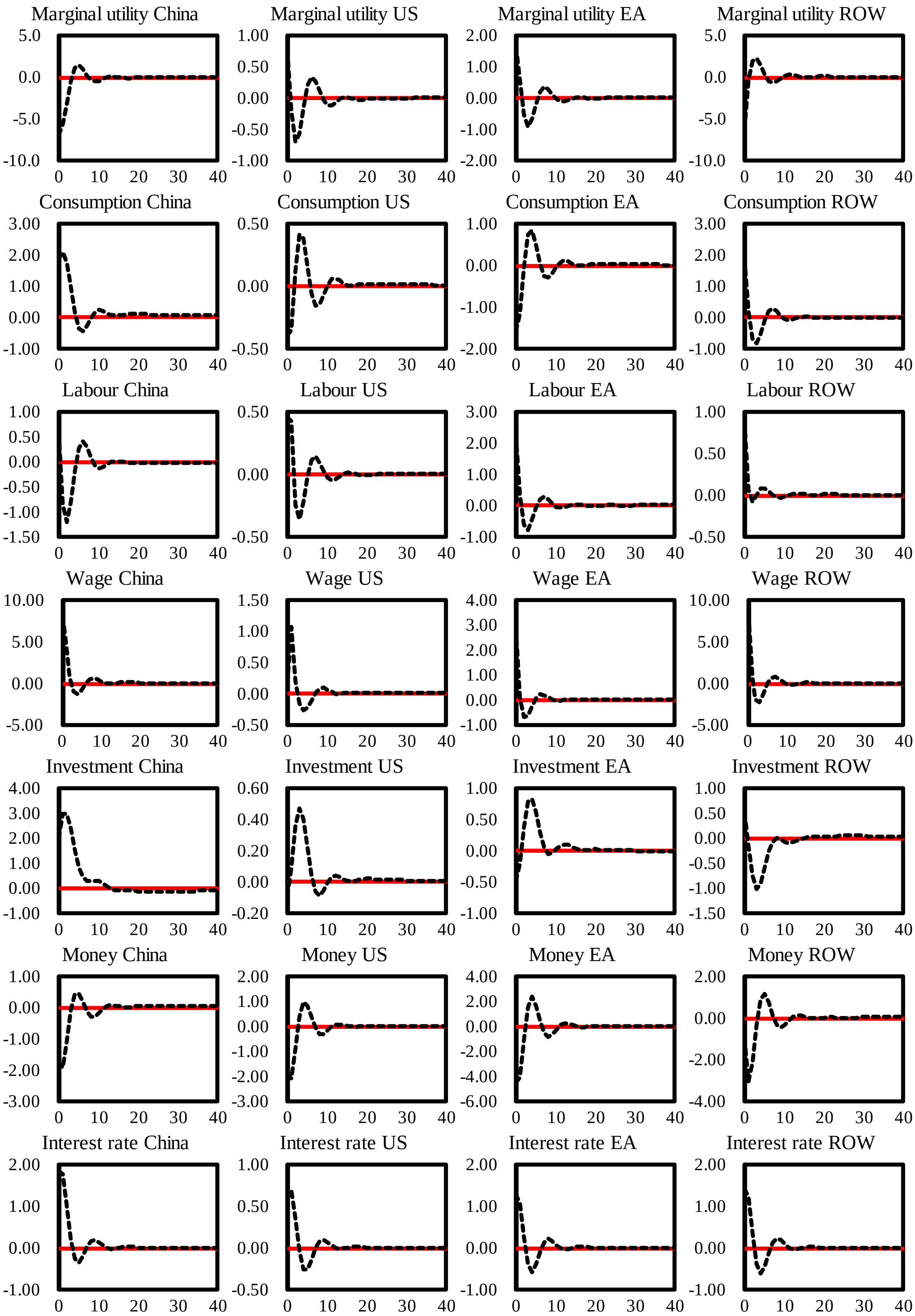

Figure 5.2 (continued) Impulse response functions to a productivity shock in US (percent)

