Monetary Policy Coordination between the United States and the Euro Area

- An Application of Indirect Inference to a Two-Country DSGE Model

by

YUQUN HONG

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy of Cardiff University

Economics Section, Cardiff Business School, Cardiff University

October 2013

Monetary Policy Coordination between the United States and the Euro Area

- An Application of Indirect Inference to a Two-Country DSGE Model

by

YUQUN HONG

Abstract

Calls for monetary policy coordination has increased as the intensified macroeconomic interdependence cultivates the conflict of interests between economics, especially following the current crisis. Yet the literature has not reached a consensus on whether monetary policy coordination is welfare-improving.

This thesis, taking from another perspective, assesses the real-world existence and extent of monetary policy coordination associated with economic interdependence between the United States (US) and the Euro Area (EA), and investigates the changes of international transmission in the presence of coordination.

Monetary policy coordination is represented by direct responses of monetary policy instruments to contemporaneous and lagged values of the real exchange rate. By using the method of indirect inference, this research also incorporates historical data into in-sample evaluation and estimation of the 'Dynamic Stochastic General Equilibrium' (DSGE) model.

Beginning with indirect inference evaluations of a two-country DSGE model of the US and EA, it is found that models with coordination generally outperform their non-coordination counterpart – indicating the existence of coordination. The real exchange rate is the essence of such improvement in the model's efficacy; and it is shown that coordination models have an excellent ability to replicate real exchange rate dynamics and volatility relative to a non-coordination model, even though it still remains a source of relatively poor performance of model.

By applying an extensive indirect inference estimation, the existence of monetary coordination is ascertained since a partial-coordination model outstrips the non-coordination model remarkably. Both the US and EA economies exhibit moderate to high levels of monetary coordination. Such features improve the model's performance; particularly in terms of dynamics of US time series, volatility of EA time series and both dynamics and volatility of the real exchange rate. Impulse responses and variance decomposition reveal substantial cross-country spillovers in contrast to the non-coordination model case.

Acknowledgements

I would never be who I am now without the support of many people. Among them, I cannot express my gratitude enough to my thesis supervisor, Professor Patrick Minford, for his invaluable guidance, inspiration, and support. I am also heavily indebted to Dr David Meenagh and Dr Vo Phuong Mai Le, whose support was crucial in producing the technical result. Without their generosity, this thesis could not possibly have reached its completion.

Among the faculty of Economics Section at Cardiff University, I am especially grateful to Dr Michael Arghyrou, Dr Helmuts Azacis, Professor David Collie, Professor Laurence Copeland, Professor Huw Dixon, Professor Max Gillman, Professor Calvin Jones, Professor Kul Luintel, Professor Gerald Makepeace, Professor Kent Matthews, Professor Garry Phillips, and Professor Akos Valentinyi. Whether I was their student, teaching assistant or was presenting my work, they were always generous with their time and comments. I especially appreciate critiques from Professor Peter Howells, Dr Juan Páez-Farrell, Professor Jon Tucker, and Reader Dennis Kristensen at the conferences I attended.

I also would like to extend my appreciation to the friendship with my classmates and peers, Dr Jingwen Fan, Dr Michael Hatcher, Dr Tingting Hu, Dr Lu Li, Dr Chunping Liu, Dr Katerina Raoukka, Dr Eric Scheffel, Dr Zhirong Ou, Dr Tiantian Zhang and a lot of others, for their generous sharing and great humour.

Finally, my special thank goes to my family for their love and continuous support. My deepest gratitude is to my late grandfather Wenpei Ye, without whose enlightenment and inspiration I could never have started my PhD journey at Cardiff University. As for my beloved parents, Yue Hong and Qifen Ye, I cannot describe how grateful I am for all they have given me. I also would like to show special thanks to my husband, Daniel Ker, who shares a lot of momery with me during the completion of this thesis.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

In the aftermath of this most recent financial crisis, the recovery of the domestic and global economy has been on top of all policymakers' agendas for a considerably long period. Multiple conventional or unconventional monetary policies, such as keeping the official interest rate at effectively zero[1], negative nominal interest rate[2], and Quantitative Easing (QE)[3] are implemented in attempts to stimulate the economy. Other unconventional policies like 'helicopter drop' attract increasing discussions among economists and policymakers as QE proceeds.

Nevertheless, it is conceded that the risk of a policy-induced inflation surge and currency devaluation can be detrimental. Despite the argument that inflationary pressure can be mitigated if production growth outstrips inflation and management of these monetary tools is successful, difficulties that economies confront are apparent and severe. More importantly, their policy implications to

[1]Since the end of 2008, Federal Open Market Committee has been keeping US effective Federal Funds Rate (FFR) at a range of 0% to 0.25%. UK official bank rate has also been kept at 0.5% by the Bank of England (BoE) since March 2009. Also, the European Central Bank (ECB) has been keeping its official interest rate below 1.5% since early 2009. And current ECB official rate has been 0.75% since July 2012.

[2]It was reported in mid-2009 that Sweden's Riksbank was the first Central Bank (CB) to implement negative interest rate. However, it is denied by the officials. In July 2012, Denmark's Nationalbank cut its deposit rate to -0.2% in order to mirror the policy decision in the ECB. In February 2013, BoE deputy governor Paul Tucker carefully raised the consideration of a negative interest rate to be implemented in the UK.

[3]Quantitative Easing (QE) is an unconventional monetary policy first used by the Bank of Japan in tackling liquidity trap and economic stagnation. It has been extensively implemented in the US and EA since 2008 when the financial crisis was at its peak.

other economies or close trading partners perhaps trigger more global anxieties. Some people view inflation as de facto devaluation. And some argue that money supply increases in a home economy effectively devalue domestic currency against foreign currency. It creates policy-induced speculations unless the same foreign policies are also implemented neck and neck with the home economy. Consequently, the worst scenario might be the so-called 'competitive devaluation', or 'currency war' in more hostile terms.

Two 21^{st} century confrontations with 'competitive devaluation' maybe the 2010-2011 conflict between the US and China over the value of the Yuan and the early 2013 Japanese Yen devaluation versus Euros. The former ended with the second sharp climb of the USD/CNY (Dollar to Yuan) exchange rate since 2005, and the latter resulted in public commitments of refrainment from 'competitive devaluation' by G7 and G20 members.

All in all, at the heart of these anxieties, it is the macroeconomic interdependence that cultivates the conflict of interests between economies. In particular, once it is translated into monetary interdependence, monetary authorities are brought up against more challenges in designing and conducting monetary policies. Foremost, feedback responses from foreign Central Banks (CBs) can potentially promote or impede the effectiveness of domestic monetary policy. Additionally, diverse policy stances may bring about persistent monetary spillovers and, consequently, inefficient monetary policies in the absence of international monetary coordination.

This interdependence among economies intensifies, from both perspectives of impact span and impact scale, gradually and vastly as exchange rate regimes shift and globalisation becomes widespread. Undoubtedly, it demands that policymakers take other economies' policy action into account when they design domestic monetary policies, regardless of their willingness to participate in such a 'strategic game'. It is not surprising that attention on macroeconomic policy cooperation or coordination[4] has surged in the recent years of growing cross-country spillover,

[4] International cooperation takes various forms: it can be institutionalised or work through

especially with the severe economic downturn[5]. After all, in times of crisis and uncertainty, economies are more attracted to coordinated actions in order to minimise negative spillovers; whereas in the time of peace, economies focus on their comparative advantages (Masson and Pattison, 2009).

Decentralised and independent policymakers can export the effects of domestic economic actions. Monetary cooperation and coordination internalise policy externalities, and thus, should improve joint welfare. Yet neither theoretical nor empirical evidence gives a definitive conclusion on whether monetary cooperation and coordination are welfare-improving. The second generation model incorporates explicit international misalignments that may disrupt international price adjustment and cause resources to deviate from flexible price allocation. Nonetheless, such a comprehensive structure still cannot permit firm evidence of welfare gains, although the scale of the gains can be more significant in such models if the gains are granted.

On the other hand, it can be quite challenging to ascertain monetary coordination by monetary authorities. After all, appearances of some monetary interactions can be similar even if there are diverse underlying policy intentions. Without explicit agreement, policymakers are inevitably engaging in some sort of 'strategic game' once their monetary policy design encompasses consideration of bilateral policy impacts with other economies in any manner. Considering the fact that the exchange rate reflects relative fundamental changes between two economies, a monetary instrument's reaction to the exchange rate can be expressed as a strategic interaction based upon the existence of monetary interdependence. That is to say, a policy instrument that is reacting to the evolution of the exchange rate may unveil a policymaker's attitude towards coordinating

international meetings of policymakers; it may simply coordinate minimum standards or set up and monitor international standards; it can be bilateral or multilateral; it can be cooperation in monetary policy, fiscal policy or financial regulation, etc. See Masson and Pattison (2009) for a detailed discussion.

[5]For instance, the G20 replaced the G8 after 2008 Washington summit for wider communication among economies; and several rescue packages were approved by the International Monetary Fund (IMF), etc.

monetary policy across nations.

Another strand of the literature that is relevant to this study is the development of structural model in recent years. Kydland and Prescott (1982) first presented a micro-founded general equilibrium macroeconomic model with fully-fledged dynamic and stochastic properties[6]. It showed that the technological development, normally serving as the main driver of long-run economic growth, could also cause short-run economic variations. The possibility of applying conventional econometric techniques to Dynamic Stochastic General Equilibrium (DSGE) models for quantitative policy analyses has attracted enormous attention from academics and policymakers.

The DSGE models' microeconomic foundation specifies the technology, resource constraints, and economic agents' preferences; thus it allows policy analysis to be carried out using utility-based welfare. The structural property of DSGE models also ensures that the analyses based on a DSGE model is not subject to the Lucas critique (Lucas, 1976). The stochastically coherent structure frees macroeconomic modelling from certainty equivalent assumptions, and enables counterfactual experiments to be carried out. Moreover, its ability to transform from structural parameters to reduced-form parameters may help to understand the inside of economic functioning.

The empirical validation of DSGE models has been extensively questioned, albeit its advantages. In fact, it is the work by Smets and Wouters (hereafter SW, 2003, 2007) and Christiano, Eichebaum and Evans (hereafter CEE, 2005) that set forth the success of DSGE models. In 2010, a piece of work by Le, Meenagh, Minford, and Wickens (hereafter Le et al., 2010) presented a two-country model of the US and EU by combining the individual model of SW (2003) and SW (2007).

[6] In the 1970s, the so-called stagflation gave rise to two new macroeconomic schools of thought – 'monetarism' and 'new-classical macroeconomics'. While two schools distinguishing themselves from 'neo-Keynesian' (For example, the 1974 Brown conference and subsequent publication Stein (1976)), the rational expectation hypothesis evolved to be the fundamental component of the new-classical macroeconomics. Kydland and Prescott (1982) is an example of such development combining a new methodological ground of micro-foundations and the new-classical thought of rational expectations.

It concluded that integrating international goods and asset markets can improve a model's performance to some extent in terms of replicating data dynamics and volatility, while the mystery remained of having a nil cross-country interaction.

In light of these two motivations, this thesis would like to assess the existence and extent of monetary coordination based upon the plausible two-country DSGE model of the United States (US) and the Euro Area (EA) presented in Le et al. (2010). The existence of monetary coordination is assessed by comparing the models' performances before and after incorporating monetary coordination specification, which is described by direct response of monetary instrument to real exchange rate at both contemporaneous and lagged values. The null hypothesis of the existence of monetary coordination holds if a model's performance is significantly improved by the presence of a policy instrument's direct response to the real exchange rate. Measurement of the extent of monetary coordination is carried out by indirect inference estimation of 37 structural parameters, including 4 parameters that characterise monetary coordination. In addition, this thesis intends to evaluate the extent of improvement in the DSGE model's performance and examine the scale of cross-country spillovers when an additional exchange rate channel is specified.

The method being used in this thesis is indirect inference methodology drawn from Method of Simulated Moment (MSM). The nature of this method decides that no tractable likelihood functions or complete set of time series are required; and that conventional statistical evaluation of the macroeconomic model can be implemented on the basis of key features of observables. Moreover, when indirect inference is used in model evaluation, the evaluating objects are the model's ability to replicate data properties rather than the model's ability at out-of-sample forecasting.

To obtain information from actual data, structural shocks are derived from the structural model using calibrated parameters and 17 macroeconomic time series of the US and EA economies. The dynamics and volatility of structural shocks are described by parameters (autoregressive (AR or $ARMA$) coefficients and variances) obtained from individual regression on those shocks with a specified structure. Vector-bootstrapping is used on exogenous innovations in order to preserve correlations between shocks. For each sample drawn from vector-bootstrapping, a set of simulated data can be generated, and in turn, be used in producing a set of auxiliary parameters, which consists of $VAR(1)$ coefficients and variances of each time series. To compute the actual Wald statistic, the set of auxiliary parameters that is obtained from actual data is compared with the set of means obtained from simulated auxiliary parameter sets (depending on the number of samples that are drawn by vector-bootstrapping). As the actual Wald statistic serves as an indication of distance between actual auxiliary parameters and simulated means of auxiliary parameters, the lower the value it has, the better the model's ability to replicate the properties of the data. In addition, for each actual Wald statistic a corresponding normalised Mahalanobis Distance (hereafter normalised MD) is also shown to give a clearer view on the overall closeness.

The structure of this thesis is as follows: following this introduction, Chapter 2 provides a literature review on exchange rate and its role in monetary policy. Chapter 3 presents a general discussion on indirect inference methodology and a short review on the benchmark models that will be used in this thesis. What follows is an evaluation and comparison of the models' performances as well as a conclusion of hypothesis testing with regard to the existence of monetary coordination in Chapter 4. Moreover, for confirming the test result and assessing the extent of monetary coordination, indirect inference estimations are carried out on both the non-coordination model and partial-coordination model in Chapter 5. And finally, Chapter 6 briefly concludes this thesis.

Chapter 2

A Literature Review on the Exchange Rate and its Role in Monetary Policy

2.1 Introduction

An entire decade has passed since a major transformation in the monetary policy framework. Even since then, inflation targeting under a floating exchange rate regime has been popularised by countries across the globe[1]. Although the CB's main objectives are still maintaining price stability and assisting economic growth, their main concerns have moved onto inflation deviation, output gap and potentially interest rate volatility[2], leaving exchange rate determination primarily to the international market.

Despite mainstream thinking, an issue remains on the role of the exchange

[1] Since 1990, pioneered by the Reserve Bank of New Zealand, the main central banks in the world have tended to converge into an inflation targeting monetary framework. The work by Bhundia and Stone (2004) provides a taxonomy of monetary regimes, according to which, by 2003, 20 countries have employed *full-fledged inflation targeting*, 5 countries have employed an *implicit price stability anchor* (relatively opaque inflation anchor) and another 20 countries are classified as *inflation targeting lite*.

[2] Strict inflation targeting refers to the case where the CB's loss function consists only of inflation deviation and output gap; flexible inflation targeting normally refers to the case where the CB's loss function consists of other variables beyond the standard inflation target.

rate in the monetary policies: should CBs be concerned about exchange rate fluctuation when they conduct monetary policy; or further, should CBs respond to or target exchange rate movements; and to what extent should they respond to exchange rate fluctuation if this is the case?

The relationship between the exchange rate and trade has become the premier focus of academics and policymakers ever since the issue arose. However, what attracts the attention of academics and policymakers is, more broadly, the macroeconomic interdependence, and consequently, the macroeconomic policy design in the context of globalisation and market integrations.

In terms of monetary policy, the questions being asked become whether or not monetary authorities should cooperate or coordinate in designing their monetary policies; and to what extent they should cooperate or coordinate if this is the case.

This literature review begins by reviewing the crucial role of the exchange rate and its associated risk (level change and volatility) in deciding macroeconomic variables. Neither from the level value of the exchange rate perspective nor the exchange rate volatility perspective can literature give a definitive conclusion on either the direction or the magnitude of exchange rate impacts on various macroeconomic aspects, such as international trade, capital flow, current account balance and monetary policy efficiency.

The review then turns to illustrate the role of the exchange rate in designing monetary policy in an open economy context. Again it is inconclusive as to whether economies should be, or actually are, responding to exchange rate or exchange risk; and whether monetary policy coordination is welfare-improving. Yet theoretically, international misalignments validate additional trade-offs between stabilising internal targets and minimising external differentials. That is to say, the necessity of international monetary cooperation or coordination may exist and maybe welfare-improving under a comprehensive global economic structure.

2.2 Why Do the Exchange Rates Matter?

Shortly after the breakdown of the Bretton Woods System in 1973, many attempts were made to restore the control of the exchange rate. Not many of these attempts were successful, instead, these attempts typically led to great losses when the currency was on the edge of collapsing. Aside from those historical moments, the theoretical viability of the fixed exchange rate regime has also been seriously questioned – attributed to a wide range of research that has demonstrated the huge difficulties and costs of maintaining a fixed exchange rate regime. On the other hand, flexible exchange rates have been advocated by both academics and policymakers, not only because of its applicability under current global economic conditions, but also its ability to facilitate the international relative price adjustment and multilateral trade. Even so, fear of floating[3] arises from the potentially large exchange rate fluctuations as the 'impossible trinity' has foreseen – mutually unsustainable exchange rate stability and monetary independence in the context of a fast growing global capital mobility. Currency Unions (CUs), with the Euro Area (EA) being the largest, have been established from the fear that a highly volatile exchange rate is substantially detrimental to price stability and multilateral trade.

The impacts of level changes as well as exchange rate volatility, either in nominal or real terms, are both core concerns because of their strong implications on macroeconomic stability, effectiveness of monetary and fiscal policies, current account balance and international capital flows.

2.2.1 Expenditure-Switching Effects

An early advocate of a flexible exchange rate, Milton Friedman (1953) viewed a system of floating exchange rates as 'absolutely essential for the fulfilment of our basic economic objective'. The argument lied in what is called the expenditure-

[3] This term first appeared in Calvo and Reinhart (2002), in which they explored the reasons for 'fear of floating' and the extent to which the official labels of exchange rate policy can account.

switching effect of the exchange rate, stemming from the Keynesian approach to international macroeconomics.

Under a flexible exchange rate regime, monetary authorities make no intervention in the foreign exchange market. That is, a country's official reserves will have no changes associated with smoothing exchange rate variations. In the presence of certain 'real shocks' in the home country, any change in the balance of payments (BoP)[4] will be immediately reflected in flexible exchange rates that represent the relative price of goods and services across countries. Consequently, the foreign price of home goods becomes flexible even when the producer price of such goods is assumed to be rigid. Hence, expenditure switches internationally and domestically towards the relatively price-competitive nation, whose current account will be rebalanced if it was previously in deficit. For example, a productivity shock in the home country implies that domestic products are cheaper relative to foreign products. Hence, the home country will experience a foreign expenditure switch from foreign products to domestic products (an increase in exports); meanwhile, the domestic demand switches towards domestic products since foreign goods become relatively expensive (a decline in imports). The real exchange rate is a measurement of foreign goods in terms of domestic goods:

$$Q_t = \frac{\varepsilon_t P_t}{P_t^*} \tag{2.1}$$

where ε_t is nominal exchange rate defined as the relative price of foreign currency

[4] The *balance of payments* is defined as 'a statistical statement that systematically summarizes, for a specific time period, the economic transactions of an economy with the rest of the world' (IMF, 1993). It consists of two main groups of accounts. The *current account* records transactions of goods and services, income and current transfers that involve economic values and occur between resident and non-resident entities. The *capital and financial account* records the transactions of 1), capital transfers and acquisition or disposal of non-produced, non-financial assets and 2), financial assets and liabilities. Typically, reserve assets (except for the valuation changes) are included in the financial account.