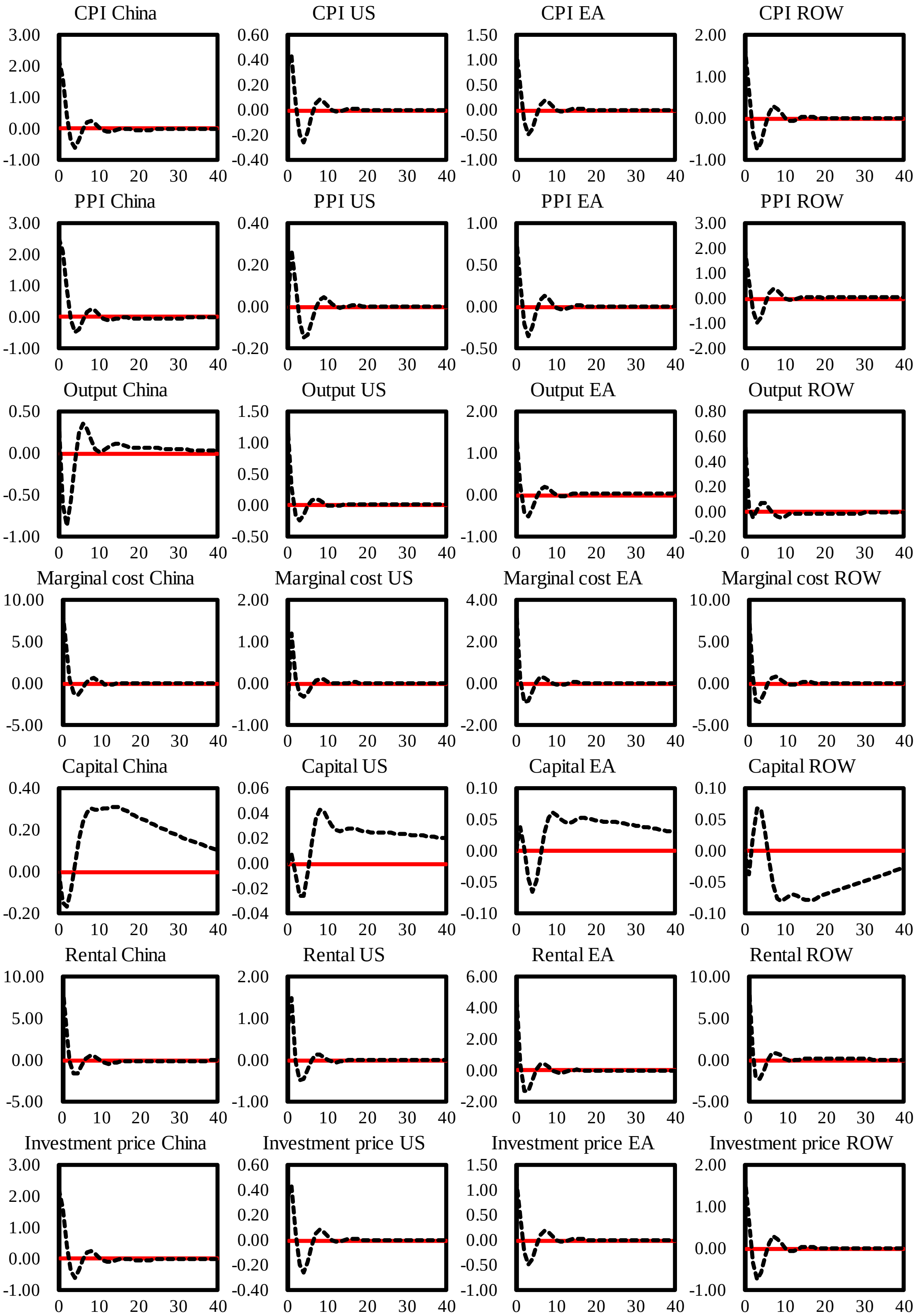

Figure 5.2 (continued) Impulse response functions to a productivity shock in US (percent)