The balance of payments manual has been revised by the International Monetary Fund (IMF) since the 1^{st} edition was published in 1948. The latest edition (BPM6, 6^{th} edition) was published in 2008. Its definition of balance of payments is consistent with System of National Accounts (SNA) and is also used by the Organisation for Economic Co-operation and Development (OECD), the statistical office of the European Union (Eurostat), and the United Nations (UN).

in terms of home currency[5]; P_t^* and P_t are the Consumer Price Indices (CPI) for the foreign and home economy, respectively. Hence, the value of Q_t rises as the home currency appreciates in real terms.

Historical evidence shows that real and nominal exchange rates have relatively close movement in the short to median term. In fact, a high degree of comovement between real and nominal exchange rates is one of the most puzzling stylised facts of exchange rate behaviour in flexible exchange rate regimes. As early evidence on this issue, Mussa (1986) found that under a flexible exchange rate regime, the variability and persistence of real exchange rates were both accounted for by nominal exchange rate behaviours. This result, therefore, implies a rejection of nominal exchange rate neutrality and support to those models that assume sluggish adjustments at national price level. Given such comovement between the real and nominal exchange rate, any economic variable that is affected by the exchange rate thus, has relatively consistent responses to both real and nominal exchange rates.

Another strand of the literature that is closely related to the expenditure-switching effect is the role of the Terms of Trade (TOT) in international trade. By definition, the home economy TOT is the relative price of imported goods in terms of exported goods:

$$\mathcal{T}_t^H = \frac{P_{F,t}}{\frac{P_{H,t}^*}{\varepsilon_t}} = \frac{\varepsilon_t P_{F,t}}{P_{H,t}^*} \tag{2.2}$$

where $P_{F,t}$ is the domestic currency price of foreign goods imported by the home economy; $P_{H,t}^*$ is the foreign currency price of home products that are exported to the foreign economy. Conventionally, the domestic economy TOT deteriorates (an increase in value) as the domestic currency depreciates. The domestic importing price $P_{F,t}$ becomes higher, subjected to the movements in the nominal exchange rate[6], while the exporting price $\frac{P_{H,t}^*}{\varepsilon_t}$ remains unaffected due to the fact that the

[5] This thesis adopts an indirection quotation for exchange rate. The home currency is treated as the fixed currency, while the foreign currency is treated as the variable currency.

[6] Foreign goods are priced in the foreign currency at $P_{F,t}^*$. As Law of One Price (LOOP) holds ($P_{F,t} = \frac{P_{F,t}^*}{\varepsilon_t}$), a domestic currency depreciation (a decrease in the value of ε_t) increases

exports are priced according to the producer price.

Both the real exchange rate and TOT, as a form of international relative price, are measurements of real competitiveness across countries. It is their role as effective facilitators in adjusting international demand and supply allocations that initiates calls for adopting the flexible exchange rate regime.

More recently, a series of papers using New Open Economy Macroeconomics (NOEM) models, pioneered by Obstfeld and Rogoff (1995, 1998, 2001), has provided evidence for Friedman's old affirmation about the equivalence of internal price flexibility and exchange rate flexibility[7]. In a model with Producer-Currency-Pricing (PCP), the foreign price of domestic products is adjusted in accordance with nominal exchange rate movements in order to keep the domestic and foreign prices of such products in line with each other. In the absence of any disturbance that creates an inefficiency wedge, the exchange rate and TOT reflect effectively the relative competitiveness across countries, and therefore, exploit the maximum possibility of expenditure-switching. The same optimal flexible price equilibrium can be achieved through the flexible exchange rate, and no policy coordination will be required in such a system.

2.2.2 Exchange Rate Pass-Through

In spite of the early attempts to explore the potential reallocative effect of the floating exchange rate, the extent of such expenditure-switching can vary subject to the influence from multiple factors. Principally, it depends on the sensitivity of importing country price level to exchange rate variations, which refers to exchange rate pass-through[8] (henceforth pass-through unless it is otherwise noted). With segmentation in the international market, particularly for global capital,

$P_{F,t}$.

[7] Friedman (1953) also emphasised in his famous 1953 paper that 'If internal prices were as flexible as exchange rates, it would make little economic difference whether adjustments were brought about by changes in exchange rates or by equivalent changes in internal prices'

[8] This phenomenon, related to a very low degree of exchange rate pass-through to consumer prices, is referred to as the purchasing power parity puzzle (PPP puzzle). The difficulties created by PPP puzzle in macroeconomic modelling are discussed in a later session.

the extent of exchange rate pass-through is essential for both intra- and international issues. For an individual economy, the conduct of monetary policies and macroeconomic stability maybe extensively constrained or promoted by the degree of pass-through; on the other hand, international transmission of shocks and policies, capital flows as well as the sustainability of current account imbalance are chiefly conditional upon exchange rate pass-through.

The complete exchange rate pass-through is when the response of importing price to exchange rate is one to one. Despite those plausible theoretical analyses, the empirical consensus has been that the pass-through is normally less than one across countries and sectors. Movements of the exchange rate and national consumer price are found to have a weak or even non-existent link in the short run.

For example, Jabara (2009) concluded that the pass-through to US aggregate import price (less oil) was 0.47 and to import price of consumption goods was 0.26. The country-specific degrees of pass-through to the US were 0.16, 0.26, 0.49 and 0.59 from Japan, the EU, Canada and Latin America, respectively[9]. Particularly, she reported a non-existent pass-through from the Newly Industrialised Economies (NIEs). Hellerstein et al. (2006) reported that the US exchange rate pass-through was 0.51 averaging over two decades before the recent financial crisis[10]. Campa and González-Mínguez (2006) found the pass-through in the Euro Area (EA) was less complete with an average of 0.62 in the short-run and was stronger with an average of 0.78 over a longer horizon[11]. In the short-run, degrees of pass-through differed across the EA members, with Spain and Finland on the high degree panel and with Belgium-Luxembourg, Ireland, Greece and Austria

[9] These results are generally consistent with the existing literature and correspond to the pricing pattern of the particular country or economic relationship. For countries that are closely trading with the US, such as Mexico and Canada, the exchange rate pass-through is higher. On the other hand, countries like Japan and the Newly Industrialised Economies (NIEs) that have extensive pricing to market pattern have typically a low degree of pass-through.

[10] They also stated that the degree of pass-through did not decline.

[11] In their study, the EA consisted of 12 countries that were already members of the EA by 2006 (excluding Cyprus, Estonia, Malta, Slovakia and Slovenia). Belgium and Luxembourg were treated as one economy.

on the lower degree panel. In the long run, pass-through has been more complete, with 6 out of 11 economies not able to reject the hypothesis of complete pass-through.

The earlier attempt to explain incomplete exchange rate pass-through focused on the diversity of countries' traded and non-traded goods sectors. It was later shown that price level of non-traded goods, pushed up by higher overall production cost, went in line with the traded goods sector. More recently, three prominent aspects in explaining the common phenomenon of low pass-through have been widely quoted in the literature - Pricing-to-Market (PTM), Local-Currency-Pricing (LCP) and cross-border production.

Pricing-to-Market

In challenging Keynesian assumptions on producer price stickiness, Pricing-to-Market (PTM) and Local-Currency-Pricing (LCP) are both pricing strategies developed by firms in accordance with observed pricing behaviour. Following the evidence that the PTM strategy is extensive internationally, Krugman (1987) offered a preliminary overview on PTM and claimed that 35% to 40% of the US dollar real appreciation is absorbed by PTM behaviour.

In terms of a US dollar real appreciation, instead of letting the dollar price of their exports float against the exchange rate, German luxury automobile exporters attempted to stabilise US import prices (in the US dollar) by effectively cutting their domestic currency export prices (in Deutsche marks), without which persistent price divergence would have induced arbitrage incentives[12]. Hence, exchange rate fluctuations are absorbed by exporters' squeezed profit margins, and the relative prices of German products in Germany compared to German exports to all the foreign economies are equivalently maintained.

[12] Maintaining the dollar price of German goods regardless of a dollar appreciation would inevitably increase German export prices to the US. The relative prices of German goods in Germany compared to German exports to the US would be lower. And so are the relative prices of German exports to other economies compared to German exports to the US. Large and persistent price divergences will induce incentives for international arbitrage.

Exchange rate pass-through to US import prices is incomplete. In fact, the degree of pass-through will depend on the frequency and the extent that exporters update their destination market prices and on other influencing factors under consideration. In an extreme case where exporters strictly maintain their destination market prices, the exchange rate pass-through to importing country price level is not viable; instead, a complete pass-through is made for the exporting country's domestic prices.

More interestingly, the inflation rate in Germany, which would otherwise increase[13], falls in response to a comparative real depreciation against the dollar, whilst the US price level is stable, *ceteris paribus*. Prior to PTM, it was common to deduce from similar models that depreciation and inflation are going side by side under a PCP scenario, regardless of the stance of macroeconomic policies. On the one hand, supply-induced inflation is caused by both higher prices of imported inputs and less price competition from foreign economies. On the other hand, demand-induced inflation is caused by the increasing demand for domestic goods from both domestic and foreign markets. More directly, higher import prices for the domestic economy can also contribute to domestic inflation. PTM pricing strategy, in contrast, demonstrates the possibility of falling inflation rate

[13] Comparatively, the Deutsche mark experienced a real depreciation as the dollar appreciated in real terms. A lower value Deutsche marks resulted in higher import prices in Germany, hence, directly pushed up the prices that Germans paid towards imported goods from the US. Indirectly, increasing demand and production costs for German goods can also push up the overall domestic price level in Germany. When the prices of German goods become cheaper, the demand for German goods from the US shall increase. Consequently, the price of German goods in Germany tend to be forced up if the share of exports to the US is large enough to compete with domestic demand that results in a decline in supply to the domestic economy (demand-induced inflation). Meanwhile, Germany's imported inputs from the US become more expensive, and so does its products that necessarily require imported inputs from the US (cost-pushing/supply-induced inflation).

This explanation simply takes the point of view of international trade theory and of the demand and supply analysis. When the stance of macroeconomic policies is also considered, a depreciation of the Deutsche mark can be an indication of the underlying macroeconomic policies. Therefore, both inflation expectations and potential policy impacts can foresee an inflationary consequence in Germany.

A theoretical framework to analyse this causal relationship between the exchange rate and inflation can be found in Kahn (1987). The empirical analyses showed that the value of the dollar had a statistically significant influence on inflation. A once-and-for-all dollar depreciation typically increased inflation over a period of five or more years, although such effects were temporary and small in the short term.

in countries that are experiencing home currency depreciation.

Local-Currency-Pricing

More widely adopted by recent general equilibrium models, Local-Currency-Pricing (LCP) and possibly Vehicle-Currency-Pricing (VCP) are argued to be more appropriate for describing a firm's pricing strategy. In particular, LCP was shown to have been extensive in traded industries.

Under LCP, exporting firms set the prices of home goods in the local currency of the importing economy[14], rather than in its home currency. In the presence of local price rigidity, the local (foreign/importing) price of home products will not adjust to exchange rate changes in the short run. Over a longer horizon, exporting firms may gradually adjust prices (in local currency) to be in line with the local price level for maintaining a firm's profit margin in terms of the local currency.

For instance, when a company based in South Korea exports electronic appliances to the US, it may set the price of those electronic appliances in US dollars rather than in the South Korean won. In the short term, such a price is kept relatively stable in line with the US price level, independent of the USD/KRW (Dollar/Won) exchange rate fluctuations. In the long term, the company adjusts the price according to its strategy and local economic conditions, such as local price rigidity and inflation. Consequently, exchange rate pass-through is incomplete in the short run; while in the long run, depending on various factors, the degree of pass-through can be higher.

Beyond the local price level, there is a possibility that firms reset their prices in accordance with exchange rate movements by re-optimising periodically; whilst it is also possible that they resist adjusting prices for certain reasons. After all, factors like market shares and the relative competitiveness are beyond companies' short term economic profitability, but undoubtedly have implications on

[14] It is also referred to as local currency invoicing or pricing to consumer currency.

their long term profitability. Under this circumstance, in order to maintain their competitiveness and market share in the destination market, exporting firms may be willing to give up the profit margins to some extent by not adjusting the price of their products frequently against the exchange rate variations. For this reason, models incorporating LCP are able to explain short-run and even long-run low exchange rate pass-through[15].

Campa and Goldberg (2005) measured the elasticity of pass-through for 23 OECD countries, including 11 Euro Area (EA) members[16], and suggested the average elasticity of pass-through to be 0.466 in the short run and 0.636 in the long run. In particular, the US economy had, among the lowest, an elasticity of 0.23 in the short run and 0.42 in the long run.

Some studies also brought increasing attention to VCP and its relevant policy implications, especially for the role of the dollar, pound, and euro as vehicle currencies in international trade. Under VCP, an exporting company sets the price of its goods neither in the domestic currency nor in the local currency of the destination market; instead, the price is set in a third currency, such as the US dollar or the euro.

The use of VCP is justified by the importance, prevalence or stability of the vehicle currency in global trade. For example, trade in raw materials like crude oil is normally invoiced in the dollar or the pound. A Nigerian exporter, who exports crude oil to China, may set its price per barrel in the British pound, rather than the Nigerian naira or the Chinese yuan.

Similar with LCP, the pricing pattern under VCP implies that exchange rate pass-through will be somehow incomplete. Gopinath et al. (2010) found that the immediate pass-through into the US import price was nearly zero if the goods were priced in dollars; while it was nearly complete if the goods were priced in

[15] In the case where local prices are less rigid, the exchange rate pass-through can be higher. Meanwhile, without the local price rigidity, if the exporters change the prices in the importing country to be in line with exchange rate changes, there is no difference between PCP and LCP in terms of having complete exchange rate pass-through.

[16] The included EA member countries were Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal and Spain.

non-dollars. Also, the median-term pass-through was 0.17 and 0.98 for goods that are priced in dollars and non-dollars, respectively.

Cross–Border Production and Import Composition

Most of the early literature would have the producer or local price rigidity as an essential assumption in order to explain the underlying causes of the incomplete exchange rate pass-through. However, another strand of the literature builds its theoretical interpretation upon the economic behaviours that are independent of nominal rigidity.

One phenomenon that describes globalisation is the increasing international fragmentation or the sharing of integrated productions, since cross-country heterogeneities and specialisation of productions appear to be crucial in deciding a country's relative competitiveness and in facilitating the global resource and wealth allocation. In practice, for maximising the efficiency of one integrated production globally, several countries may each participate in a small fragment of the production that it has expertise in, and export its products as intermediate goods. This global practice complicates the way that the exchange rate pass-through is determined.

Considering a static case with two trading partners, the home country imports a portion of its inputs (intermediate goods) and exports final products; the foreign country, on the other hand, exports intermediate goods (its final products) to the home country and imports final goods to satisfy its domestic consumption demand. When companies in both countries adopt a PCP strategy, the apparent exchange rate pass-through of a single product from one economy to another is complete. That is to say, the final good prices are primarily set in the home currency; the foreign prices of final goods will float fully against exchange rate variations. Meanwhile, the intermediate good prices are primarily set in foreign currency; the home prices of intermediate goods will also float fully against exchange rate variations.

However, the observed pass-through to the foreign price level may not be complete. When the home country's final products consist of an equal portion of domestic and foreign intermediate goods, a 5% home currency depreciation pushes up production costs by 2.5% in the home country, *ceteris paribus*. In order to maintain their profit margin, firms in the home country adjust their final good prices fully to the production costs. The importing price of final goods that foreign country confronts is 2.38% cheaper, relative to the price prior to home depreciation.

In fact, as the proportion of imported inputs in the final good production increases, the percentage decrease of the final good prices that the foreign country confronts is narrowed down[17]. That is to say, exchange rate pass-through to the final price level diminishes as the proportion of the imported inputs grows, *ceteris paribus*. This simple example ignores the potential demand switching due to the relative price changes. Nevertheless, the conclusion will not be reversed unless the demand elasticity for the intermediate and final products is exceptionally high.

Hence, even with complete pass-through at both intermediate and final good levels, because of cross-border production sharing, the observed exchange rate pass-through may not be complete. As a further matter, incomplete pass-through at either intermediate good level or final good level can result in dispersion of the observed degrees of pass-through. Moreover, the import composition and the availability of alternative resources are also crucial in shaping exchange rate pass-through in the presence of cross-border production sharing.

Ghosh (2009) provided a theoretical framework of international fragmentation. He studied two simple cases with either complete or incomplete pass-

[17] As the proportion of imported inputs in the home country increases from 25% to 75%, the percentage increase of final good production costs rises from 1.25% to 3.75%. The percentage decrease of final good prices that the foreign country confronts declines from 3.57% to 1.19%. In the case where no imported inputs are involved in the final good production, the final good prices that a foreign country confronts shall decline by 4.76% in response to a 5% home currency depreciation. In the case where the entire intermediate good production is dominated by the foreign country, the final good production costs rise by 5%, and the final good prices that the foreign country confronts has not been changed even though the home currency experiences a 5% depreciation.

through at the intermediate good level, and confirmed that a higher pass-through at the intermediate good level was translated into a lower pass-through to final good prices between two trading partners. Further complication of the model with multiple resources of intermediate goods allowed firms to moderate their production costs, which may have a consequence of even more stable final good prices.

Exchange Rate Pass-Through Determinants

The determinants of exchange rate pass-through are still open to debate. Firms' diverse pricing behaviour under nominal price rigidity is the most investigated among various interpretations and is most prevalent in macroeconomic modelling for incorporating the incomplete pass-through. Nevertheless, some recent research has revealed endogeneity in firms' pricing strategies, and also the degree of pass-through, to macroeconomic fundamentals and conditions, including the relative macroeconomic stability, country sizes, competitiveness and inflation growth as well as the prevalence or the importance of currency in trade, and volatility of exchange rate.

One earlier but rather strong piece of evidence presented in Taylor (2000) was that persistently low inflation during the great moderation, coupled with prevalent monetary policies, helped to lower firms' expectation on persistent and volatile changes in costs and product prices. Low uncertainty, in turn, prevented firms from passing through cost and price changes associated with exchange rate changes into local prices. Provided stability, exchange rate pass-through acts to mitigate inflation variability even further, whereas in a period of instability the high pass-through induced by larger uncertainty accelerates deterioration in macroeconomic conditions.

Moreover, other arguments that are not pricing-strategy based and are not closely linked to nominal price rigidity emerge as international economic relations are complicated by modern economic structure. It was also made clear in Campa and Goldberg (2005) that macroeconomic stability was essential in determining the degree of pass-through; in addition, the evolvement of import composition was also one of the determinants, which had certain implications from an earlier discussion about the international fragmentation.

2.2.3 Volatility of the Exchange Rate

An important implication drawn from the Mundell-Fleming model is the impossible trinity (trilemma), which says that exchange rate stabilisation, monetary independence and free capital mobility are not jointly achievable in an open economy. It suggests that policymakers will have to give up one in the trade-offs among these three desirable objectives.