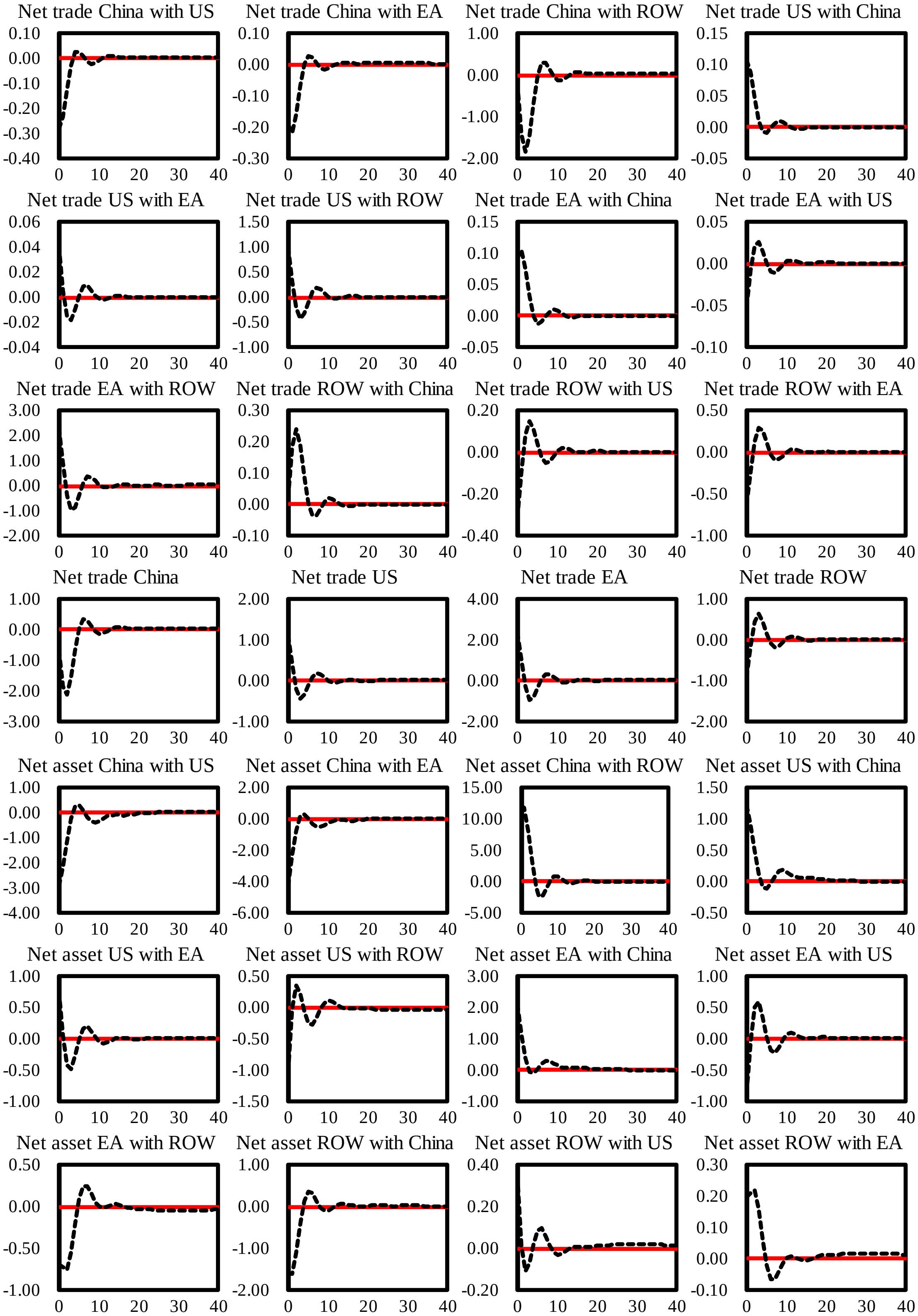

Figure 5.2 (continued) Impulse response functions to a productivity shock in US (percent)

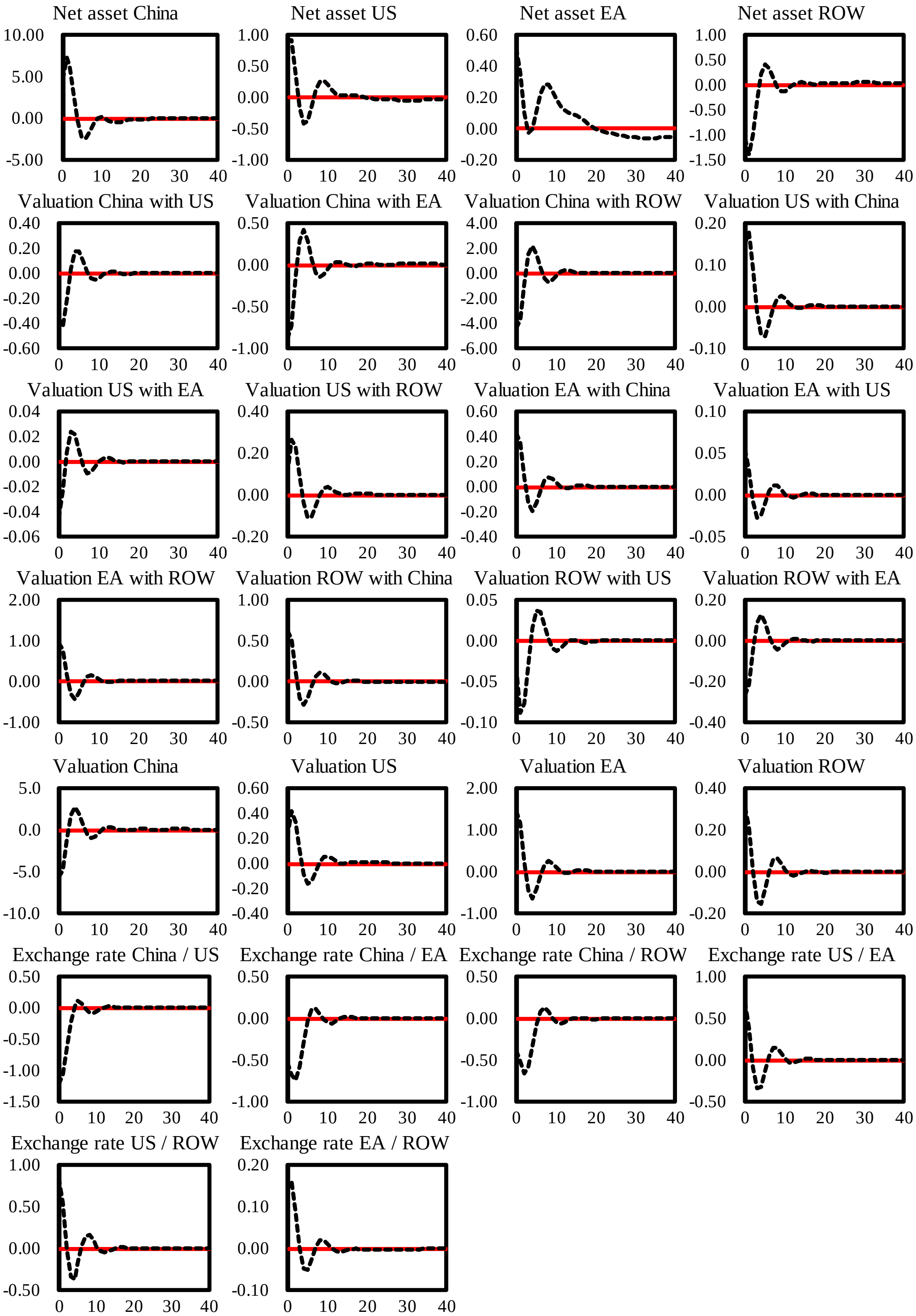

Figure 5.3 Impulse response functions to a productivity shock in EA (percent)

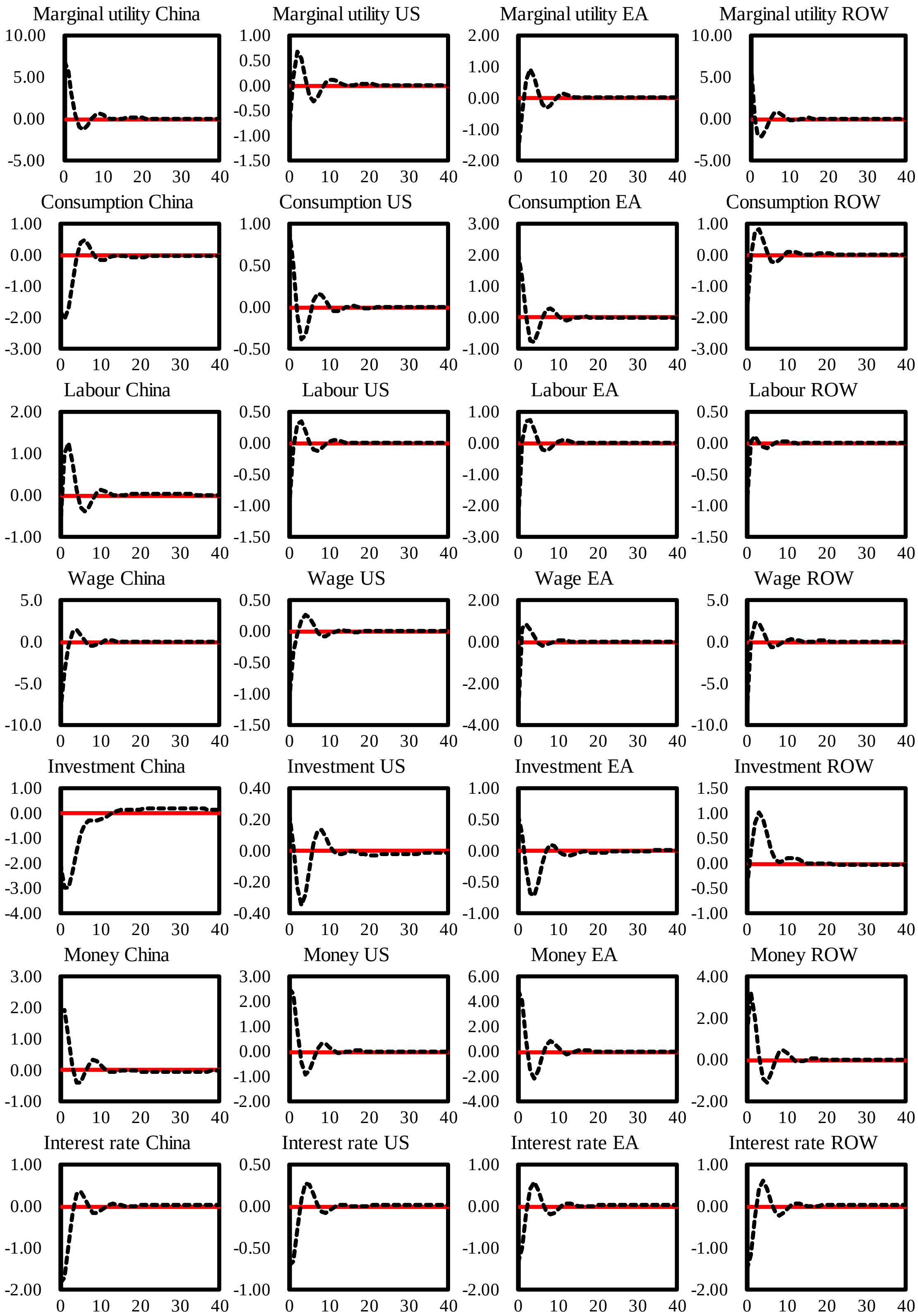

Figure 5.3 (continued) Impulse response functions to a productivity shock in EA (percent)