There is a great deal of anecdotal evidence, such as the numbers of failures and their associated huge losses in attempting to restore limited exchange rate movement in the post Bretton-Woods era. The desire for monetary autonomy and high capital mobility across borders unavoidably lead to enormous difficulty in controlling the exchange rate.

In the literature, few studies have examined how binding the impossible trinity constraint is. Rose (1996) first attempted to examine the nature of these trade-offs econometrically, but found very little evidence of trade-offs among the three objectives, at least in the short run[18]. However, he claimed that the conclusion was not definitive and subject to the measurement difficulties and the time scale of the analysis[19]. On the contrary, Obstfeld et al. (2005) examined historical data covering the classical gold standard, the post-World War II Woods system and the modern flexible exchange rate system, and concluded with strong evidence in

[18] The main results in his analysis were that the exchange rate volatility was significantly but weakly related to underlying macroeconomic and monetary fundamentals; and that the government exchange rate policy can affect 'exchange rate volatility above and beyond the effects of actual macroeconomic policy'.

[19] Indeed, measuring empirically the underlying objectives of the trilemma, particularly monetary independence and capital mobility, is very challenging. It may raise some disputes and can potentially bias the result of the statistical analysis. On the other hand, there are factors that can alter the degree of any of these phenomena in the short run. For example, both price stickiness and an imperfect international asset market can dampen short-run capital mobility, leading to rejections of the trilemma.

favour of the trilemma[20].

The classical gold standard period was characterised by almost fixed exchange rates and unfettered capital flows, but a limited level of monetary autonomy. The Bretton-Woods system, established in an effort to rebuild the economic system and facilitate international trade, was a period of fixed but adjustable exchange rates and monetary independence, but strictly limited capital mobility. Both eras enjoyed both real and nominal exchange rate stability, which is desirable due to its reduced risk in international trade.

Yet towards the end of the 20th century, the flexible exchange rate regime as well as capital liberalisation undoubtedly were popularised by modern economists and policymakers. Exchange rate, theoretically predicted by the impossible trinity and widely observed across the globe, is inevitably left floating on the foreign exchange market. Ever since then, the determinants of exchange rate volatility and the channels through which increasing volatility can have impacts on the real side of the economy have been at the centre of a rich academic debate.

The nature and the extent of the impact on international trade and investments from volatile exchange rates is one of the core concerns of economists and policymakers, especially in a period of crisis and the recent fear of currency war. Indeed, on the advent of the floating exchange rate era, economists conceded that volatile exchange rates might have detrimental impacts on trade, and consequently on the current account balance. McKenzie (1999) interpreted exchange rate volatility as 'the risk associated with unexpected movements in the exchange rate'. It is taken from the belief that the uncertainty induced by volatile exchange rates depresses risk-averse exporters' willingness to trade. The subsequent welfare losses due to the 'discouraged' trade become the rationale of currency unions and one explanation for the radical movement toward single currency among some

[20] The data cover periods of the classical gold standard, post-World War II Bretton Woods system and modern flexible exchange rate system. The classical gold standard period was marked by low monetary autonomy since the rapid interest rate shock transmission was observed. In the Bretton Woods era, countries were still entitled to have monetary independence in the fixed exchange rate system because extensive capital controls were imposed.

European countries in 1999. Nonetheless, over the decades of the post Bretton-Woods period, numerous theoretical and empirical studies have found a rather ambiguous relationship between exchange rate volatility and the volume of trade. Even when exchange rate volatility was found to negatively influence the trade flows, the impact was small on average. The relevant literature surveys can be found in McKenzie (1999), Clark et al. (2004), Ozturk (2006), and Auboin and Ruta (2011).

Early theoretical analysis leaned towards supporting adverse effects of exchange rate volatility on trade. An intuitive demonstration of such an impact is that without he means of hedging exchange rate risk, a risk-averse firm that cannot alter its production in the short term to match the demand and supply misalignment due to exchange rate movements is subject to volatility in its revenue (Clark, 1973). Thus, exchange rate movements are largely responsible for the variability and uncertainty of a firm's profits, and as a result, the decision of cutting exports might be reached at the individual company level, and even at the industry level. Yet this theory is heavily restricted and to a great extent unrealistic. Further studies have relaxed some assumptions – lack of hedging opportunities, perfect competition, the role of invoicing currency, the absence of imported intermediate goods, the fixed level of production and the level of risk aversion – and concluded rather ambiguously.

It was argued that in the modern global market, numerous ways of hedging exchange rate risks or offsetting negative exchange rate movements will to some extent neutralise the impacts. Even so, Either (1973) incorporated the forward exchange market and found that international trade was disturbed and depressed by exchange rate volatility even with the forward exchange covering, when the revenue of trading companies is uncertain to the future exchange rate movements or when the forward exchange rate cannot accurately reflect traders' expectation on future spot rate. Sensitivity of the trade volume to exchange rate volatility, however, is affected by factors like expectation, accuracy of forward rate reflecting future exchange rate and level of speculative activity by firms. Obstfeld and

Rogoff (1998) also pointed out that adverse effects can also be introduced by higher export prices that are translated from high hedging costs. Firms with high risk-aversion have a higher tendency in hedging exchange risks when the exchange rate is highly volatile, with which they reduce the revenue uncertainty associated with the exchange risks, and may arguably maintain the trade volume. However, the hedging costs, accounting for fees incurred by actual hedging actions, will be reflected in higher exporting prices, and adversely affect the world demand and trade flows. In such a case, uncertainty created by exchange rate volatility not only enters firms' revenues but also their costs. In other words, certainty equivalence pricing accounts for not only revenue uncertainty but also cost uncertainty.

In addition, the accessibility and costs of risk hedging instruments vary across economies with diversities in size, openness and financial market completion, and efficiency. Multinational corporations (MNCs), for instance, have more opportunities to access the international capital market and may have relatively low hedging costs. Besides, their involvement in multi-currency trading maybe functioning as an instrument for the short run mutual hedging. Baron (1976) provided an extreme case of risk neutralisation by integrating a perfect forward exchange market when the exchange risk was the only risk that is associated. He also put forward the fact that the floating exchange rate has impacts on firms' pricing behaviour and correspondingly the risks associated with their pricing strategies. Neither PCP nor LCP can completely screen a firm's profits from exchange rate uncertainty – there is either a transaction exposure when transferring profits into the home currency under LCP or a quantity uncertainty when the foreign price moves with the exchange rate under PCP. The combined effect of pricing strategies and diverse degrees of risk aversion may be responsible for the unpredictability of trade flows relative to the exchange risk.

Integration of the global market enables cross-border production sharing. The entire production process can even be switched to those relatively cost competitive or low exchange risk countries. Clark (1973) mentioned that there were offsetting effects arising when the exporters indeed import intermediate goods for production; in other words, the production cost becomes uncertain and variable with the exchange rate (Baron, 1976).

De Grauwe (1988) also suggested that ambiguous positive effects might be possible when the relative risk aversion (RRA) was sufficiently high (greater than unity). His theory was derived from the fact that divergent optimum might be reached depending upon whether RRA was above or below unity. The economic intuition is that when an exporter is of higher risk aversion, the income effect outweighs the substitution effect – exports become more attractive since the marginal revenue of exports has risen in accordance with exchange rate volatility. The exporter re-allocates more resources into producing export goods in order to maintain the same level of expected utility from export revenues without higher risk. Some other relevant findings can be found in early literature such as Hooper and Kohlhagen (1978) and Cushman (1983).

The 'sunk' costs involving setting up export-related productions and networks may also alter exporting decisions. Due to the existence of such costs, firms are less sensitive to short term variations of the exchange rate, but are more cautious about their enter and exit strategies when the observed exchange rate volatility is high and persistent. Furthermore, instead of trade volume, trade composition is found to be adjusted against exchange rate volatility. Capacities for adjusting the production level in the event of sudden increases in the exchange risk also play an important role in firms' import and export strategies and in mitigating detrimental impacts from the exchange risk.

2.2.4 Recent Developments

Since the 2000s, concerns about the impacts of the exchange rate on the trade balance and other macroeconomic aspects reappeared in the aftermath of the serious currency crisis in conjunction with seemly unsustainably large global external imbalances. Albeit large attention still remains on impacts from exchange rate volatility, effects from persistent movements of level exchange rate, which are reflected in exchange rate misalignment, became the new focus of research. Questions that attract policy concerns are whether prolonged currency undervaluation improves the current account balance and boosts output growth; whether the sustained exchange rate misalignment creates distortions in achieving efficient outcomes; and whether prolonged misalignment created artificially by monetary and fiscal policies actually exports the domestic crisis to trading partners and dampens the global market; and last but not least, a long-asked question on welfare changes and corresponding optimal policies in response to all those changes in the global economic architecture. Another issue also being considered is the extent to which policies can influence the exchange rate, which has great implications on how macroeconomic policies affect the global economy and how they should be designed in achieving the domestic and global efficiency.

The relatively short-time horizon in past studies is one aspect that has received criticism. The J-curve effect is in common use nowadays for summarising impacts of currency depreciation on the trade balance – at the beginning of a real exchange rate depreciation the price effect dominates, leading to a temporary deterioration of the trade balance; as it proceeds, the quantity effect takes over as trade orders are replaced with adjustments to the price change, leading to a long term positive impact on the trade balance. In fact, it is agreed that short-run responses of the trade balance to currency misalignment are far from clear, and are subject to various conditions. Designing appropriate policies, however, requires understanding of the long-run effects, although short-run impacts are also under consideration.

Another criticism of past studies is the ignored heterogeneities across firms, sectors, and economies, and the use of aggregate trade data that may result in misleading implications. Diversity of firms in size, production specialisation, competitiveness, risk aversion as well as the market environment has a varied impact on a firm's exporting strategies, which shape the global trading pattern to some extent. There are also heterogeneities across sectors and industries in response to exchange rate movements. Trade composition, built upon such diverse industries and sectors, also shapes the aggregate trade pattern differently. Moreover, economies differing in size, openness and financial market development influence individual trading companies and hence an individual country's trade pattern differently. From these arguments, there are calls for the use of disaggregated data to avoid aggregation problems.

Furthermore, beyond the trade balance, studies have started exploring the relation between the exchange rate and other macroeconomic variables such as economic and technological growth. Most of the empirical evidence, in fact, leans towards supporting positive effects of undervaluation on economic growth, even in the long run. In particular, emerging economies that are heavily relying on exports benefit from prolonged undervaluation, in spite of the large exchange rate risk related to their under-development of the financial market.

Progress in the literature since the late 1990s takes on the advantages of advances in micro-founded, stochastic general equilibrium macroeconomic models. Instead of approximating equilibrium using certainty equivalence assumptions, the stochastic general equilibrium models capture the exchange rate and other macroeconomic risks within the model setting, and allow for interactions to be observed. That is, in such a setting the exchange rate volatility, trade and other closely related macroeconomic variables are endogenously determined. In addition, their microeconomic foundations allow welfare analyses of an explicit specification – the utility of economic agents – and provide an optimisation-based monetary policy analysis framework. Even so, the extent to which the exchange rate and its volatility have impacts on various macroeconomic aspects, such as international trade, capital flows, current account balance and monetary policy efficiency, is still inconclusive.

2.3 The Role of the Exchange Rate in Monetary Policy

The debate about the role of the exchange rate in monetary policy is still very much alive even though the flexible exchange rate regime has been dominating for decades. One strand of the literature that frequently asks whether monetary policies should consider, or to some extent even target, the exchange rate is the analysis of open economy monetary policies. In particular, can monetary policies designed for a closed economy also fit an open economy?

In a closed economy, an obstacle of designing monetary policies lies in the trade-off between stabilising inflation and stabilising outputs. In an open economy, however, natural heterogeneities across nations take various forms and contribute to the complexity of achieving a stabilising monetary policy. Therefore, in an open economy context, transmission of monetary policies, which is otherwise dominated by the interest rate channel, also has a large contribution from the exchange rate channel. An inward-looking monetary policy rule, which has exactly the same objective as in a closed economy, attempts to target domestic price stability and possibly economic growth and interest rate variability regardless of the degree of economic openness. This type of policy might be optimal when the exchange rate is instrumental to relative price adjustments. For instance, the classical view of open economy monetary policy is often based upon the assumptions of a frictionless international asset market and PCP, and thus, complete exchange rate pass-through. 'Divine coincidence'[21] is achievable, and therefore, monetary policies in the closed and open economies are 'isomorphic'. Contrarily, when exchange rate volatility serves as a source of uncertainty, a stabilising monetary policy should be capable of maintaining inflation at a low and

[21] The definition of this term is usually attributed to a seminal paper by Olivier Blanchard and Jordi Galí in 2005, which was later published in the Journal of Money, Credit and Banking (Blanchard and Galí, 2007). The 'Divine coincidence' referred to a property of the new Keynesian framework where CBs face no trade-off between stabilising inflation and stabilising the welfare-relevant output gap. In their paper, they argued that this property was due to the absence of non-trivial real imperfections, such as real wage rigidities.

stable level while minimising international resource misallocation.

2.3.1 Empirical Evidence

Empirical evidence of CBs indirectly influencing the exchange rate through monetary policies has been largely exploited. Some studies follow Structural Vector Autoregression ($SVAR$) put forward by Sims (1980). Clarida and Gertler (1997) provided a narrative together with $SVAR$ evidence that Bundesbank responded to the exchange rate 'in a clearly countercyclical fashion'. Cushman and Zha (1997) argued that appropriate monetary policies for a small open economy like Canada needed to account for endogenous policy reactions to the interest rate and the exchange rate. Kim and Roubini (2000) focused on G7 countries and concluded that US Federal Funds Rate (FFR) was endogenously responding to the USD/JPY (Dollar/Yen) and the USD/DM (Dollar/Mark) exchange rate, and vice versa. They interpreted these findings as either Germany and Japan were sufficiently large economies to affect the world interest rate or FFR responded to monetary actions in these two countries to avoid the impact of exchange rate variations on US inflation. By extending the Kim and Roubini model Brischetto and Voss (1999) claimed that Australian monetary policy can be explained better by including the authorities' responses to the nominal exchange rate.

Another group of studies estimate monetary policy rules directly. Gerlach and Smets (2000) found that those CBs using the Monetary Condition Index (MCI) as an operating target, such as the Bank of Canada and the Reserve Bank of New Zealand, reacted to the exchange rate strongly, while the Bank of Australia did not. Additionally, the large amount of literature focusing on Emerging Market Economies (EMEs) puts even more attention on this issue since CBs in EMEs are known to be highly active in foreign exchange market interventions and strongly react to the exchange rate.

Meanwhile, the meetings of international macro-policymakers often put much emphasis on the 'appropriateness' of exchange rate (and current account) developments. Meyer et al. (2002), providing a narrative study on macroeconomic policy coordination, summarised the reasons for such a focus on the exchange rate: it constitutes the transmission channel by which macro-policies in one country are transmitted to another; it is an information variable of the appropriateness of macro-policies; movements of the exchange rate can lead to immediate and substantial pressures on inflation in some countries; and the foreign exchange market can be susceptive to macro-policy actions and subject to irrational movements. The study concluded that policymakers viewed large exchange rate movements as undesirable *per se*.

2.3.2 Analytical Framework

In an era when adopting the floating exchange rate framework is overwhelmingly trendy, two issues put the exchange rate at the frontline of macroeconomic research: 1), the detrimental impacts on the wide aspect of the economy generated by the highly volatile exchange rate and 2), the possible instrumental function of the flexible exchange rate in stabilising inflation, output and other real macroeconomic variables. Theoretically, exchange rate volatility not only has negative impacts on economies from various aspects, such as trade, output and employment, its associated uncertainty may also dampen welfare[22]. Also, the instability that large exchange rate volatility may bring is of particular concern in EMEs and in times of economic crisis. Indeed, 'highly stable' was one requirement put together with 'free to vary' when Milton Friedman (1953) advocated flexible exchange rates. He also claimed that 'Instability of exchange rates is a symptom of instability in the underlying economic structure'. On the other hand, flexible exchange rates facilitate adjustments of relative prices, and hence Terms of Trade (TOT), relative demand, and resource allocation globally. Analytical studies have a more clear-cut conclusion on the existence of some degrees of expenditure-switching effects that vary due to heterogeneities across countries, sectors and time. In sum, it is the trade-off between detrimental high volatility

[22] See Obstfeld and Rogoff (1998) for an initial discussion.

and instrumental flexibility of the exchange rate that CBs and policymakers are interested in.

Arguments for differentiated monetary policies in closed and open economies lie in the differences of the underlying monetary transmission mechanism. In an open economy that is targeting inflation, transmission channels are the interest rate channel, the main channel in a closed economy, as well as the exchange rate channel. The interest rate channel, illustrated by imposing the Taylor rule, works by altering the real interest rate, and hence aggregate demand to affect inflation. The exchange rate channel influences inflation either directly by the exchange rate pass-through to traded and possibly untraded good prices[23], or indirectly, by the expenditure-switching effect that re-allocates the aggregate demand and resources globally, which may alter the domestic inflation. A common suggestion is thus adding responses to various measurements of the exchange rate when implementing monetary policies. Possible specifications of the reaction to the exchange rate vary in the literature depending on whether one focuses on real or nominal exchange rates, on level or changes in the exchange rate, and similarly, on contemporaneous or lagged effects of the exchange rate[24]. One simplest form of monetary policy rule presented in Taylor (2001) is:

$$r_t = \rho_y y_t + \rho_\pi \pi_t + h_0 Q_t + h_1 Q_{t-1}, \tag{2.3}$$

where r_t, y_t and π_t are the short-term nominal interest rate set by the central bank, the deviation of real GDP from potential GDP and the rate of inflation, respectively; Q_t and Q_{t-1} are current and lagged values of the real exchange rate (it also applies to nominal exchange rate, depending on the focus of the study), where an increase in values of Q indicates real appreciation of the domestic currency.

[23] Directly, inflation is affected by the exchange rate pass-through to the imported final good price, which would eventually enter domestic CPI. Indirectly, inflation is affected by the exchange rate pass-through to the imported intermediate good price, which in turn changes the price of domestic products.

[24] A comparison of these different types of specification can be found in Batini et al. (2003)

Early Research and Classical View

It was suggested in Obstfeld and Rogoff (1995) that the exchange rate is an important economic indicator, and thus it should not be ignored when setting monetary policies. Or in other words, relaxing monetary policies might be initiated by exchange rate changes under certain circumstances[25]. As pointed out in Taylor (2001), the implied policy rule to the exchange rate required either $h_0 < 0$ if the level exchange rate is the concern, or $h_0 < 0$, $h_1 = -h_0$ if the change of the exchange rate is the concern[26]. Formal analytical frameworks allowing for the appearance of exchange rates in monetary policy rules were evaluated by Ball (1999b), Taylor (1999) and Svensson (2000). In general, marginal improvements in macroeconomic performance were found in these studies, yet the findings were not enough to support the proposal for including a direct exchange rate response in monetary policy rules.