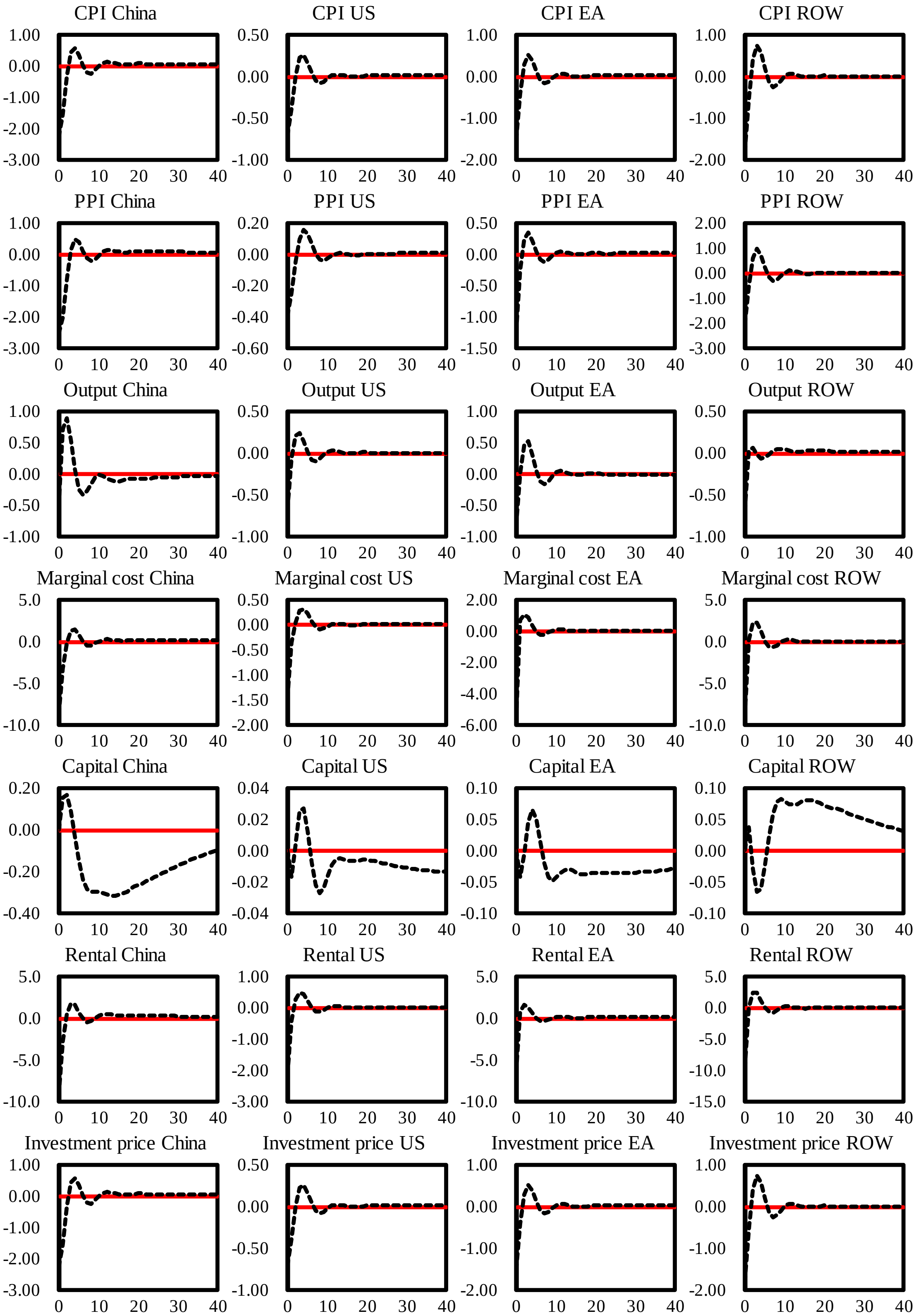

Figure 5.3 (continued) Impulse response functions to a productivity shock in EA (percent)

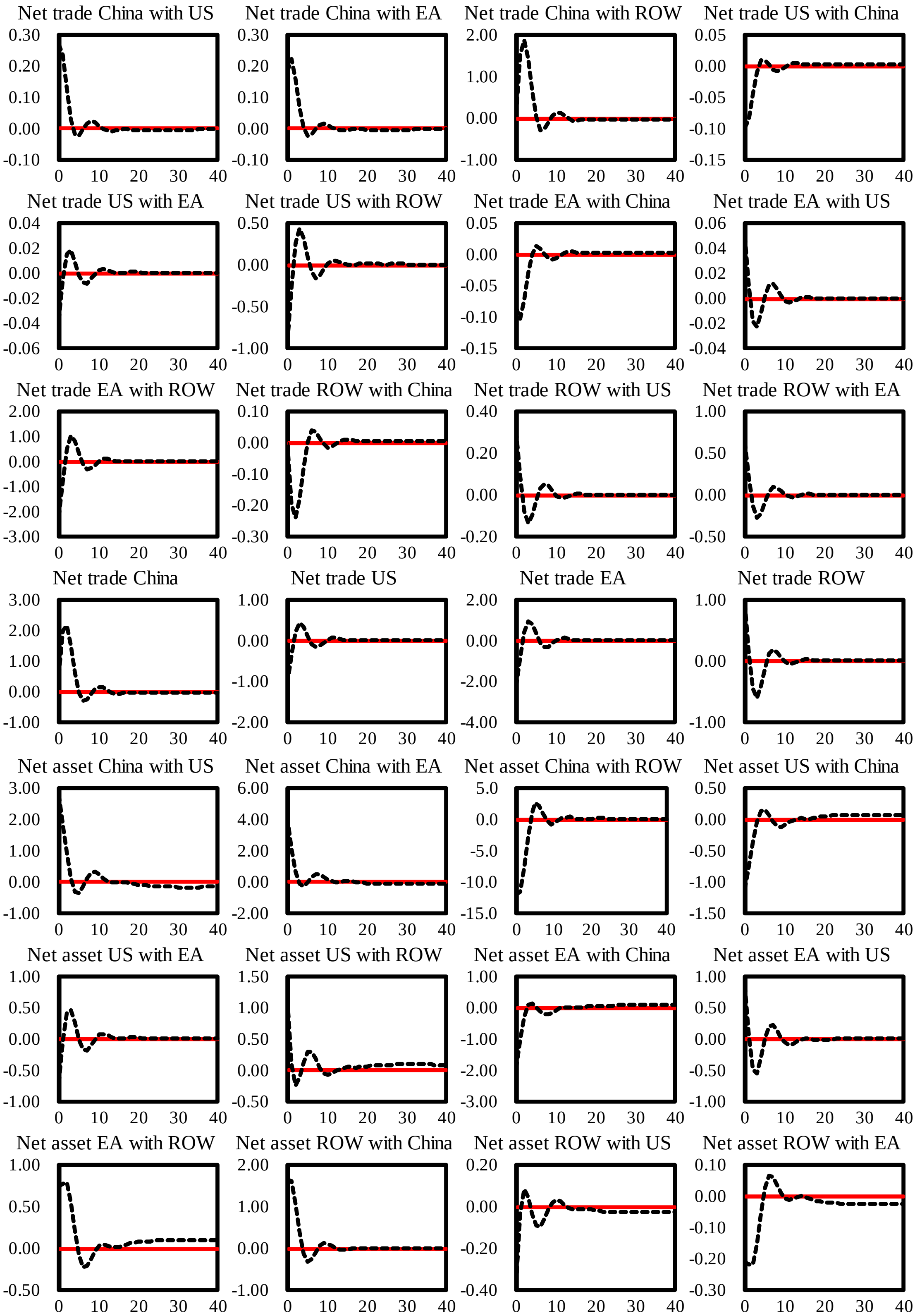

Figure 5.3 (continued) Impulse response functions to a productivity shock in EA (percent)

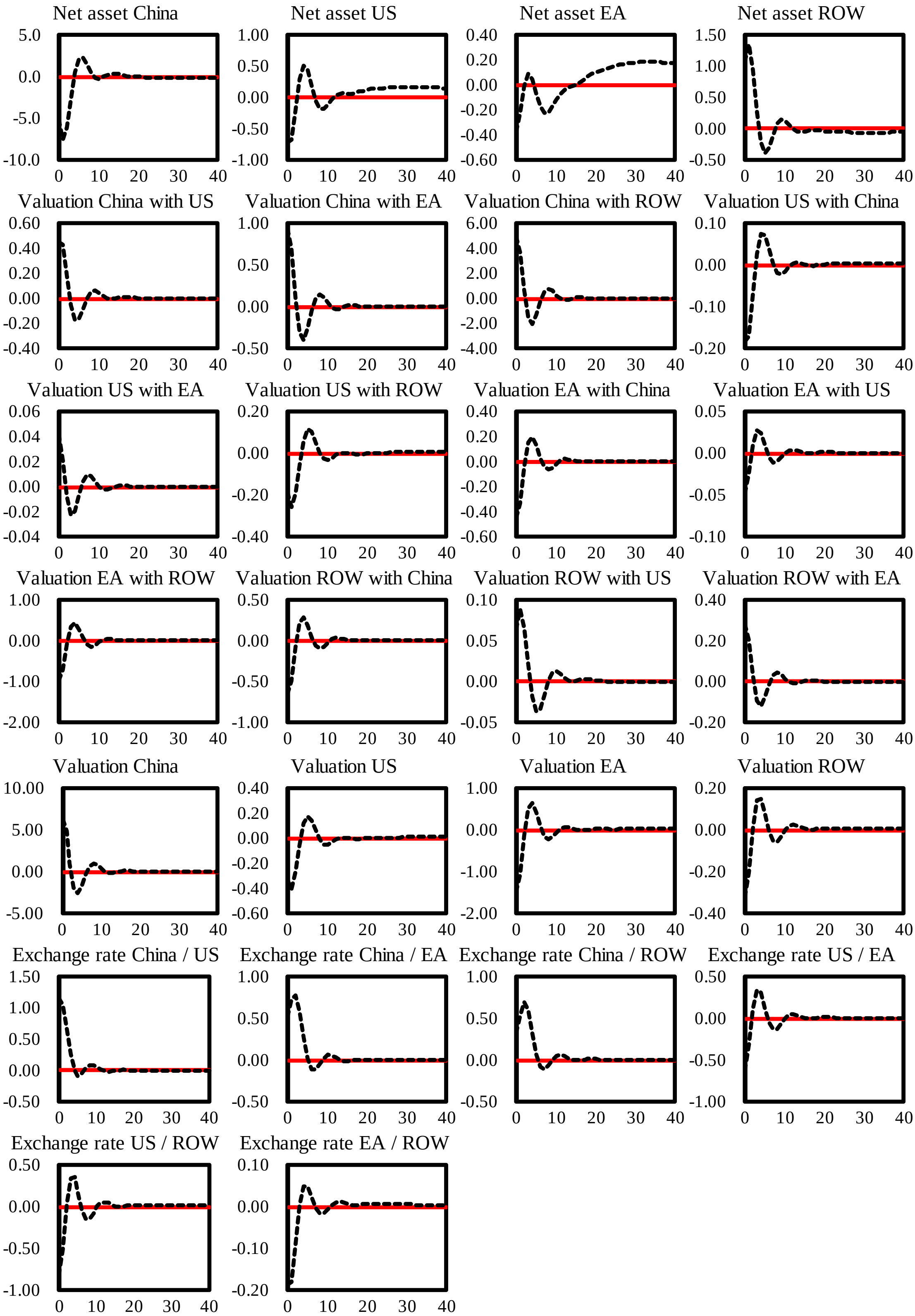

Figure 5.4 Impulse response functions to a productivity shock in ROW (percent)