Using a model with a simple open-economy IS curve, Phillips curve and an exchange rate reaction function to interest rate[27], Ball (1999b) derived an optimal monetary policy rule targeting a weighted average of the real interest rate and the real exchange rate. Such optimal policy rule was supportive to a branch of popular practice that used MCI as a policy instrument[28]. He illustrated the

[25] They wrote that 'substantial appreciation of the real exchange rate accompanied by slow output growth furnishes a prima facie case for relaxing monetary policy'. Nevertheless, they also pointed out that policy responses to the exchange rate could also cause substantial deviations from purchasing power parity (PPP). The second interpretation of weak analytical support for open economy monetary policy in Taylor (2001) also stemmed from this statement.

[26] Althernatively, the policy rule can be expressed as $r_t = \rho_y y_t + \rho_\pi \pi_t + h\left(Q_t - Q_{t-1}\right)$, where $h = h_0 = -h_1$ indicates the elasticity of the policy rate to changes in the real exchange rate.

[27] Instead of assuming Uncovered Interest Parity (UIP), he assumed a simple rule of the real exchange rate, $Q = \theta r + v$, where r is the real interest rate and v is a white noise shock. The real exchange rate responds to the real interest rate at $\theta = 2$.

[28] From the late 1980s, several CBs adopted MCI (in real or nominal terms) as either their operating targets or as one of the indicators for guiding monetary policy setting. The purpose of this practice was to incorporate the exchange rate into policy implementations. The Bank of Canada and the Reserve Bank of New Zealand are two CBs that treated MCI as an operating target – policy responses to certain economic fluctuations consisting of changes in both the interest rate and the exchange rate, depending on the weights specific to an individual CB's preference. CBs of Sweden, Norway, Finland and Iceland used MCI merely for one economic indicator among others. For more analytical discussion on MCI, see Gerlach and Smets (2000), Freedman (1996) and Guender (2005).

term $\pi_t + \gamma Q_{t-1}$[29] as a 'long-run inflation forecast' that might deviate in the short run due to real exchange rate deviations (when $Q_{t-1} \neq 0$). Hence, the existence of lagged real exchange rates implies that monetary policies should not only target contemporaneous inflation, but also adjust to the temporary impact of real exchange rate changes on inflation, which may otherwise cause excessive reactions and inefficient oscillations in output and inflation. The paper came to the conclusion that an optimal open economy monetary policy rule would (1), use weighted sum of the interest rate and the exchange rate as policy instruments and (2), target long-run inflation to counteract fast effects from the direct exchange rate channel.

Svensson (2000) provided a more sophisticated model with built-in domestic inflation and CPI inflation, $\pi_t^c = \pi_t - \omega (Q_t - Q_{t-1})$[30], and found that the flexible CPI inflation targeting generated low to moderate variability in all variables. His interpretation was that policy reactions might entail impacts from a certain forward-looking variable Q_t due to the property of CPI inflation. Differing from a closed economy policy rule that merely responds to domestic inflation and output gap, there is a considerable amount of real exchange rate stabilisation in the open-economy policy rule, subject to the constraint respecting the cross-country output-gap stabilisation. Hence, he concluded that the flexible CPI-inflation targeting maybe an attractive alternative in the open economy.

Another early study, done by Taylor (1999), applied a multi-country general equilibrium model to seven countries including three Euro Area (EA) member countries[31] and the US. The simulated policy rule for the European Central Bank (ECB) implied that $h_0 = -0.25$, $h_1 = 0.15$. That is, 100% appreciation of the euro will be eventually reflected in a 10% reduction in the policy rate – 25% in the

[29] π_t being inflation and Q_{t-1} being the lagged real exchange rate. γ is the elasticity of inflation in response to the lagged exchange rate growth. It first appears in the open economy Phillips curve: $\pi_t = \pi_{t-1} + \alpha y_{t-1} - \gamma (Q_{t-1} - Q_{t-2}) + \eta$, where y_{t-1} is the lagged value of real output (in logarithm), η is a white noise shock.

[30] π_t^c being CPI inflation; π_t being domestic inflation; ω being the share of imported goods in the CPI; $Q_t - Q_{t-1}$ being changes in the real exchange rate.

[31] Three EA member countries were France, Italy and Germany. The bilateral exchange rates among these three countries were fixed, and a single short-term euro interest rate was assumed.

current period, offset in the following period by a 15% adjustment. Nevertheless, welfare analysis revealed that neither the simple rule nor the open economy rule with exchange rate responses strictly dominated the other. In particular, inclusion of the exchange rate lowered inflation in all three EA countries marginally, while output variance in Germany was higher. This result was subsequently echoed by the analysis of welfare-based optimal monetary policy rules that exchange rate targeted and cooperative monetary policies generated marginal or no welfare gains.

Taylor (2001) put such unsupportive analytical evidence on welfare gains into twofold explanations. First, even in a closed economy policy rule, the short-term interest rate responds to the exchange rate implicitly due to 'inertial effects' in exchange rate transmission. This interpretation lies in the fact that the exchange rate is a forward-looking variable that has impacts on expectations of inflation and expectations of policy rate movements, which in turn alter the current policy rate indirectly. Second, responding to exchange rate deviations from PPP that 'should not be offset by changes in interest rate' causes excessive fluctuations in the exchange rate and hence other real variables. In the case of strong unnecessary responses to the exchange rate from policy rules, welfare gains from exchange rate stabilisation come at the cost of welfare losses of harmful variability of the interest rate and other real variables. If the former explanation is true, the direct exchange rate reaction becomes redundant; while if the latter case holds true, it becomes undesirable.

The advance of DSGE models, which imposes micro-foundations and restrictions upon open economy analyses, provides theoretical insights into the open-economy transmission mechanism. The majority of studies focus on Small Open Economies (SOEs), particularly those with export or import dominations or with fewer trading partners. SOEs have a higher exposure to foreign shocks since they are more likely to be influenced by exchange risks.

In Clarida et al. (2001), a SOE model showed that monetary policies under both open- and closed-economy contexts were 'isomorphic'. International factors only affected the domestic policy design to the extent that domestic inflation or the equilibrium real interest rate was affected. Hence, under complete exchange rate pass-through, the CB should target domestic inflation rather than CPI inflation. Clarida et al. (2002) further confirmed such 'isomorphism' in a Nash-equilibrium case. Nonetheless, potential cooperative gains were achievable under a cooperative equilibrium, even though such gains are 'supply side' in nature. The optimal cooperative policy required attention on not only the real interest rate and domestic inflation, but also foreign inflation.

Galí and Monacelli (2005) developed a SOE-DSGE model with the Calvo sticky price and wage setting for analysing monetary policies. They demonstrated that equilibrium dynamics of an open economy were somehow canonical to the closed economy, but with dissimilarities in coefficients of equilibrium and the natural rate of output and the interest rate. They also showed the presence of two stabilisation trade-offs between the nominal exchange rate and TOT, and between the domestic inflation and output gap. The resulting superior policy rule in terms of welfare hence is domestic inflation targeting, although it also induces a larger exchange rate and TOT volatility out of three monetary policies.

A summative demonstration of an open-economy optimal monetary policy in the DSGE framework with 'divine coincidence' can be found in Corsetti et al. (2010). Comparing with the closed economy New Keynesian Phillips Curve (NKPC), macroeconomic interdependence appears in an open-economy NKPC as the modified marginal cost of production[32]. When the coefficient for the home consumption bias $a_H = 1$, this open-economy NKPC collapses into a canonical closed economy NKPC. In an open economy ($a_H < 1$), however, the domestic

[32]The open-economy frictions are represented in the log-linearised marginal costs as an additional term $-(1-a_H)\left[(\sigma\phi-1)\left(\hat{\mathcal{T}}_t - \tilde{\mathcal{T}}_t^{fb} + \hat{\mathsf{Q}}_t - \tilde{\mathsf{Q}}_t^{fb}\right) - \hat{\Delta}_{H,t} - \hat{\mathcal{D}}_t\right]$. $\hat{\mathcal{T}}_t$ is the deviation of the home economy TOT transformed from the ratio of import prices to export prices $\frac{\varepsilon_t P_{F,t}}{P^*_{H,t}}$, where $P_{F,t}$ is the home price of imported goods, $P^*_{H,t}$ is the foreign price of home goods in the foreign currency and ε_t is the nominal exchange rate that increases when the home currency depreciates. $\hat{\Delta}_{H,t}$ denotes deviation from Law of One Price (LOOP). $\hat{\mathsf{Q}}_t = \frac{\varepsilon_t P_t}{P^*_t}$ is the real exchange rate where P^*_t and P_t are the utility-based foreign and domestic Consumer Price Index (CPI), respectively. $\hat{\mathcal{D}}_t$ is the Purchasing Power Parity (PPP) adjusted cross-country demand differential.

inflation dynamics is also subject to 1), the misalignment of relative prices of good $\left(\hat{\mathcal{T}}_t + \hat{\Delta}_{H,t}\right)$ and of consumption $\hat{Q}_t$; 2), the relative demand imbalance $\hat{\mathcal{D}}_t$. In other words, open-economy NKPC resembles its closed economy counterpart only with the presence of perfect risk sharing and complete exchange rate pass-through across countries. Not surprisingly, in response to efficient shocks, optimal cooperative monetary policy in an open-economy model with complete financial market and PCP coincides with that of a one-sector closed economy with flexible prices. This can be demonstrated by showing a linear relation between the TOT deviation from the efficient level and the cross-country output gap that removes trade-offs in regard to stabilising the international relative price.

That is to say that exchange rates or TOT acts as an effective international shock absorber, and converges to its effective rate once output gaps are stabilised at individual country and hence cross-country level. Regardless of the various degrees of nominal rigidity in an individual economy, country-specific shocks are transmitted into exchange rate and hence, given complete pass-through, into importing economy inflation. Flexible exchange rate becomes a proxy to international price flexibility and transmission of macroeconomic distortions, which ensures achievability of flexible price optimum at international level – a justification to Friedman's assertion.

Intuitively, unnecessary responses to international relative price movements induce disruption in the process of convergence, and hence, welfare losses. The necessity of including any formation of exchange rate in monetary policy rule occurs only when either price misalignment or demand imbalance is non-zero, regardless of the existence of nominal rigidities in either economy.

Alternative Views

Recent criticism questions the classical view skeptically by examining two postulations that are crucial for achieving 'divine coincidence' in the classical model – perfect exchange rate pass-through and perfect international risk sharing. Any infringement of either assumption validates additional trade-off between stabilising domestic targets and minimising international misalignments. As a consequence, closed economy monetary policy may no longer be proper in an open economy context.

Incomplete exchange rate pass-through and LCP As mentioned in the previous section, even with nominal home price rigidity, complete exchange rate pass-through featured in PCP ensures price flexibility globally. Hence, efficient resource reallocation is achieved by the exchange rate acting as a shock absorber. Borrowing notations from Corsetti et al. (2010), $P_t(h)$ and $\frac{P_t^*(h)}{\varepsilon_t}$ denote prices in domestic currency set by domestic firm h at time t for the domestic and foreign market, respectively. Law of One Price (LOOP) holds since all the firms optimally equalise the prices of their goods in both markets - $\frac{P_{H,t}^*}{\varepsilon_t} = P_{H,t}$ and $P_{F,t} = \frac{P_{F,t}^*}{\varepsilon_t}$. Terms of Trade (TOT) which is defined as the ratio of domestic importing price to exporting price can be rewritten as:

$$\mathcal{T}_t{}^c = \frac{P_{F,t}}{\frac{P_{H,t}^*}{\varepsilon_t}} = \frac{P_{F,t}}{P_{H,t}} \tag{2.4}$$

The real exchange rate in log-linearised form is thus a function of TOT[33]:

$$Q^c = -(2a_H - 1)\,\mathcal{T}_t \tag{2.5}$$

In the case of LCP, each firm h chooses its price in domestic market $P_t(h)$ in terms of the home currency and in foreign market $P_t^*(h)$ in terms of the foreign currency regardless of the nominal exchange rate. In an economy with Calvo nominal rigidity, those firms who receive market signal reoptimise prices in both markets, otherwise the prices would be kept constant. With optimising probability being α, reoptimisation promises positive pass-through, and therefore, deterioration of TOT. However, without a reoptimising signal, there is zero pass-through to prices regardless of movements in the exchange rate. With $P_{F,t}$ and

[33] This function is derived from the assumption of symmetric parameters across countries – $a_H = a_F^* = (1 - a_H^*)$. Further discussion in this section also assumes symmetric parameters.

$P^*_{H,t}$ fixed, home currency depreciation (decrease in ε_t) results in improvement of TOT, rather than deterioration deduced from classical thinking. As a whole, subject to degrees of local nominal rigidity, thus incomplete exchange rate pass-through, TOT movement is indecisive – it improves when the former dominates, but deteriorates when the latter dominates.

The violation of LOOP creates a wedge between real and nominal exchange rates. The real exchange rate is also subject to a term describing deviations from LOOP:

$$Q^{LCP} = -\left(2a_H - 1\right)\mathcal{T}_t - 2a_H\Delta_t \tag{2.6}$$

where $\Delta_t = \Delta_{H,t} = \Delta_{F,t}$ is deviation from LOOP, assuming symmetric parameters across countries. Since it enters marginal cost of production in each country, this deviation also appears in the relation between cross-country output gap and TOT as an additional term. Consequently, the design of monetary policy encounters an international trade-off between stabilising domestic and cross-country output gap and domestic inflation. Tightening or easing monetary policy in order to close output gap $\left(\hat{Y}_{H,t} - \hat{Y}^f_{H,t}\right) - \left(\hat{Y}_{F,t} - \hat{Y}^f_{F,t}\right)$, which implies changes in relative currency values, will unavoidably cause deviations from LOOP. As mentioned in the previous section, misalignment of relative prices $\left(\hat{\mathcal{T}}_t + \hat{\Delta}_{H,t}\right)$ and $\hat{Q}_t$ drive inflation further away from its target. To the extent that monetary policy can open a wedge between an observed price to its efficient level, the trade-off between stabilising inflation deviation and output gap are exaggerated. This result stresses the need for policy concerns on international relative prices – including the real exchange rate, terms of trade and their misalignments.

Adolfson et al. (2007) described an open economy model of EA with both nominal and real rigidities and working capital channel, treating foreign variables as exogenous. Most importantly, by specifying local currency invoicing and imposing local currency price rigidities, the model allowed incomplete exchange rate pass-through in both import and export sectors. They also specified a monetary policy rule with response to lagged real exchange rate in addition to other conventional influential factors. The degrees of pass-through in EA were found to be low – 45% to price of imported consumption and 25% to price of imported investment – and were subject to specific types of shocks. Bayesian estimation of the model's parameters suggested that monetary policy responds to lagged real exchange rate positively but weakly. It is consistent with Ball's argument that the policy rate tightens up in response to lagged exchange rate for adjusting short term inflation over-reaction to exchange rate. Nevertheless, the highest elasticity of response at $h_1 = 0.018$, in particular being under the assumption of low capital adjustment cost, largely worsens the models' fit measured by log marginal likelihood.

Leitemo and Söderström (2005) found that optimised $h_0 = -h_1 > 0$ (both in the nominal and real exchange rate case when exchange rate pass-through is lower than 0.5. This, as opposed to the 'rule of thumb' summarised in Taylor (2001), implies that the policy rate declines when exchange rate appreciates. They interpreted it as the potential conflict between 'direct exchange rate channel and other channels of monetary policy' as exchange rate is forward-looking – when exchange rate pass-through to inflation is high, the interest rate responds negatively to exchange rate volatility for the purpose of reducing inflation variability, but at the cost of higher exchange rate and interest rate volatility (cases in Svensson (2000) and the case of Germany in Taylor (1999) were referred to); meanwhile, when exchange rate pass-through to inflation is low, interest rate and exchange rate volatility can be reduced by letting the policy rate respond positively to exchange rate changes, but at the cost of allowing higher inflation. This explanation is somehow in line with Taylor's second point that also results in the trade-offs between stabilising exchange rate (and potentially interest rate) and other real variables.

Incomplete International Asset Market Another necessary condition assuring effective allocation to be the best – flexible price allocation – is the complete international asset market. A perfect global asset market generates perfect international risk sharing that determines the real exchange rate:

$$Q_t^c = -\sigma \left(C_t - C_t^*\right) + \left(\zeta_{C,t} - \zeta_{C,t}^*\right) \tag{2.7}$$

where $\zeta_{C,t}$ and $\zeta_{C,t}^*$ are consumption preference shocks in domestic and foreign economy, respectively. The global demand imbalance, defined as $\mathcal{D}_t = Q_t - \sigma\left(C_t - C_t^*\right) + \left(\zeta_{C,t} - \zeta_{C,t}^*\right)$ is zero whenever the above risk sharing holds. An efficient shock moves TOT and the exchange rate in an opposite direction – positive home productivity shock, for example, results in depreciations in the real exchange rate and TOT. With complete pass-through, flexibility of the exchange rate allows effective adjustment, by which the induced expenditure-switching effect can restore efficient reallocation of cross-country demand of consumption.

On the other hand, an imperfect asset market confines international risk sharing. Ambiguity of exchange rate and TOT movements in response to efficient shocks is permitted in contrast to the perfect asset market. Assuming financial autarky and symmetric parameters across economies, the determination of the real exchange rate, instead of depending solely on intertemporal elasticity of substitution, depends on both degree of home bias a_H and elasticity of substitution between home and foreign goods ϕ. The log-linearised exchange rate and TOT can be presented in terms of global demand and production gaps as:

$$Q_t = -\frac{2a_H - 1}{2a_H\phi - 1}\left(C_t - C_t^*\right) \tag{2.8}$$

$$-\left(1 - 2a_H\left(1 - \phi\right)\right)\mathcal{T}_t = Y_{H,t} - Y_{F,t} \tag{2.9}$$

Compared with perfect risk sharing (2.7), the equation (2.8) deviates in terms of elasticity of global demand to real exchange rate and preference shocks. The global demand imbalance, thus, is non-zero unless in extremely rare circumstances. Noticeably, when $\phi < \frac{2a_H - 1}{2a_H}$, TOT responds to home productivity shock negatively. The classical thought of the expenditure-switching effect can no longer be assured when strong preference towards home goods prevails. It was presented in an earlier section that a non-zero global demand imbalance distinguishes open-economy NKPC from its closed economy counterpart. The design of monetary policy confronts a trade-off between global output differential and relative demand imbalance in addition to home inflation and output gap trade-off.

2.3.3 The Exchange Rate and International Macroeconomic Puzzles

Despite the voluminous literature arguing an important role for exchange rates in monetary policy, uncertainty about the determinants of exchange rate movements and the connection between exchange rates and macroeconomic variables can easily turn such efforts into futility. The undesirability of volatile exchange rates to macroeconomic policymakers stems from the perception that the exchange rate is an information variable and has significant impacts on macroeconomic fundamentals. Yet, various unresolved exchange rate puzzles can affect, and potentially sabotage, models incorporating the preceding assumption.

The Mussa puzzle (Mussa, 1986) describes the high level of co-movements between real and nominal exchange rates. To enable a model to re-produce such co-movements, a certain level of price rigidity at national level will be required.

The consumption-real exchange rate anomaly, which focuses on the correlation between the exchange rate and the relative level of consumption, describes the contradiction between the positive correlation predicted by macroeconomic models and the negative (or positive but small) correlation observed by empirical studies. Chari, Kehoe and McGrattan (hereafter CKM (2002)) intended to model the consumption-real exchange rate anomaly in a general equilibrium monetary model by introducing an incomplete bond market and habit persistence. The result was not promising for eliminating the anomaly.