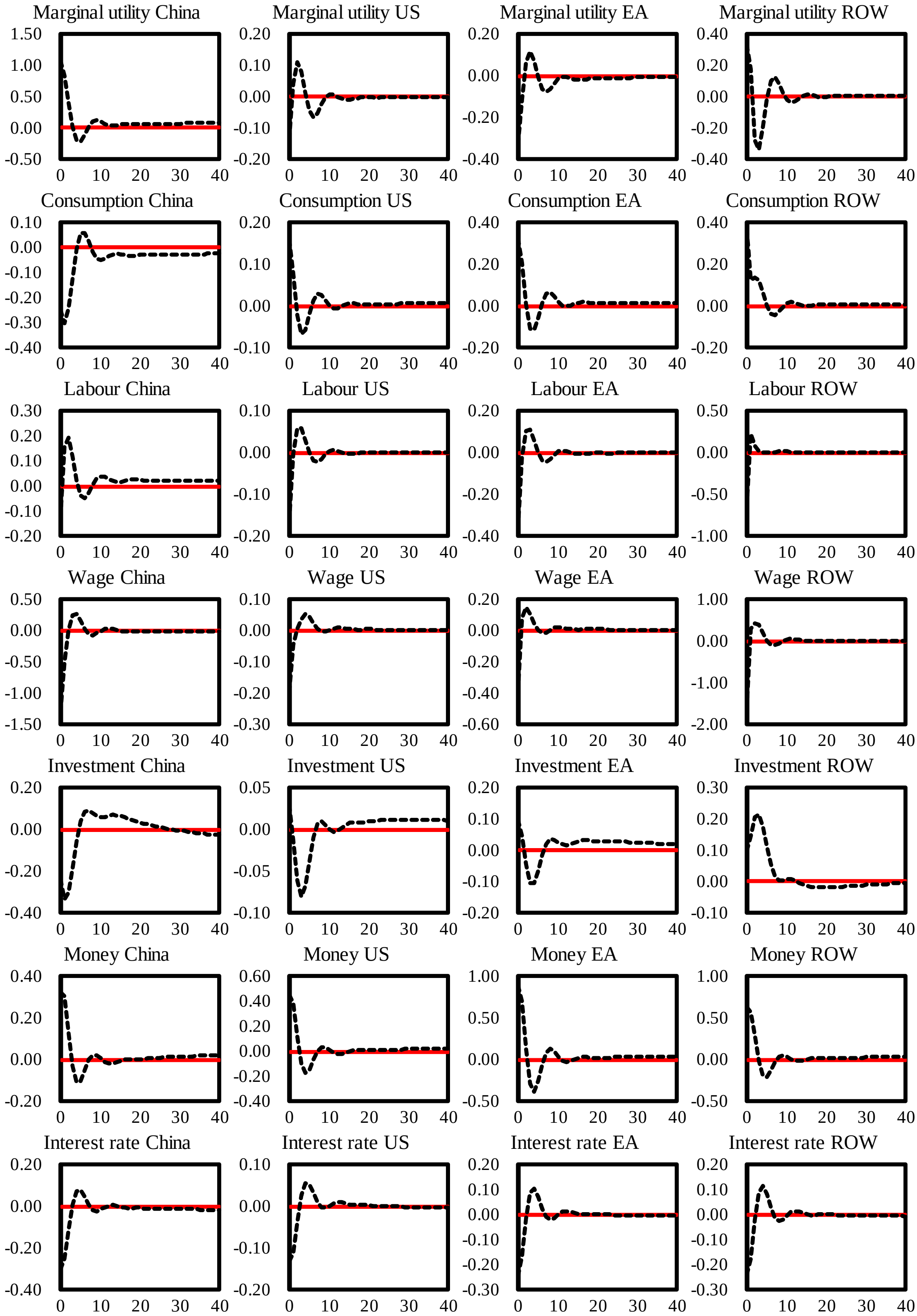

Figure 5.4 (continued) Impulse response functions to a productivity shock in ROW (percent)

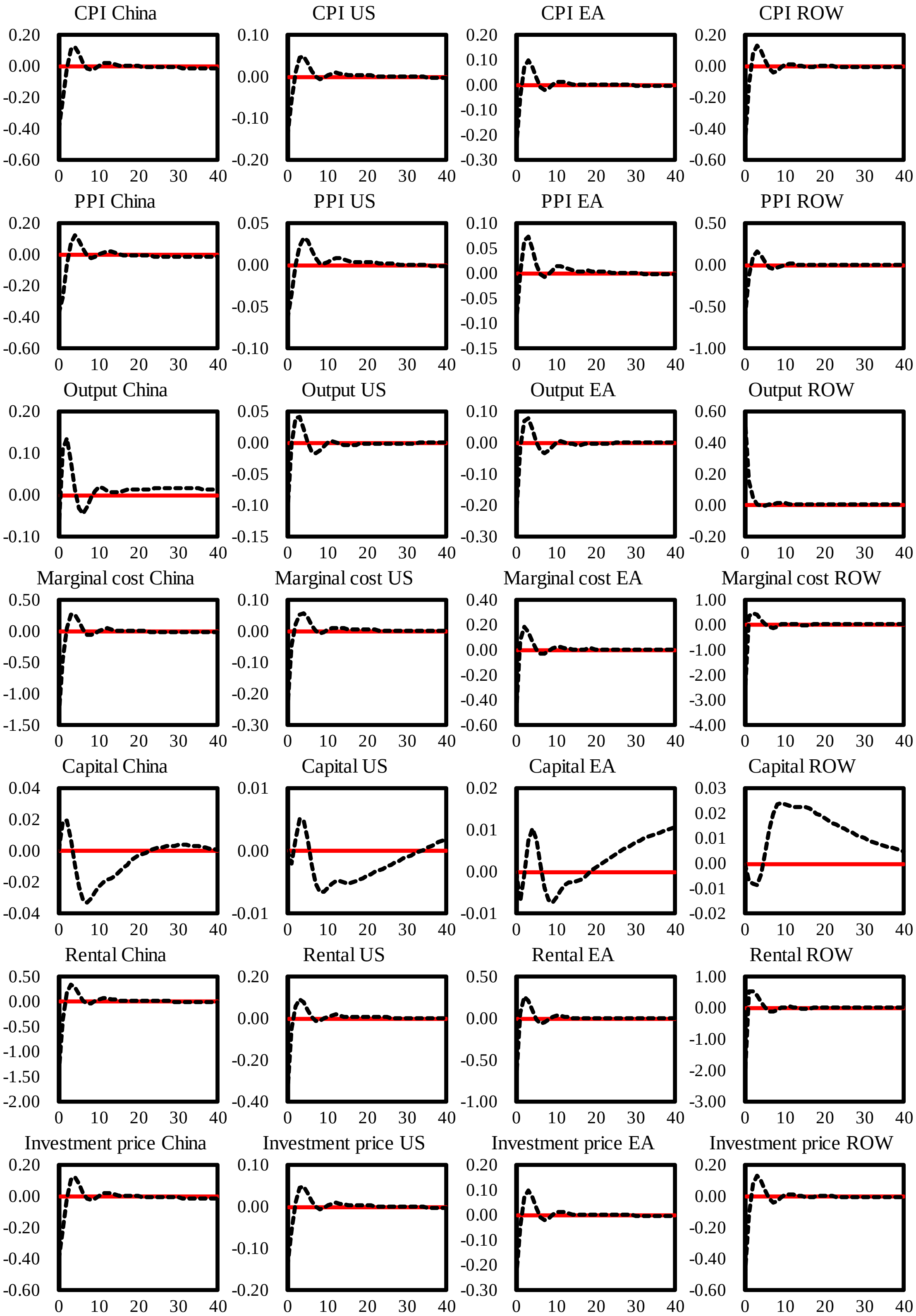

Figure 5.4 (continued) Impulse response functions to a productivity shock in ROW (percent)

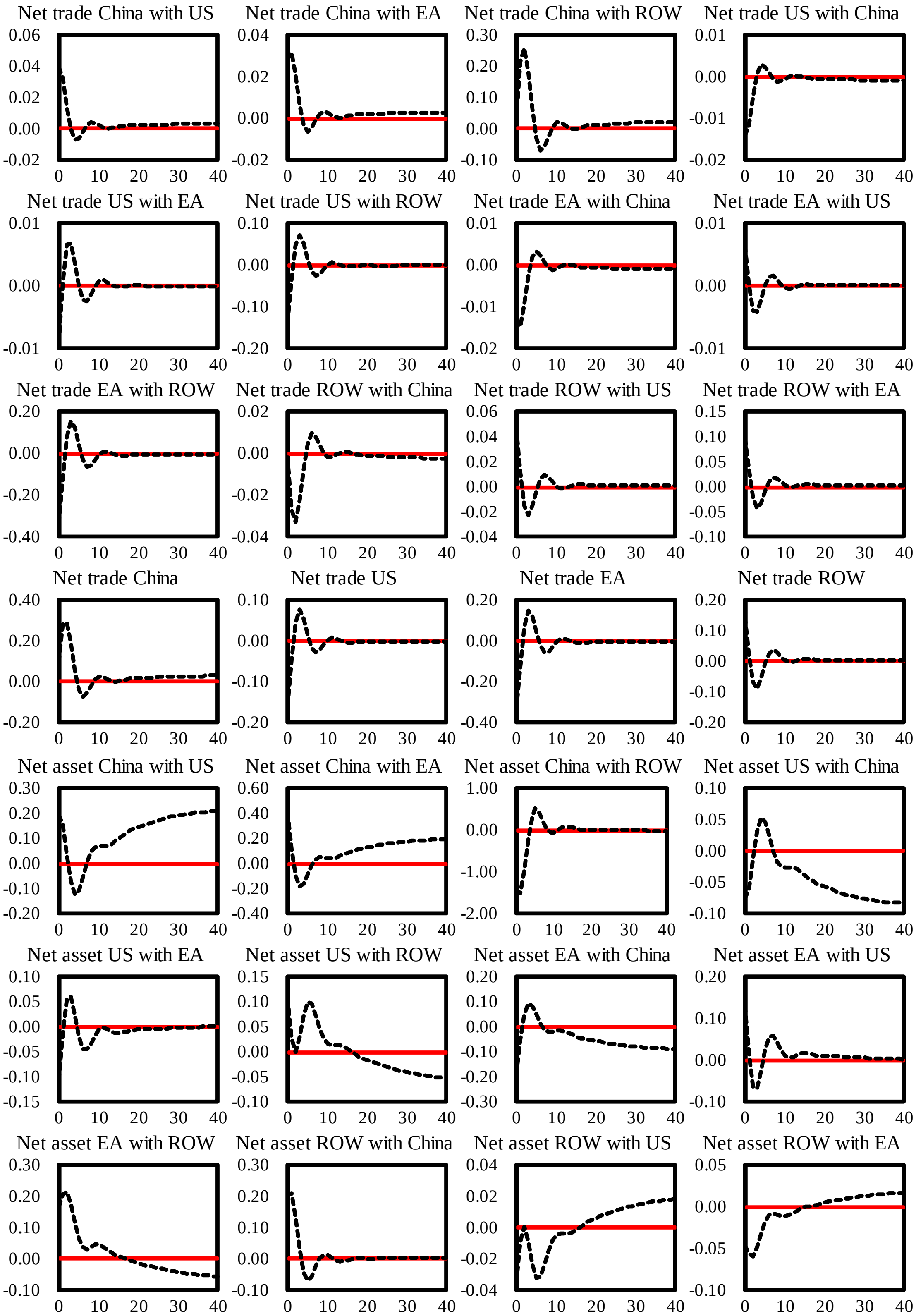

Figure 5.4 (continued) Impulse response functions to a productivity shock in ROW (percent)