Obstfeld and Rogoff (2001) included two exchange rate puzzles in the list of the six major puzzles in international macroeconomics – the PPP puzzle emphasising the weak connection between exchange rates and national price levels; and the exchange-rate disconnect puzzle.

The PPP puzzle is characterised by an observed high level of volatility and persistence in exchange rates. Such a phenomenon is difficult to account for through a theoretical model. Monetary and financial shocks are normally considered as the major source of volatility, but will require an unrealistic level of nominal rigidity to account for the persistence. On the other side, without monetary or financial shocks, macroeconomic models have difficulties in generating enough exchange rate volatility.

The exchange-rate disconnect puzzle describes the phenomenon that the observed exchange rate volatility is much higher relative to the volatility of macroeconomic fundamentals – the exchange rate fluctuates widely without having a sizable contemporaneous impact on the real economy. This phenomenon weakens the arguments for including exchange rates in the CB loss function - if the loss induced by the exchange risk were lower than the cost of hedging, why should a CB target the exchange rate?

In addition, the failure of UIP and its associated puzzles can be held against the models with a UIP specification. The UIP implies that the currency in the country with higher interest rates should depreciate (a positive relationship); and the expected excess returns from the foreign currency arbitrage[34] should be zero. Yet the empirical observations regarding time periods and currency pairs say the opposite – thus the UIP puzzle; and the expected excess returns are not zero - thus the forward premium puzzle.

The anecdotal evidence shows undetermined exchange rate responses to an interest rate differential. In theory, the assumption of perfectly flexible prices implies a positive relationship between the exchange rate and the nominal interest rate differential; whereas the sticky price assumption predicts a negative relationship. Depending on the magnitude of the inflation differential (either large

[34]The linearised approximation of the UIP is $E_t\varepsilon_{t+1} - \varepsilon_t = r_{ft} - r_t$, where r_t and r_{ft} are nominal interest rates in the home and foreign economies, respectively. The expected excess returns from foreign currency arbitrage is then defined as $E_t x_{t+1} = \varepsilon_{t+1} - \varepsilon_t + r_t - r_{ft}$.

or small), these two theoretical interpretations can each explain certain historical moments or geographical variations. However, given a commonly observed, moderate inflation differential, it is difficult to develop a model describing the relationship between the real interest rate and real exchange rate well.

Dornbusch (1976) was one early paper establishing a model to interpret the relationship between real interest rates and real exchange rates. In the short-run, a monetary expansion resulted in an immediate domestic currency depreciation; such exchange rate overshooting can in turn lead to an expectation of appreciation – the movement of exchange rates will be reverted towards the long-run depreciation level. The extent to which the monetary policy can affect the interest rate and the exchange rate depends on the behaviour of output – fixed output leads to a combination of a depreciation and lower interest rates; whereas, adjustable output leads to a combination of a depreciation and higher interest rates.

In a structural model, UIP imposes an 'empirically false' restriction on the relationship between the interest rate differential and the exchange rate differential, undermining the model's performance. Moreover, the UIP has a strong implication on the cross-country differential in monetary stances – it effectively demonstrates that the difference between monetary policy rates in two countries will be reflected in a bilateral exchange rate differential. Pippenger (2013) suggested that these two puzzles can be explained by a combined effect from monetary policy and the covered interest parity. More interestingly, Backus et al. (2010) restated UIP in terms of monetary policy, in particular the domestic and foreign Taylor rules. An asymmetric case (the foreign monetary policy, but not the domestic monetary policy, reacted to exchange rate variations) was able to explain the UIP puzzle and yielded a best model performance.

2.4 Monetary Policy Coordination and Cooperation in the Exchange Rate

2.4.1 Economic Interdependence and its Policy Implications

Literature on open economy monetary policy often emphasises the importance of exchange rate by its role as trade facilitator and destabiliser. Therefore to some extent, the presumption of these analyses is monetary independence among economies – similar to what is pointed out by Hamada (1976) that traditional approaches normally 'assume the monetary policies of other countries as given or take the international cooperation of monetary policies for granted'. Nevertheless, the complication of designing monetary policy in an open economy may be beyond the exchange rate impact dimension.

Interdependence among economies emerged gradually and vastly as exchange rate regimes were switched and the phenomenon of globalisation became widespread. Cooper (1969) referred economic interdependence as 'marginal propensities to import and the interest sensitivity of international capital movements'. Hamada (1976) also summarised two channels of economic interdependence: the world inflation is weighted average of credit expansion of all economies; and one country's deficit is made up by another country's surplus. More specific to monetary policies, existence of such macroeconomic interdependence is translated into monetary interdependence that challenges monetary authorities in designing and conducting monetary policies.

Foremost, potential feedback responses from foreign CBs have crucial implications for domestic policy design in response to both domestic and foreign shocks. In particular, impacts that a small open economy may receive from policy changes in large or closely traded counterparties and the extent to which monetary spillovers can impede the effectiveness of domestic policies are heavily studied. In addition, heterogeneity in monetary policy stances may lead to monetary spillovers, and hence, inefficiency in conducting domestic monetary policy without international monetary cooperation or coordination. Empirically, persistent undervaluation of currency is supportive to domestic economic growth, especially for emerging economies; whilst, it is also found to be hindering foreign counterparties by introducing distortions and weakening policy effectiveness.

In such an increasingly interdependent world, there is an incentive for rational policymakers to take other countries' policies into consideration when they design domestic policies. The concepts of monetary policy non-cooperation, cooperation and coordination hence arose in response to such intuition. The non-cooperative policy of an economy, normally referred to as Nash equilibrium, is designed by policymakers maximising the welfare of their own economy, taking other countries' policy actions as given. In contrast, cooperation often refers to two or more economies to decide jointly on policies that will be conducted in all of the collaborated countries – using strategic game theory, it is designed by the policymakers to 'jointly maximise a weighted average of their individual welfares' (Canzoneri and Henderson, 1991).

The distinction between coordination and cooperation maybe ambiguous within the literature – they appear interchangeable sometimes. Or more broadly, coordination also refers to the entire subject area. Cooper (1969) referred coordination to the extent that 'policymakers take into account the objectives and prospective actions of other policymakers'. Even for independent policymakers, there are unavoidable 'game aspects' in designing their own policies due to macroeconomic interdependence, regardless of whether or not an explicit agreement is settled and regardless of whether they participate in the game willingly or unwillingly. Canzoneri and Henderson (1991) described coordination as choosing one solution in the entire set of multiple cooperative game solutions. Despite such ambiguity, it is greatly debated by academics and policymakers whether or not monetary coordination or cooperation is necessary and whether or not such coordination or cooperation is welfare-improving.

2.4.2 First Generation Models for Monetary Cooperation and Coordination

The first generation of models for monetary policy cooperation mostly started in the 1970s when the floating exchange rate was popularised. Strategic game models were adopted and some theoretical support for the necessity of monetary policy coordination was found. Externalities or spillover, generated by implementation of certain policies in one economy on its foreign counterparties, were the core of the arguments. Being the earliest analytical study, Hamada (1976) showed that aggravation of world inflation occurred under both fixed and floating exchange rate, although the underpinning of such a phenomenon differs – the preference of monetary authority leaned towards overall account deficit in the former case, while towards current account surplus in the latter case. Oudiz and Sachs (1984) made new progress in their attempt to quantify welfare gains from coordination in a game theory framework. Their overall findings were positive but small – 1.5%, or slightly above, of GNP gain as a result of coordinated expansion.

Canzoneri and Gray (1985), on the other hand, emphasised the importance of economic structure, in determining gains from policy cooperation. They compared cooperative, Stackelberg and non-cooperative fixed-exchange-rate solutions and concluded that switches of exchange rate regimes might be the result of large economic structure changes since the early 20^{th} century. In addition to conventional interest rate (capital mobility) and good demand channel (trade), wage indexation and fixed oil price channels were all brought to attention. They argued that economic structure determined the relative importance of these four channels in international transmission, and hence, the welfare benefit of different degrees of cooperation.

Rogoff (1985), contradicted with the previous literature and argued that coordination could be counterproductive when coordinating CBs lost credibility to private sectors. The cooperative agreements mitigate the negative impacts of exchange rate depreciation, due to domestic monetary expansion, on either the domestic or foreign economy. As a result, policymakers have less incentive on restricting inflationary surprises. But instead, unanticipated monetary expansion will be used more frequently in order to systematically boost employment. The CB's lack of credibility and commitment triggers demand for higher time-consistent wage, and eventually leads to higher equilibrium inflation. Ever since then, different counterproductive conditions have been derived. Canzoneri and Henderson (1991) also presented a third-party model alongside two cooperative economies, and showed that a coalition might be counterproductive if the third-party reaction was also considered. In addition, they also found that a trigger mechanism in repeated games gave policymakers incentives to stick with cooperative agreement, rather than cheating to gain an immediate advantage.

Furthermore, since monetary spillover is the main argument in advocating policy coordination, it is intuitive in thinking that the larger the spillover between two economies, the stronger the welfare gain from their cooperative policies. Canzoneri and Minford (1988), however, used the Liverpool World Model, which incorporated strong economic interdependence, and found empirically that strong spillover was necessary but not sufficient in guaranteeing expected cooperative gains. Sufficiently large disturbances and certain restrictions on policy preference were also required.

Henderson and McKibbin (1993), using a multi-region model, carried out empirical comparison of paired monetary policy regimes – an individual country might be targeting interest rate, money supply, nominal income, combined real output and inflation or nominal exchange rate. The shocks under consideration consisted of three categories – money demand, good demand, productivity shocks – as well as one exchange rate risk premium shock and one global oil supply shock. The property of these shocks were also extended to be either symmetric, asymmetric or country-specific. There were no clear-cut answers on which policy regime dominated the others – the stabilisation property of each monetary regime varied by wage contracts, shocks and shock properties. Coupled with other studies in the book, there was no definitive conclusion on the gains from policy coordination; rather, it was suggested that gains, and even losses, from coordination might depend on the policy regime upon which each country was conducting monetary policy.

This generation of models provided a rationale for monetary policy coordination, although the nature and extent of gains from coordination was ambiguously shown. For a thorough understanding of early game-strategic literature, one can refer to Canzoneri and Henderson (1991), within which a wide range of theoretical analyses, including both static and dynamic, were taken out. A general empirical survey on this issue can be found in McKibbin (1997), although the focus was on industrial economies. It also discussed some studies on the impact of uncertainty upon coordination gains. The uncertainties, such as in information exchange, true models and individual policy multipliers, were said to potentially raise the gains. Yet, an overall empirical evaluation found that the gains from monetary coordination were quantitatively small.

2.4.3 New Generation Models for Monetary Cooperation and Coordination

Since the early 2000s, literature has followed recent contributions from the New Open Economy Macroeconomics (NOEM) and the dynamic stochastic general equilibrium (DSGE) models with nominal and real rigidities. The advantage of this approach stems internally from the characteristics of the model adopted. Foremost, its microeconomic foundations featured by economic agents' optimisation provide structural complications that enrich our understanding of the whole economy relative to conventional reduced form econometric models – and provide an explicit utility-based welfare framework that enables more comprehensive policy analysis. Besides, the integration of dynamic general equilibrium and stochastic modelling characterise both intra- and inter-temporal trade-offs and enrich the models' dynamics without relying on certainty equivalence assumptions.

Corsetti and Pesenti (2001) were among the earliest to lay down foundations of a new analytical framework for economic interdependence and policy induced welfare changes. They showed that domestic monetary expansion could not promise output and employment improvements in an open economy; instead, Beggar-Thyself might occur when negative TOT deterioration overwhelms positive current account improvement. This argument was also well specified in their recent paper Corsetti et al. (2010). The directional movement of efficient flexible price TOT hinges on whether or not $\sigma\phi$ is above or below unity – whether home and foreign goods are complementary or substitutional[35]. This unconventional conclusion hence suggests no incentive for competitive devaluation.

Obstfeld and Rogoff (2002) presented a NOEM model with incomplete international asset market and wage rigidity. They showed that cooperative monetary rule is equivalent to Nash equilibrium rules under either separable utility function with respect to tradable and non-tradable goods or all the shocks are global rather than country-specific. The implication was that monetary policy is self-enforcing under those exceptional circumstances, and cooperation can be sustained even without clear agreements. Differing from conventional arguments, this suggested that lack of cooperation may not be an issue since country-specific monetary policies would approximate cooperative outcomes as global market integration proceeds. This echoed early studies, such as Canzoneri and Minford (1988), that found cooperative and non-cooperative allocations were clustering or 'operationally indistinguishable', although there were exceptional cases.

Nonetheless, they also pointed out that the smaller the cross-country monetary spillover, the less need there is for policy cooperation. As covariance, which was absent in the conventional certainty equivalence modelling, appeared in TOT and consumption spending. Monetary policies directly affected consumption through agents' expectations and attitude towards risk (presented by the covariance term)[36]. The monetary authorities, hence, have an incentive to manipulate

[35] Additionally, it is also shown that output spillover is not entirely neutralised even with $\sigma\phi = 1$, since preference shocks have a separate channel from TOT transmission.

[36] Recent empirical discussions on the 'risk-taking channel' of monetary policy and time-

the exchange rate, TOT or global demand gap, which reduces covariance between world demand and exchange rate, for pure domestic benefits at the expense of other economies – the Beggar-Thy-Neighbour issue.

Benigno and Benigno (2003), in contrast, argued that conditions for non-cooperative monetary policies to coincide with efficient policy, or flexible price allocation, were more stringent. Their main arguments lied in what was also echoing the findings in Obstfeld and Rogoff (2002) that independent policymakers had an incentive to implement Beggar-Thy-Neighbour policy, unless there was strict assumptions on policymakers' preference. In a closed economy, ex ante policy commitment is sufficient in avoiding the Barro-Gorden argument of inflationary bias; whilst in an open economy, there is an incentive for policymakers to exploit TOT volatility in correcting cross-country production differentials, and even to create negative externality on other counterparties. Therefore, unless the TOT channel is ineffective or domestic economy is invariant to TOT variations[37], there are potential gains by cooperative policies even when the global good and financial markets are integrated and exchange rate pass-through is complete.

Note that, in spite of the minor impact from international preference shock differential, the elasticity of substitution between home and foreign products exhibits crucial role in determining welfare gains from coordination. As criticised by Sutherland (2004), restriction of unity elasticity of substitution between home and foreign goods ϕ in some studies potentially ruled out the expenditure switching effect and restricted the role of financial markets in analysis of welfare gains from coordination. They, therefore, used second-order approximation to derive explicit policy rules and corresponding welfare gains from a model with non-unity assumption on elasticity of substitution between home and foreign products. They suggested that when ϕ was greater than unity, increasing in particular,

varying risk-aversion are supportive to such an argument.

[37] When the elasticity of substitution between home and foreign products is $\phi = 1$, the TOT channel becomes ineffective since there is no home bias in creating global demand imbalance. When $\phi = \sigma^{-1}$, (the inverse of intertemporal consumption substitution, or $\phi\sigma = 1$) cooperation is self-enforcing since domestic output is the only condition needed to gain equilibrium solution. These two conditions were also shown in Corsetti et al. (2010).

the existence of the financial market exaggerated spillover effects. The extent of gain, however, was shown to be sensitive to financial market structure – whether trade of asset took place before or after policy in their case.

Canzoneri et al. (2005) also pointed out the missing TOT externality in the model potentially limited the scope and extent of gains from policy coordination. By examining models in Corsetti and Pesenti (2001) and Obstfeld and Rogoff (2000), they asserted that gains from coordination might be of more importance in models of a new generation relative to the first generation. This general view on new generation models contradicted the view of the first generation models that their structure has limited the gains from coordination (Canzoneri and Minford, 1989).

As presented in Corsetti et al. (2010), either incomplete exchange rate pass-through or incomplete risk sharing could create disturbances in exchange rate, TOT and global demand in adjustment to an efficient level. Under incomplete exchange rate pass-through, there is an additional trade-off between stabilising cross-border output differentials and domestic output gap and inflation; while under an incomplete global financial market, there is an additional trade-off between stabilising domestic inflation and global demand imbalance. Similarly, these international trade-offs can emerge when decentralised policymakers export externality of domestic policy impacts, for instance, competitive devaluation in an attempt to boost the domestic economy. In either case, the design of open economy monetary policy hence requires attention on correcting global misalignments in addition to deviation of international relative price, such as exchange rate or TOT, to its efficient level. Therefore, monetary policy coordination is potentially welfare-improving, except for some special cases presented earlier in this section, such as assumption of $\phi\sigma = 1$ and global symmetric shocks.

2.5 Conclusion

This chapter has given a rough review on the importance of the exchange rate and its volatility in the modern global economy with integrated markets, capital mobility and macroeconomic spillovers. The first half reviewed the crucial role of the exchange rate and its associated risk in deciding macroeconomic variables.

The initial argument is that changes in the value of the exchange rate induce expenditure-switching. However, the extent or even the existence of the expenditure-switching effect relies heavily upon exchange rate pass-through. Since empirical evidence is not supportive to complete pass-through, the impact of changing the exchange rate value on macroeconomic variables cannot reach a definitive conclusion. The exchange risk, or volatility of exchange rate attracts more attention since the new generation of general equilibrium models, NOEM and DSGE models, become prevailing tools in analyses. Even though these models can incorporate exchange risk into their comprehensive structure, the impact of exchange risk remains ambiguous.

The second half of this chapter turned to explore the role of exchange rate in designing monetary policy in an open economy context. The globalisation and integration of the market facilitate international spillover and promote macroeconomic interdependence. The additional trade-off that a monetary authority may confront in designing monetary policy implies a need for policies to react, or even target the exchange rate. The reactions of monetary policy to exchange rate can take multiple forms – either to real or nominal exchange rates, and either to level or change of exchange rate and either to the contemporaneous or lagged values. The empirical evidence suggests that some countries do take actions in response to exchange rate in some forms. Yet welfare analyses give rather ambiguous implications.

Again, it is inconclusive whether monetary cooperation and coordination are welfare-improving. The first generation model calls for monetary coordination due to the externalities that maybe generated by decentralised policies, but leaves a rather controversial conclusion that gains from monetary coordination marginal marginal. The second generation model, using NOEM and DSGE models, reveals explicitly the international misalignments that may hinder international relative price from adjusting to its efficient level, and cause economic resources to deviate from flexible price allocation. That is to say, the comprehensive structure of a new generation model permits larger, but still uncertain, welfare gains from coordination.

Chapter 3

Methodology and Benchmark Model

3.1 The Method of Indirect Inference

3.1.1 Indirect Inference Estimation

Modern macroeconomics incorporates an enormous amount of complexity into modelling, causing computational difficulties. For instance, intractability of the likelihood function can potentially weaken the efficiency of estimating model parameters. Much literature has taken the approach of replacing the criterion by either an approximation of the exact likelihood function, or the exact likelihood function of a model approximation, while other researchers are devoted to finding an alternative.

Earlier attempts include, for example McFadden (1989), which introduced the Method of Simulated Moment (MSM). He argued that when the moment condition cannot be evaluated directly, a Monte Carlo simulated moment condition can be used instead. Smith (1993) compared 'Simulated Quasi-Maximum Likelihood' (SQML) with 'Extended MSM' (EMSM), and concluded that although EMSM was asymptotically more efficient, the requirement of estimating a weighting matrix could compromise the efficiency when the sample size was limited, which is a common phenomenon in Macroeconomic studies. Gourieroux et al. (1993), which was titled 'Indirect Inference', described in steps how to obtain consistent indirect estimators and how to conduct significance tests and hypothesis tests with applications on various areas. In the recent literature the method of 'indirect inference estimation' has been used in model estimation to some extent. Canova (2005) summarised the 'simulation estimator' following the GMM estimator, with detailed discussion on its asymptotic properties and various applications.

Estimations using indirect inference choose a set of parameters to simulate data from a macroeconomic model. The simulated data are then compared to the actual observations using the chosen auxiliary model, which produces certain criterions on both simulated data and actual data. The optimal parameter set is the one that can minimise the distance between simulated data and actual data, represented by a statistical measurement such as Wald statistics. Indirect inference estimation requires neither a tractable likelihood function, nor a complete set of time series involved in the model[1].

Assuming a set of parameters θ, which takes the form of $k \times 1$ vector, the structural model can generate a vector of time series $x_t(\theta)_{m\times 1}$, where $t = 1, \ldots, T$, m is the number of variables. The set of variables in $x_t(\theta)$ can be selected variables, instead of the entire variable set included in the model specification. Let y_t $(t = 1, \ldots, T)$ represent an $m \times 1$ vector of corresponding observed time series. Assuming that both $x_t(\theta)$ and y_t are stationary and ergodic, there is a unique set of parameters θ_0 with which these two vectors of time series have identical conditional stationary distributions. Accordingly, if we choose a particular density function, corresponding to which an 'auxiliary model' f is then chosen, the conditional density functions can be shown identically:

$$f[x_t(\theta_0), \alpha_S] = f[y_t, \alpha_T]$$

[1] More discussion on the advantages over the GMM estimation in the cases of missing data and unobserved shocks can be found in Canova (2005).

where α_S and α_T are parameter vectors of the auxiliary model (the auxiliary parameter vectors/sets) corresponding to simulated data $x_t(\theta_0)$ and actual data y_t, respectively.

α_S and α_T can then be estimated using Maximum likelihood estimation (MLE):

$$\hat{\alpha}_S(\theta) \equiv \arg\max_{\alpha\in\Theta} L_S[x_t(\theta);\alpha_S]$$

$$\hat{\alpha}_T \equiv \arg\max_{\alpha\in\Theta} = L_T[y_t;\alpha_T]$$

Define an $n\times 1$ vector of function $g(\hat{\alpha}_T)$ and $g(\hat{\alpha}_S(\theta))$, which are the measurements we use to compare the distance between the auxiliary parameters obtained from actual data and the auxiliary parameters obtained from simulated data[2]. And let $G_T(\hat{\alpha}_T) = \frac{1}{T}\sum_{t=1}^{T} g(\hat{\alpha}_T)$ and $G_S[\hat{\alpha}_S(\theta)] = \frac{1}{S}\sum_{s=1}^{S} g[\hat{\alpha}_S(\theta)]$. Hence, EMSM estimator θ_0 can be achieved by minimising the distance between $\hat{\alpha}_S$ and $\hat{\alpha}_T$, which can be measured by $\{G_T(\hat{\alpha}_T) - G_S[\hat{\alpha}_S(\theta)]\}$:

$$\tilde{\theta}_0 \equiv \arg\min \{G_T(\hat{\alpha}_T) - G_S[\hat{\alpha}_S(\theta)]\}' W_T \{G_T(\hat{\alpha}_T) - G_S[\hat{\alpha}_S(\theta)]\}$$

where W_T is an $n \times n$ positive definite 'weighting' matrix.

3.1.2 Indirect Inference for Model Evaluation

The method that is used to evaluate models comes from the same root as indirect inference estimation, but differs in the sense that it is taking indirect inference from the aspect of appraising how well the calibrated model can replicate actual data, or how close actual data are to the simulated data. That is, instead of finding a parameter set that enables the structural model to simulate data closer to actual observations, the indirect inference model evaluation takes the structural

[2]Note that, this vector of function $g(\cdot)$ can be any functional forms that is focused in a research, such as the moments, the impulse response functions, the autocorrelations or the coefficients produced by the auxiliary model, as long as the function is continuous and the parameters are identifiable. (See Canova (2005) for more discussion of the problems in identifying parameters)

model parameter θ as given, either calibrated in previous studies or estimated from other estimation methods, and simulates a certain number of sets of data.

Given the stationary and ergodic assumptions of actual and simulated data, the auxiliary parameter set derived from simulated data and the auxiliary parameter set derived from actual data are of the same distribution. Therefore, the Wald Statistic (WS) and the Mahalanobis Distance (MD) are both suitable in assessing the distance between these two sets of parameters.

The hypothesis of indirect inference model evaluation is that if the structural model is correctly specified, the set of parameters obtained from auxiliary model f based on the model-simulated data should not significantly differ from those obtained from auxiliary model f based on actual data. Put differently, the Wald statistic or the Mahalanobis distance used to measure the distance between parameter sets can also be interpreted as a numerical indication of the models' performance, as they both give statistical measurements of the closeness between the data replicated from the structural model and actual data.

To test the performance of a particular macroeconomic model, the specific set of model parameters $\bar{\theta}$ is taken as calibrated or partially estimated by other methods. Vector-bootstrapping of exogenous model innovations are carried out in order to replicate the exogenous shock profile over the sample period. For each vector-bootstrapped sample, one dataset is simulated from the structural model, and so is an auxiliary parameter set $\hat{\alpha}_{S,n}\left(\bar{\theta}\right)$, where $n = 1, \ldots, N$ is the total number of bootstraps. The bootstrapped mean of the matching function can be defined as $G_S\left[\hat{\alpha}_S\left(\bar{\theta}\right)\right] = \frac{1}{N}\sum_{n=1}^{N} g\left[\hat{\alpha}_{S,n}\left(\bar{\theta}\right)\right]$. Meanwhile, $G_T\left(\hat{\alpha}_T\right) = g\left(\hat{\alpha}_T\right)$ is obtained by applying the auxiliary model to actual data. The Wald statistic, which is the square of the Mahalanobis distance, can be presented as:

$$WS = \left\{G_T\left(\hat{\alpha}_T\right) - G_S\left[\hat{\alpha}_S\left(\bar{\theta}\right)\right]\right\}' W\left(\bar{\theta}\right)\left\{G_T\left(\hat{\alpha}_T\right) - G_S\left[\hat{\alpha}_S\left(\bar{\theta}\right)\right]\right\}$$

The following section explains in steps how the Wald test is implemented using the vector-bootstrapped exogenous innovations of the structural model and the chosen auxiliary model.

- Step 1: Derive structural errors and estimate exogenous innovations using the observed data and $\bar{\theta}$.

Derive structural errors ε_t^i, where $i = US, EA$, from the structural model given observed data and the structural parameter set $\bar{\theta}$. For equations not involving expectations, errors are derived simply by solving the error terms from equations. For those with expectations, the expectation terms are first derived using the instrumental variable procedure, followed by solving the error term as normal. The distributions of the structural error are not necessarily assumed to be normal. But given the assumption that effects of the omitted variables are all reflected in these structural errors, empirical distributions of the structural error can then be given by the structural error we derived. In most cases, structural errors are assumed to be autoregressive processes, including the SW's models that are being tested in this paper. Based on the assumption we have made about the specification of structural errors, exogenous innovations can then be derived as residuals from either $AR(1)$ or $ARMA(1,1)$ regressions.

- Step 2: Simulate data using the structural model and bootstrapped exogenous innovations

To generate N sets of simulated data, N sets of vector-bootstrapped exogenous innovations need to be drawn following the procedures described in step 1. In order to preserve correlations among exogenous innovation, this thesis adopts the vector-bootstrapping method, rather than the bootstrapping of individual exogenous innovation. In vector-bootstrapping, because it is the time line that is being bootstrapped, exogenous innovations are kept in line with each other at each time period; thus, the empirical distributions of each shock are preserved. The model with the given structural parameters is solved and represented as a $VAR(1)$ using Dynare. And hence, N sets of simulated data are synthesised by combining the $VAR(1)$ representation of the structural model, a set of initial values, and N sets of vector-bootstrapped exogenous innovations.

- Step 3: Estimate using the auxiliary model and calculate Wald statistics and normalised Mahalanobis distances

Auxiliary parameters that reflect data's dynamic properties, are estimated by applying the auxiliary model, $VAR(1)$, to a dataset. That is, the auxiliary parameters obtained from actual data $\hat{\alpha}_T$ can be estimated by applying $VAR(1)$ to a set of actual data. The auxiliary parameters obtained from simulated data $\hat{\alpha}_S$ can be estimated by applying $VAR(1)$ to a set of simulated data.

Alternative auxiliary parameters, such as the moment conditions of time series, are also considered in this study. More specifically, for analysing data's volatility property, variances of the selected time series are also included in the auxiliary parameter vectors $\hat{\alpha}_T$ and $\hat{\alpha}_S$.

As discussed earlier, the objective function $g(\cdot)$, whose distance is being minimised, can vary. In this study, the comparison is based on the $VAR(1)$ coefficients and variances of time series that represent properties of either actual data or simulated data. That is, $g(\hat{\alpha}_T) = \hat{\alpha}_T$, $g\left[\hat{\alpha}_S\left(\bar{\theta}\right)\right] = \hat{\alpha}_S\left(\bar{\theta}\right)$, where $\bar{\alpha}_S\left(\bar{\theta}\right) = \frac{1}{N}\sum_{n=1}^{N}\hat{\alpha}_{S,n}\left(\bar{\theta}\right)$ is the mean of N auxiliary parameter sets derived from N simulated datasets.

Hence, the distance between the auxiliary parameter vector of actual data and the auxiliary parameter vector of simulated data (the mean) is

$$G_T(\hat{\alpha}_T) - G_S\left[\hat{\alpha}_S\left(\bar{\theta}\right)\right] = \hat{\alpha}_T - \bar{\alpha}_S\left(\bar{\theta}\right).$$

Furthermore, the optimal weighting matrix $W\left(\bar{\theta}\right)$ is taken as the inverse of the covariance matrix estimated directly from simulated data, which can be shown as:

$$W\left(\bar{\theta}\right)^{-1} = \frac{1}{N}\sum_{k=1}^{N}\left(\hat{\alpha}_k - \bar{\alpha}_k\right)'\left(\hat{\alpha}_k - \bar{\alpha}_k\right) \tag{3.1}$$

where $\bar{\alpha}_k = \frac{1}{N}\sum_{k=1}^{N}\hat{\alpha}_k$ is the mean of the coefficients across all simulated samples.

For a particular coefficient $a \in \hat{\alpha}_S$, a collection of the value a_k (where $k = 1, \ldots, N$) reflects the sampling variation by the structural model with regard to this particular coefficient. Hence, the vector of coefficient $\hat{\alpha}_k$ $(k = 1, \ldots, N)$ represents the sampling variation across all coefficients by the structural model.

Hence, the actual Wald statistic measuring the distance between actual data and the mean of simulated data is calculated as

$$WS_T = \left[\hat{\alpha}_T - \bar{\alpha}_S\left(\bar{\theta}\right)\right]' W\left(\bar{\theta}\right)\left[\hat{\alpha}_T - \bar{\alpha}_S\left(\bar{\theta}\right)\right] \tag{3.2}$$

Accordingly, the corresponding Mahalanobis Distance is written as

$$MD_T = \sqrt{[\hat{\alpha}_T - \bar{\alpha}_S(\bar{\theta})]'W(\bar{\theta})[\hat{\alpha}_T - \bar{\alpha}_S(\bar{\theta})]} \tag{3.3}$$

Similarly, the Wald statistic measuring the distance between one bootstrap-simulated dataset and the mean of simulated data is

$$WS_{S,n} = [\hat{\alpha}_{S,n} - \bar{\alpha}_S(\bar{\theta})]'W(\bar{\theta})[\hat{\alpha}_{S,n} - \bar{\alpha}_S(\bar{\theta})], \tag{3.4}$$

where $n = 1, \ldots, N$. And the corresponding Mahalanobis Distance is:

$$MD_{S,n} = \sqrt{[\hat{\alpha}_{S,n} - \bar{\alpha}_S(\bar{\theta})]'W(\bar{\theta})[\hat{\alpha}_{S,n} - \bar{\alpha}_S(\bar{\theta})]} \tag{3.5}$$

A Wald statistic percentile measured by $P\left(WS_S < WS_T\right)$ is shown to indicate the probability that a model is not rejected by indirect inference:

$$Wald\ Percentile = \frac{number\ of\ WS_S\ \ less\ than\ WS_T}{total\ number\ of\ WS_S} \tag{3.6}$$

Additionally, for a better representation of the closeness between actual data and the simulated mean, a normalised Mahalanobis Distance (normalised MD) is computed alongside the Wald statistic percentile. The Wald statistic, which is the square of the Mahalanobis distance, follows a χ^2 distribution. As the degree of freedom gets large, it can be approximately normalised to have unit variance

(Fisher ,1928)[3]. Hence, the normalised MD is presented as

$$normalised\ MD = \frac{\sqrt{2MD_T^2} - \sqrt{2n-1}}{\sqrt{2MD_{S,95\%}^2} - \sqrt{2n-1}} \times 1.645 \tag{3.7}$$

where $MD_{S,95\%}$ is the value of the Mahalanobis distance corresponding to the 95% tail in the simulated distribution of MD_S; n is the degree of freedom. This presentation ensures the normalised MD is 1.645 when MD_T coincides with the 95% critical value of the simulated distribution.

3.2 Two-country Model of the US and the EA

The purpose of this study is to find out whether there is significant evidence of monetary policy coordination between the US and the EA, two large economic blocs in the world. Our benchmark non-coordination model is a US-EA two-country model adopted from Le et al. (2010)[4]. They constructed the model by putting two individual models of the EU (SW, 2003) and the US (SW, 2007) together, leaving out the Rest of the World (ROW). By doing this, fluctuations of key macroeconomic factors from the ROW form part of the 'shocks' to the US and EA economies. For instance, exports to the ROW enter the residual term in the US market clearing equation; and hence are explained as a demand shock from the ROW to the US economy. Thus it is expected that the correlation between shocks is amplified due to the fact that a quarter of the world economy is missing in the model. While this leaves room for the further completion and

[3] Fisher ,1928 stated that given large degrees of freedom, a χ^2 distribution can be transformed into a standard normal distribution using the expression $\sqrt{2\chi^2} - \sqrt{2n-1}$. Wilson and Hilferty (1931) also showed that $\sqrt[3]{\frac{\chi^2}{n}}$ is normally distributed with mean $1 - \frac{2}{9n}$ and variance $\frac{2}{9n}$.

The formation being used in this paper follows Fisher's expression. In some cases where Wilson and Hilferty's expression is used, they would be indicated by 'WH'.

[4] Note that, SW (2003), Meenagh et al. (2009) and Le et al. (2010) all named the European counterpart as the EU model, although the data they used were the Euro Area aggregates. This study will continue to use 'EU' when referring to their models. However, the model used in this study will be referred to a US-EA two-country model for distinguishing from the EU 27-country aggregate.

improvement of the model, it does simplify the problem – we are finding evidence that is consistent with the existence of monetary coordination between these two economic blocs.

3.2.1 Smets and Wouters' EU and US models

SW's EU and US DSGE models are applications of the Real Business Cycle (RBC) model with a twist of the 'New Keynesian' literature. Households maximise an intertemporal utility function with separable consumption, labour, and real money balance[5]. Also, they act as labour suppliers in the market with a certain degree of monopoly power. Finally, for deciding the level of investments they maximise an intertemporal objective function by choosing the level of investments and maintaining a certain level of capital stock. On the producer side, each economy has a perfectly competitive final good sector and an intermediate good market with a continuum of intermediate good producers competing monopolistically. The aggregate price is then determined by the cost minimisation in the final good sector; meanwhile, the law of motion of prices is then given by the cost minimisation in the intermediate good market.

Some additional elements provide the model with 'New Keynesian' features. The use of Calvo-style sticky nominal prices and wages implies that households, which are acting as the labour supplier, can re-optimise the nominal wage once a 'wage changing signal' is released to them from the market. In such a way, nominal wages are set in a forward-looking manner, taking account of the probability of not being able to re-optimise nominal wages in accordance with fundamental changes for some periods. Otherwise, they adjust the nominal wage according to the past inflation following a partial indexation rule, with which more backward-looking dynamics is brought into the wage setting strategy. On the production side, the intermediate goods producers behave similarly, and hence the price mark-up varies over time with exogenous shocks from the economy. Also, the

[5] The real money balance is not analysed in this study, therefore it is left out in the model specification and is not mentioned again in the paper.

cost of the capital adjustment is more dynamic as it is positively correlated to the changes in the investment, rather than to the investment level. Furthermore, the external habit formation smooths consumptions dynamically to be consistent with empirical findings of consumption persistency. Finally, the model is closed by a flexible inflation-targeting monetary policy rule specified to let the interest rate respond to current or past inflation deviations from a set inflation objective. A certain degree of interest rate smoothing and current output gap is also taken into account in the policy rule.

The SW's EU (2003) model consists of ten structural shocks – two supply shocks (a productivity shock and a labour supply shock), three demand shocks (a preference shock, an investment shock and an exogenous government spending shock), three cost-pushing shocks (a price mark-up shock, a wage mark-up shock and a capital risk premium shock) and two monetary policy shocks (a shock to the inflation objective and a shock to the nominal interest rate).

The structural parameters were then estimated using Bayesian estimation on seven quarterly time series ranging from 1980Q2 to 1999Q4. They formed the prior information from micro- or macro-econometric studies for preserving the 'explicit link with the previous calibration-based literature'. All exogenous innovation variances and coefficients representing the dynamics of structural errors were also estimated given their own priors. Furthermore, performances of the DSGE model to a non-theoretical VAR by marginal likelihood and cross-covariance were compared. The impulse response and the variance decomposition were then used to identify the main shocks that drive volatility in the Euro Area.

The Bayesian estimators appeared to be reasonable and significant. High degrees of price and wage stickiness were required by the model specification for generating enough data persistency. The model seemed to be able to capture key features of the EA macroeconomic figures, but only when there were enough structural shocks for capturing the stochastics. It was not fitting the data cross-variance well, as it produced large cross-covariance error bands. Overall, persistent monetary policy shocks had a small output effect, but no liquidity effect consistent with the argument in Galí (2002).

In SW's US (2007) model, the number of structural shocks was reduced to seven – a total factor productivity shock, a risk premium shock, an investment-specific technology shock, a wage mark-up shock, a price mark-up shock, an exogenous government spending shock and a monetary policy shock. Instead of detrending data before the estimation, a deterministic growth rate driven by the labour-augmenting technology was specified in the model. Furthermore, the US model replaced the Dixit-Stiglitz aggregator in the intermediate good market and the labour market by a more general aggregator developed in Kimball (1995). The structural parameters were then estimated over a period from 1966Q1 to 2004Q4 using the Bayesian method. The performance of the out-of-sample forecast was improved relative to the VAR and $BVAR$ models, which made this micro-founded DSGE model more suitable for the policy analysis. The model also required both Calvo sticky price and wage frictions to be high; while partial-indexations were not necessary in generating the model dynamics. Regarding real frictions, it was costly to cut down the elasticity of adjustment costs and the habit formation; while the variable capital utilization was found to play a trivial role. Moreover, the overall impact from a monetary shock on the output and inflation volatility was small, apart from the recession and the following disinflation period from the 1970s to early 1980s.

3.2.2 Indirect Inference Testing on SW's EU and US models

As early experiments that implemented model evaluations using indirect inference, Meenagh et al. (2009) and Le et al. (2011) evaluated SW's EU and US model individually. In Meenagh et al. (2009), the SW's EU model was tested over the sample period of 1970 to 1999 (quarterly) on five main observables: inflation, interest rate, output, investment and consumption. The test focused on the model's dynamic features, that is, only 25 $VAR(1)$ coefficients, but no data variances, were taken for computing Wald statistics. Moreover, apart from the original version of the SW New Keynesian model (SWNK), a version of the New Classical model (SWNC) was also taken into consideration.

They found that both models performed reasonably well as long as proper error properties were chosen. When using the scaled down actual disturbances, both models generated excessive variances but far fewer autocorrelations compared with actual data, although the actual source of the models' poor performances differed. The NK model was mainly driven by demand shocks that limited nominal variations reasonably well, but were not persistent enough to generate the data's dynamics. On the contrary, the NC model was mainly driven by supply shocks that transferred too much volatility into nominal variables such as inflation and the nominal interest rate. Further study devoted to finding the optimal combination of SWNK and SWNC models showed a small share of New Keynesian behaviour in the economy: 8% in the labour market, 6% in the goods market and 4% in the monetary policy rule. In general, the contradictory results between using Bayesian estimated errors and model-derived actual errors, as well as the relative success of the mixed model, called for further work on the model specification.

Le et al. (2011) provided an indirect inference model evaluation on SW's US model over the post-war period of 1947Q1-2004Q4 with more detailed robustness checks. Various detrending methods were used to test the impact of these methods on the testing result. The findings confirmed that the choice of detrending methods did not create significant divergence, and thus linear-detrending was used for keeping filtered information at least. Both the New Classical (SWNC) and the New Keynesian (SWNK) versions of the SW models were tested, but results were discouraging. Again, corresponding to the findings in Meenagh et al. (2009), a hybrid model, a weighted combination of the SWNC model and the SWNK model, was then tested based on the discussion that the NK model failed to deliver enough nominal variations while the NC model did the opposite.

They found that optimal weights for the NK model are 0.1 in the wage setting equation and 0.2 in the price setting equation. The US market showed stronger stickiness than the EU market, but in general, the overall evidence indicated that markets behave predominantly in a New Classical way. Although the hybrid model was 100% rejected by full Wald statistics (for both dynamics and volatility), the same as the SWNC and SWNK were, the normalised MD indicated a substantial improvement in the model's capability of replicating data dynamics. The result, however, favoured the high degree of nominal rigidity in a way discussed earlier that limited nominal variations in the NK model, which helped to fit in with the 'Great Moderation' quite well.

3.2.3 US-EU Two-Country DSGE Model

Based on the previous testing on two individual models, Le et al. (2010) presented a two-country model and performed the indirect inference model evaluation on the two-country model. The model linked the US and the EU regions using trade and the exchange rates while exogenising ROW's economic activities. Hence, statistically one quarter of the World GDP was left unconstructed, and ROW's economic fluctuations were treated exogenously as part of the error term in the structural model. A summary of factors that combine two individual models into one is presented below.

First, households from both economies are able to choose their consumption bundles over home and foreign goods according to the relative price. By allowing arbitrage, the real exchange rate reflects the same home-to-foreign good price in each country. An identical CES (constant elasticity of substitution) function for consumption, which consists of home and foreign goods from each economy, takes the form of an Armington (1969) aggregator

$$C_t = \left[\omega \left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t \left(C_t^f\right)^{-\rho}\right]^{\left(-\frac{1}{\rho}\right)} \tag{3.8}$$

where C_t^d and C_t^f are the domestic consumption of home and foreign goods, respectively; ω and $(1-\omega)$ are weights of home and foreign goods in the consumption composite; the elasticity of substitution between home and foreign goods is $\sigma = \frac{1}{1+\rho}$; and ς_t is the preference error. The households therefore maximise the consumption composite with respect to choices of home goods (C_t^d) and foreign goods (C_t^f), given that the total expenditure on consumption ($\tilde{C}_t$) has been chosen over the trade-off between consumption and leisure. Define P_t^d as the domestic good price in the domestic market, P_t^f as the foreign good price in the domestic market, and P_t as the general price level in the domestic market; the total amount of goods consumed by an economic agent can be represented by $\tilde{C}_t = \frac{P_t^d}{P_t} C_t^d + \frac{P_t^f}{P_t} C_t^f$, which can also be expressed as

$$\tilde{C}_t = p_t^d C_t^d + q_t C_t^f \tag{3.9}$$

where $p_t^d = \frac{P_t^d}{P_t}$ is the relative price of domestic goods to the general price level; and $q_t = \frac{P_t^f}{P_t}$ is the relative price of foreign goods in the home currency to the general price level. The maximisation expresses the home demand for home goods and foreign goods as equation 3.10 and 3.11

$$\frac{C_t^d}{C_t} = \omega^\sigma \left(p_t^d\right)^{-\sigma} \tag{3.10}$$

$$\frac{C_t^f}{C_t} = \left[(1-\omega)\,\varsigma_t\right]^\sigma q_t^{-\sigma} \tag{3.11}$$

Hence, the consumption budget can be represented as:

$$1 = \omega^\sigma \left(p_t^d\right)^{\sigma\rho} + \left[(1-\omega)\,\varsigma_t\right]^\sigma q_t^{\sigma\rho} \tag{3.12}$$

A logarithmic approximation of the consumption budget is

$$\log p_t^d = -\left(\frac{1-\omega}{\omega}\right)^\sigma \log\left(q_t\right) - \frac{1}{\rho}\left(\frac{1-\omega}{\omega}\right)^\sigma \log \varsigma_t + const \tag{3.13}$$

Second, the existence of the foreign bonds market gives the Uncovered Interest

Parity (UIP)

$$r_t + E_t \ln \varepsilon_{t+1} - \ln \varepsilon_t = r_{ft} \tag{3.14}$$

Subtracting the expected inflation, we obtain the uncovered interest parity in real terms. That is, the differential between home and foreign real interest rates reflects the expected change in the real exchange rate.

$$rr_t + E_t \ln Q_{t+1} - \ln Q_t = rr_{ft} \tag{3.15}$$

where rr_t and rr_{ft} are the real interest rates in the domestic and foreign economies, respectively.

The linearised model was tested using indirect inference over a period of 1975Q1 to 1999Q2. A $VAR(1)$ in eight variables, including output, inflation and interest rate from each region, real exchange rate, and US-EU trade balance, was formed as an auxiliary model representing key macroeconomic behaviour of the open economy. As noted that neither the SWNK model nor the SWNC model performed well in previous studies, the test on the two-country model focused on the weighted model combining both the NK and the NC features in the price setting equation, the labour supply equation and the monetary policy rule in each region. The weights of New-Keynesian behaviour in the price-setting, the labour supply and the monetary policy were 0.2, 0.1 and 0 for the US and 0.06, 0.08 and 0.04 for the EU, respectively. The complete model is shown in Appendix B[6].

The weighted model showed better performance of matching data variances. Although it was fully rejected by Wald test statistics (including the data dynamics and volatility), the average t-test Wald statistic (the normalised MD) indicated substantial closeness of model-simulated data to actual data. The supply shocks, especially the productivity shock and the labour supply shock were the main resource for macroeconomic variations. It is worth noting that the EU economy, especially EU inflation, was much more sensitive to monetary shocks; on the

[6] The price setting equation, the labour supply equation and the monetary policy rule are shown in a New-Keynesian style.

contrary, monetary shocks only had trivial impacts on the US output and interest rate, and slightly more impact on inflation. It was due to the fact that elasticities of the interest rate in the EA monetary policy rule declined largely under the NC setting, which was the dominant behaviour in the weighted model. The influences on the interest rate were not as diversified as the original SW's EU model; hence, monetary shocks stood out as a major contributor to variations in the interest rate and inflation.

Surprisingly, the model showed few cross-country interaction, that is, domestic shocks mostly only affected the domestic economy in a similar way to a closed economy. The supply shock, particularly in the US, contributed predominately to variations in the real exchange rate and the trade balance. But clearly, in each of the economies, the transmission of fluctuations in the real exchange rate and the trade balance to other macro-variables was not bi-directional as we thought it would be. A negative supply shock in the US economy causes a real appreciation in the US dollar, represented as a real exchange rate increase; and thus, the EA trade balance is positively affected, mainly by a foreign demand shock. It was noted that the economy predominantly behaves in a NC style, and demand shocks have little influence; therefore, this foreign demand shock may be absorbed by changes in the consumption composite, but not transmitted into fluctuations in the EA output, inflation or interest rate.

Chapter 4

Testing the US-EA Two-Country DSGE Model Using Indirect Inference - Does Monetary Policy Coordination Matter?

4.1 Introduction

Issues in monetary policy coordination have always been revisited, as globalisation has deeply planted the thought of interaction between economies in our mind. The existence of macroeconomic interdependence undoubtedly requires policymakers to take other economies' policy actions into account when they design domestic macroeconomic policies. It is intuitive to think that the decentralised and independent policymakers will not internalise their policy externalities; thus, macroeconomic policy coordination may be welfare-improving in terms of its ability to internalise policy externalities and to achieve joint welfare-improvement. The majority of the literature focuses on welfare changes from a non-cooperative (non-coordinated) to a cooperative (coordinated) world, yet neither theoretical nor empirical studies since the 1970s have given a definitive answer.

On the other hand, the existence of monetary coordination is difficult to identify since it is more likely to be embedded in the CBs' actions or monetary policy rules implicitly. After all, even without an explicit agreement, policymakers will inevitably engage in some sort of 'strategic game' willingly or unwillingly. This study would like to test its existence by comparing the performance the models with and without monetary coordination based on a well-developed, two-country DSGE model of the United States (US) and the Euro Area (EA). The monetary policy coordination, referring to the interdependence between economies, is represented by direct responses of the monetary instrument to real exchange rate fluctuations. The null hypothesis of monetary coordination existence holds when the model's performance is significantly improved by the presence of the monetary instrument's direct responses to the real exchange rate.

In an increasingly interdependent world, countries unavoidably respond to each other's situations in a variety of ways – through macroeconomic policies, trade policies and even retaliatory policies in response to hostile actions by their counterparties. Monetary authorities, a focus in this study, reveal themselves through their responses to exchange rate fluctuations[1]. The change in the real exchange rate, which measures movements in the international relative price and competitiveness, is a reflection of relative fundamental changes in economies. In spite of the noise that may be contained in exchange rate volatility, a response of monetary policies to the exchange rate signals a CB's concern regarding the potential spillover from its counterparties.

Indeed, a monetary policy action can be the result of a CB's optimal cooperative strategies as well as be due to some self-interest-oriented thoughts. However, the spectrum of these underlying reasons has yet to be clearly identified. Therefore, instead of those inseparables, the focus of this study is to look for the evidence of economic interdependence, which involves both types of actions, and

[1] CBs might respond to the exchange rate in different manners. Some might have implicit concerns on exchange rate variations, while others might target the exchange rate explicitly and even fix the exchange rate in extreme cases.

its impacts on the behaviour of the world economy. The fact that purely self-oriented actions inevitably affect foreign economic counterparts has potential in limiting self-oriented actions, and thus ensuring strategic cooperation. Monetary policy coordination, therefore, is broadly defined in a way that was described in Cooper (1969); nevertheless, the possibility of self-interest oriented actions cannot completely rule out.

The two-country DSGE framework is built on the basis of the well-known papers by Smets and Wouters (hereafter SW, 2003, 2007), in which individual models of the US and the EA are suggested to be plausible in fitting certain features of macroeconomic variables. Despite the great advances of DSGE models, especially the role it has gained in CB policy analyses, its questionable empirical validation has been largely undermining studies adopting the DSGE framework. In particular, it is argued that DSGE models should not be tested against their forecasting abilities due to various difficulties that can bias the statistical test towards rejecting the DSGE model[2]. Furthermore, a subsequent study by Le, Meenagh, Minford, and Wickens (hereafter Le et al., 2010) suggested that economies act orthogonally to each other when there are only goods market and financial market links. This study intends to build up macroeconomic interdependence by allowing monetary policy coordination, and to evaluate DSGE models' performance through their ability to replicate actual data properties drawn by an auxiliary model, rather than through forecasting ability as with the Likelihood Ratio (LR).

The method used for evaluating DSGE models is drawn from the method of indirect inference; instead of estimation, it is used as an approach to draw the classical statistical inference out of a calibrated or an estimated model, while maintaining key features of actual data. To extract information from actual

[2] For example, Wickens (2012) suggested that the 'DSGE model should not be tested through their forecasting ability', since forward-looking dynamics that are difficult to forecast might result in over-rejection of the model. Edge and Gurkaynak (2010) also argued that 'forecasting ability during the Great Moderation is not a good metric by which to judge models due to the nature of macroeconomic fluctuations that make certain macro-variables unforecastable.

data, shocks are derived from a structural model given structural parameters and 17 macroeconomic time series. They are then vector-bootstrapped ensuring that correlations between shocks are preserved. Indicating the distance between model-simulated data and actual data, Wald statistics are computed on the basis of auxiliary parameters ($VAR\,(1)$ is chosen as an auxiliary model) from actual and model-simulated data. For overall evaluation of the models' ability to replicate data dynamics and volatility, VAR coefficients and simulated variances are both included in computing Wald statistics, while evaluations can also be carried out to separately account for dynamics or volatility. In addition, the corresponding normalised Mahalanobis Distance (normalised MD) is shown to give a clear view on the overall closeness between actual and model-simulated data.

In general, coordination models outperform the baseline non-coordination model across a large number of variable combinations[3], mainly as a result of the higher prediction precision as well as the lower prediction uncertainty generated from coordination models. The EA's coordinating policy plays a crucial role in cutting down volatility across both economies in spite of the trade-offs between degrees of coordination. On the contrary, sole US coordination has no obvious benefit, but might become one of the causes of high exchange rate volatility. It is also found that model performance deteriorates heavily once the real exchange rate is included, regardless of the presence of monetary coordination. On the other hand, inclusion of the real exchange rate sharply widens the performance gap between coordination and non-coordination models, which implies that the representation of the exchange rate is essential in improving DSGE model performance.

Moreover, the international transmission mechanism of shocks is enhanced by the additional exchange rate channel. In particular, the US productivity shock, price mark-up shock, and government spending shock become largely influential to the EA economy. Engaging in monetary coordination can be beneficial domestically and internationally, as it speeds up policy impacts on aggregate

[3] In total, there are 38 variable combinations drawn from 7 key macroeconomic variables.

targets, such as inflation and output, as well as accommodates shocks and stabilises economies through policy adjustment feedback reflected in the exchange rate. However, the coordinating economy is also more likely to encounter global fluctuations, especially when its counterparties have no intention to demonstrate policy coordination. On the other hand, an economy with no coordination might be able to isolate itself from foreign shocks while benefit from the fact that the coordinative actions taken by the coordinating economy tend to lower real exchange rate volatility and act as a stabiliser to some domestic shocks.

4.2 Models in Practice

As discussed previously, the two-country model showed rather weak economic interdependence in terms of its trivial responses of one economy to the shock or the policy change in another economy. Presumably, given all aspects of globalisation and the extensive empirical evidence on business cycle comovements, this models' prediction on the correlation between key macroeconomic variables might not be robust. In the statistical practice, a weak cross-country spillover potentially compromises a model's performance and may become one of the explanations leading to the rejection of a model. After all, in order to embrace actual data parameters, the benchmark model needs to produce really large simulated $VAR(1)$ coefficient bounds. It, therefore, will be interesting to see whether monetary coordination can enhance spillovers and improve a model's performance in terms of both model dynamics and volatility.

4.2.1 Monetary Policy Rules

Taylor (1993a) proposed a simple interest rate rule shown to describe the FFR well for most of the period from the 1980s to early 1990s:

$$r_t = \pi_t + 0.5y_t + 0.5\left(\pi_t - 2\right) + 2 \tag{4.1}$$

where r_t is the FFR; π_t is the rate of inflation over the previous four quarters; y_t is the percent deviation of real GDP from trend real GDP. It is subsequently adopted in much of the literature as a 'rule of thumb' of monetary policy – the short-term nominal interest rate systematically responds to real economic activities and inflation.

Extensions of the Taylor rule include adding policy inertia (interest rate smoothing), adding lead and lag terms of inflation and output, or adding the short-term deviation represented by a first order differential of inflation or output. Some empirical estimations suggested that the Taylor rule generally represented CBs' policy, particularly in industrialised economies. Such a conclusion stems from the observation that interest rates approximately follow a Taylor rule.

Nevertheless, as pointed out by Srinivasan et al. (2002)[4], there is an 'observational equivalence' between a Taylor rule and 'Taylor-type' rules. Other economic relations can potentially resemble the statistical relevance of interest rates, inflation, and the output gap. For example, a money supply rule could 'give rise to interest rate behavior that looks like a Taylor rule' (Minford et al. , 2002). More recently, Minford and Ou (2013) showed that the DSGE model with an optimal timeless rule[5] could reproduce the data that resembles a Taylor rule.

That is to say, a Taylor rule cannot distinguish itself from other policy regimes in terms of the observed interest rate behaviour; and one cannot identify a CB's policy by simply estimating a single-equation Taylor rule. In practice, although the representations of the interest rate behaviour remain similar, the underlying monetary policy regimes are different, and so are economic agents' behaviours – it is made clear by Lucas (1976) that the structure of econometric models is altered as the policy changes. Since the early 1970s, both the US and EA have undergone a series of changes in the way that the monetary policy is implemented[6]. In

[4] A modified version of this paper is published in Economics Letters (Minford et al. , 2002).

[5] The optimal timeless rule is derived by minimising the social welfare loss function. It specifies an implicit instrument rule that achieves the trade-off conditional $\pi_t = -\frac{\alpha}{\gamma}(x_t - x_{t-1})$.

[6] For example, the US Federal Open Market Committee (FOMC) mainly targeted the price of bank reserves (Federal Funds Target Rate) before 1979. Between 1979 and 1982, the FOMC targeted the quantity of money (non-borrowed reserves) in order to control inflation. In late

particular, the recent financial and banking crises have led to variations in the approach to monetary policy. Put differently, using a Taylor rule to summarise the US or the EA monetary policy since the 1970s can potentially victimise the associated analyses by the identification problem or structural changes.

Despite the aforementioned arguments, the use of an extended Taylor rule as the monetary policy rule can be justified as follows:

First, this study focuses on finding out whether the CBs of the US and EA directly respond to the real exchange rate, rather than uncovering their exact monetary policy rules. The Taylor rule, treated as a semi-reduced form of the policy actions, unveils the macroeconomic interdependence and its associated policy actions at both the domestic and international levels. From a partial perspective, the Taylor rule simplifies the analysis and enables the focus to be on the role of the real exchange rate in monetary policy.

Second, DSGE models are built on microeconomic foundations specifying the technology, resource constraints, and economic agents' preferences; the parameters of a DSGE model are structural. In principle, it is possible to analyse the evolution of macro-aggregates in response to various shocks and policy changes using a DSGE model. In other words, the DSGE model, in principle, should not be subject to the Lucas critique.

4.2.2 Monetary Coordination

Monetary coordination refers to how an economy coordinates its monetary policy, implicitly or explicitly, with another economy in terms of the real exchange rate. Changes in economic fundamentals and policies in one country can cause potential spillovers for its foreign counterparties, particularly when cross-country interdependence is growing markedly. Monetary authorities inevitably encounter situations where monetary policies are needed to counteract such cross-country

---

1982, the FOMC shifted back to target the price of money, while there was also some focus on the broader monetary aggregate (M2). In the EA, the largest change is the adoption of the euro and the transition from individual national central banks to a centralised monetary authority (the ECB).

impacts. Beyond its appearance, the design of a domestic monetary policy in an open economy is far more complicated than that within a closed economy context, as it is also subject to the feedback impacts from foreign counterparties.

Monetary interdependence and its corresponding monetary coordination from monetary authorities, though sophisticated, can be revealed through the policy response to the real exchange rate. As a measure of the international relative price and competitiveness, the real exchange rate unveils relative changes in economic fundamentals and policy stances between two economies. As a consequence, a monetary instrument is responding to fundamental and policy changes in the foreign economy as long as reactions to the exchange rate are included in its rule under the floating exchange rate regime; or as long as the nominal exchange rate is aimed to be fixed (the fixed exchange rate regime). In either case, a monetary policy can be considered to be game-strategically coordinating in response to the economic interdependence.

For instance, under the floating exchange rate regime, shocks and policy changes in one economy will be transferred immediately into real exchange rate variations. Under the complete pass-through, the real exchange rate moves side by side with TOT (Equation 2.5); and with the complete risk sharing, the real exchange rate is determined purely by the cross-country demand differential and preference shocks (Equation 2.7).

When the completeness of exchange rate pass-through is violated, a wedge is created between the real exchange rate and the TOT movement – the real exchange rate contains information on the relative import to export price as well as possible price misalignments – expenditure switching effects are distorted. On the other hand, with completeness of the international financial market being violated, a wedge is created between the real exchange rate and the cross-country demand differential – the real exchange rate contains information of the cross-country differential for both production and consumption as well as the cross-country demand misalignment – and allocative efficiency of the exchange rate is distorted. Consequently, a monetary policy that includes responses to the real exchange rate ensures the monetary instrument responds to fluctuations and policy changes in the other economy, that is, monetary authorities are coordinating strategically.

Under a fixed-exchange-rate regime, where one country (follower country) aims to fix its nominal exchange rate against another country's (leader country) currency, the follower's monetary policy is also said to be 'cooperative' to the leader's monetary policy. In essence, a pegged-exchange-rate regime is a form of asymmetric monetary policy cooperation.

Assuming that the log real exchange rate identity holds as $Q_t = \varepsilon_t + P_t^{us} - P_t^{ea}$, where ε_t is the nominal exchange rate between the US dollar and the euro (USD/EUR; the US dollar appreciates when the value of the nominal exchange rate increases), it can be rewritten in the form of inflation as $\Delta Q_t = \Delta\varepsilon_t + \pi_t^{us} - \pi_t^{ea}$, where ΔQ_t is the change in the real exchange rate; $\Delta\varepsilon_t$ is the change in the nominal exchange rate and $\pi_t^{us} = \Delta P_t^{us}$ and $\pi_t^{ea} = \Delta P_t^{ea}$ are US inflation and EA inflation, respectively. Since the follower country targets the nominal exchange rate, differential of the nominal exchange rate is set to be zero ($\Delta\varepsilon_t = 0$), assuming the nominal exchange rate was at the target rate in the previous period. Thereby, when the US leads the policy making, EA inflation is determined by US inflation and real exchange rate adjustments:

$$\pi_t^{ea} = \pi_t^{us} - \Delta Q_t \tag{4.2}$$

Similarly, when EA is the leader country and US is the follower country, EA acts as an independent policymaker; hence, US inflation follows EA inflation and real exchange rate changes:

$$\pi_t^{us} = \pi_t^{ea} + \Delta Q_t \tag{4.3}$$

The dynamics of the real exchange rate, thus, demonstrate inflation differentials across two economies. And the follower country cooperates to the extent that its inflation is dependent externally on the leader country's inflation.

Intuitions of monetary coordination can be drawn from both domestic and international perspectives. Domestically, it creates an exchange rate channel that delivers effects of the monetary policy faster than the conventional interest rate channel[7]. An attempt to reduce real exchange rate variations driven by domestic shocks or policy changes may also internalise the associated externalities to the foreign economy. The less spillover, the less feedback impact from the foreign economy, and hence the less complication in designing domestic monetary policies, since international trade-offs of an open economy monetary policy are minimised.

Additionally, in a world of two economies, one economy's coordination may accommodate the impacts of policy changes and shocks from the other economy more directly and effectively. With the traditional trade channel, an economy responds to foreign shocks when the spillover appears in domestic variations or cross-country differentials. Time-lag of the expenditure-switching effect – the real variables need time to adjust – potentially slows down, not to mention the fact that the degree of exchange rate pass-through is still indecisive and that the price misalignment and demand misalignment are not accounted for. In contrast, an economy responds to foreign shocks directly when the real exchange rate appears in the monetary policy rule. Monetary changes associated with the contemporary changes in the real exchange rate are, hence, able to counteract foreign shocks prior to the actual impact on the real side of the domestic economy. The stabilised real exchange rate and the minimised domestic fluctuations are, in turn, expected to mitigate the feedback of domestic policy response and ease stabilisation burden for the foreign economy.

[7] For example, Ball (1999b) illustrated this using a simple three-equation open economy model. The empirical literature also confirms that the monetary policy takes one year to affect inflation through the exchange rate channel, rather than two years through the interest rate channel.

Type 1 Model (Benchmark): Non-Coordination Model(NonC)	
US	$r_t^{us} = \rho^{us} r_{t-1}^{us} + (1-\rho^{us}) \left[r_\pi^{us}\pi_t^{us} + r_y^{us}\left(y_t^{us} - y_t^{usf}\right)\right] + r_{\Delta y}^{us}\left(y_t^{us} - y_t^{usf} - y_{t-1}^{us} + y_{t-1}^{usf}\right) + \varepsilon_t^{r,us}$
EA	$r_t^{ea} = \rho^{ea} r_{t-1}^{ea} + (1-\rho^{ea}) \left[r_\pi^{ea}\pi_{t-1}^{ea} + r_y^{ea}\left(y_t^{ea} - y_{t-1}^{eaf}\right)\right] + r_{\Delta\pi}^{ea}\left(\pi_t^{ea} - \pi_{t-1}^{ea}\right) + r_{\Delta y}^{ea}\left(y_t^{ea} - y_t^{eaf} - y_{t-1}^{ea} + y_{t-1}^{eaf}\right) + \varepsilon_t^{\pi,ea}$
Type 2 Models: Fixed exchange rate with *no* coordination from dominating country	
DOM-2.1 US dominates Model	
US	$r_t^{us} = \rho r_{t-1}^{us} + (1-\rho) \left[r_\pi^{us}\pi_t^{us} + r_y^{us}\left(y_t^{us} - y_t^{usf}\right)\right] + r_{\Delta y}^{us}\left(y_t^{us} - y_t^{usf} - y_{t-1}^{us} + y_{t-1}^{usf}\right) + \varepsilon_t^{r,us}$
EA	$\pi_t^{ea} = \pi_t^{us} - (Q_t - Q_{t-1} - \varepsilon_t^{\pi,ea})$
DOM-2.2 EA dominates Model	
US	$\pi_t^{us} = \pi_t^{ea} + (Q_t - Q_{t-1} - \varepsilon_t^{r,us})$
EA	$r_t^{ea} = \rho^{ea} r_{t-1}^{ea} + (1-\rho^{ea}) \left[r_\pi^{ea}\pi_{t-1}^{ea} + r_y^{ea}\left(y_t^{ea} - y_{t-1}^{eaf}\right)\right] + r_{\Delta\pi}^{ea}\left(\pi_t^{ea} - \pi_{t-1}^{ea}\right) + r_{\Delta y}^{ea}\left(y_t^{ea} - y_t^{eaf} - y_{t-1}^{ea} + y_{t-1}^{eaf}\right) + \varepsilon_t^{\pi,ea}$
Type 3 Models: Coordination Model: C-3.(1 to 11)	
US	$r_t^{us} = \rho^{us} r_{t-1}^{us} + (1-\rho^{us}) \left[r_\pi^{us}\pi_t^{us} + r_y^{us}\left(y_t^{us} - y_t^{usf}\right)\right] + r_{\Delta y}^{us}\left(y_t^{us} - y_t^{usf} - y_{t-1}^{us} + y_{t-1}^{usf}\right) + h_0^{us}Q_t + h_1^{us}Q_{t-1} + \varepsilon_t^{r,us}$
EA	$r_t^{ea} = \rho^{ea} r_{t-1}^{ea} + (1-\rho^{ea}) \left[r_\pi^{ea}\pi_{t-1}^{ea} + r_y^{ea}\left(y_t^{ea} - y_{t-1}^{eaf}\right)\right] + r_{\Delta\pi}^{ea}\left(\pi_t^{ea} - \pi_{t-1}^{ea}\right) + r_{\Delta y}^{ea}\left(y_t^{ea} - y_t^{eaf} - y_{t-1}^{ea} + y_{t-1}^{eaf}\right)$ $+h_0^{ea}Q_t + h_1^{ea}Q_{t-1} + \varepsilon_t^{\pi,ea}$
Type 4 Models: Fixed exchange rate with coordination from dominating country	
DOM_C-4.(1 to 3) Coordination Model with US domination	
US	$r_t^{us} = \rho^{us} r_{t-1}^{us} + (1-\rho^{us}) \left[r_\pi^{us}\pi_t^{us} + r_y^{us}\left(y_t^{us} - y_t^{usf}\right)\right] + r_{\Delta y}^{us}\left(y_t^{us} - y_t^{usf} - y_{t-1}^{us} + y_{t-1}^{usf}\right) + h_0^{us}Q_t + h_1^{us}Q_{t-1} + \varepsilon_t^{r,us}$
EA	$\pi_t^{ea} = \pi_t^{us} - (Q_t - Q_{t-1} - \varepsilon_t^{\pi,ea})$
DOM_C-4.(4 to 6) Coordination Model with EA domination	
US	$\pi_t^{us} = \pi_t^{ea} + (Q_t - Q_{t-1} - \varepsilon_t^{r,us})$
EA	$r_t^{ea} = \rho^{ea} r_{t-1}^{ea} + (1-\rho^{ea}) \left[r_\pi^{ea}\pi_{t-1}^{ea} + r_y^{ea}\left(y_t^{ea} - y_{t-1}^{eaf}\right)\right] + r_{\Delta\pi}^{ea}\left(\pi_t^{ea} - \pi_{t-1}^{ea}\right) + r_{\Delta y}^{ea}\left(y_t^{ea} - y_t^{eaf} - y_{t-1}^{ea} + y_{t-1}^{eaf}\right)$ $+h_0^{ea}Q_t + h_1^{ea}Q_{t-1} + \varepsilon_t^{\pi,ea}$

This table lists the Monetary Policy rules in the NK model;
The actual monetary policy rule in model simulations would be the weighted Taylor rule of the NK and NC models

Table 4.1: Monetary policy rules for testing models

For example, when a positive total factor productivity shock strikes the US economy (particularly in the traded good sector), US output is expected to rise with the higher productivity, while inflation may fall on the impact due to lower marginal costs[8]. Meanwhile, by the Balassa-Samuelson effect, the cross-country productivity differential implies a US dollar appreciation[9]. Coupled with the potential larger increases in the US consumption and investment relative to the increased output, the US net exports can decline in the short run[10].

Such changes in the US translate into the EA economy as a short-run inflationary effect, assuming TOT moves in the same direction with the real exchange rate, pulling up the short-run EA output, and possibly inflation depending on its trade structure and production capacity. Conventionally, the EA interest rate will only respond with periods of delay when EA output and inflation become higher. With the direct exchange rate channel, contrarily, the EA interest rate increases in response to a real appreciation of the euro instantaneously, with further adjustments to be made if the EA economy is still affected by the foreign shocks. Meanwhile, the EA policy response feeds back to the US economy through the real exchange rate with a depreciating effect on the US dollar, which counteracts with the US dollar's appreciating trend, and contributes to the stabilisation of the US economy.

Optimistically, by opening a direct exchange rate channel one can expect (1), the interaction between economies to be more substantial due to the direct

[8] In an RBC model with no price and wage rigidities, inflation can fall as long as the price decrease due to lower marginal costs is larger than the real wage increase due to the higher marginal product of labour. In the presence of wage and price stickiness, producer price inflation experiences a fall on the impact of the productivity shock, due to lower marginal costs. With a longer time horizon, inflation can climb as the real wage is gradually adjusted to the level consistent with the productivity level.

[9] Although the empirical analyses found ambiguous evidence for the relation between the real exchange rate and the cross-country productivity differential, the Balassa-Samuelson effect is the principle hypothesis in the relevant exchange rate literature.

[10] Backus et al. (1992) extended the closed economy RBC model to an international RBC model, and showed a sharp decline in net exports in the home economy upon the impact of a home technology shock. However, it is also shown that after trade frictions are introduced, the volatility of net exports is less volatile.

transfer of shocks through real exchange rate variations; and (2), if shocks in one economy pass-through to the other economy more substantially, the model predicted variance would decline due to the accommodating effect on both economies. Nevertheless, it is possible that the exchange rate channel will produce excess volatility if the interaction is substantially weak.

In the case where exchange rate pass-through is highly incomplete in the US, EA shocks do not affect US output and inflation, since the US import price is not adjusting at all or sufficiently to induce the expenditure-switching effect (with sufficiently low demand elasticity). The immediate interest rate response to exchange rate changes initiates impacts on the US economy, which need to be offset by subsequent interest rate adjustments. Therefore, the direct exchange rate channel acts as a good policy channel domestically, but also potentially exposes the domestic economy to foreign shocks.

Studies often find that direct responses to the real exchange rate do not stabilise output and inflation better, but sometimes even enlarge the variation compared to policy rules that are inward looking. The aim of this study is then to reconsider the impact of the exchange rate coordination in a more complete DSGE environment. The Null hypothesis, therefore, can be summarised as data simulated from coordination models are substantially closer to the actual data, or equivalently, monetary coordination exists. The potential improvements lie in the closeness between any of the dynamic, correlation and variance properties in simulated data and in actual data.

4.2.3 Models

Table 4.1 lists four types of models evaluated in this study – non-coordination (benchmark) model under a floating-exchange-rate context (NonC), fixed-but-adjustable-exchange-rate model with the dominating economy not coordinating (DOM-2), coordination models under a floating-exchange-rate regime (C-3) and fixed-but-adjustable-exchange-rate model with the dominating country also coordinating (DOM_C-4).

As introduced in the previous section, the 'two-country model' in Le et al. (2010) is adopted as a benchmark of the non-coordination model (Model NonC). First of all, individual models of the US and the EU and the joint US-EU two-country model have been tested using indirect inference in Meenagh et al. (2009), Le et al. (2011) and Le et al. (2010). The experimental practices provide some useful directions on the choices of method over various aspects, such as choices of detrending method, testing time ranges, and possible weights attached to the NK economy and the NC economy. Second, although findings in Le et al. (2010) showed substantial closeness between model-simulated data and actual data in a two-country DSGE model compared to individual country models, some issues still remain unsolved, such as the surprisingly weak interaction between the two countries. Such a weak link is not supported by the empirical evidence or the real world observations, particularly during a period of widespread financial crisis and the disastrous aftermath across industries and the globe. The well-established DSGE framework and those previous conclusions potentially facilitate experiments in this study that are aiming to identify missing links.

The non-coordination benchmark model (NonC) is a simple floating-exchange-rate open economy DSGE model, within which economies set up monetary policy rules that are consistent with their own interests[11], but have no response to the real exchange rate at all. And hence, both economies would have to react to foreign economic fluctuations transited via the 'weak link' of cross-country demand differential and UIP, but would not coordinate in the real exchange rate

[11] Taken from SW (2003), the EA monetary policy instrument (the short-term EA real interest rate) is a function of an interest rate smoothing term, a lagged inflation deviation from the inflation target, an output gap between the current output and the output that prevails in the corresponding flexible economy, a short-term inflation deviation featuring the difference between the current and lagged inflation rate, and a short-term output gap featuring the change of current output gap from the previous period.

Taken from SW (2007), the US monetary policy rule is slightly different. The US monetary policy instrument (the short-term US real interest rate) is a function of an interest rate smoothing term, an inflation deviation from the inflation target, an output gap between the current output and the output that prevails in the corresponding flexible economy, and a short-term output gap featuring the change of current output gap from the previous period.

The mathematical expressions of the monetary policy rule in the US and the EA are shown in Appendix B2.

for potential stabilisation effects.

The second type of model (DOM-2) is under a fixed-but-adjustable-exchange-rate regime, where the leader country specifies a monetary policy rule in accordance with its own domestic interests, whilst the follower country insists on a fixed-but-adjustable-exchange-rate policy with an objective to fix the nominal exchange rate against the leader country's currency. Notably, although the leader operates under a floating-exchange-rate regime, the design of its monetary policy excludes policy reactions to the real exchange rate. Technically, this is a cooperative model with the follower country 'cooperating' entirely with the leader country's policy stance. Even so, this cooperative commitment differs from the type of coordination this study is investigating – monetary policy rules that are designed to respond to real exchange rate fluctuations. Models fitting into this category are, therefore, coded by 'DOM-2', indicating their 'one country domination' and 'no response to the real exchange rate by the dominating country' setting.

In particular, model DOM-2.1 is a 'US domination model', where the US as a leader sets its monetary policy rule according to its own interests to the inflation target and output gap, whilst the EA inflation adjusts in a way that the nominal exchange rate can be restored to the target rate. A shock in the US makes US inflation and the real exchange rate fluctuate, while EA inflation is determined entirely by US inflation and real exchange rate differentials. On the other hand, as the EA economy has no monetary independence, it cannot self-accommodate domestic shocks using the monetary policy. Thereby, the EA economy can only be stabilised, if not by other means, by the responsive US inflation and real exchange rate movements. Model DOM-2.2 is an 'EA domination model', which is the exact opposite of model DOM-2.1. US inflation is determined by the EA inflation rate and the real exchange rate differential. In each model, one monetary policy shock ($\varepsilon_t^{r,us}$ for the US and $\varepsilon_t^{\pi,ea}$ for the EA) is included in the follower's inflation determination equation for catching the change in the 'adjustable' exchange rate target by the follower country's authority.

The third type of model is the partial-coordination model (C-3) in a floating-exchange-rate context, within which both the US and the EA have their independent monetary policy rules and may respond to the real exchange rate in different ways. In either economy, exchange rate coordination comes into the monetary policy rule in the form of interest rate responses to the current and past value of the real exchange rate at various degrees. Impacts from shocks and the difference of policy responses are then eventually absorbed by the floating exchange rate. A flexible inflation-targeting monetary policy consists of the same components as in the benchmark model, as well as the current and past value of the real exchange rate.

Four parameters (h_0^{us}, h_1^{us} for the US model and h_0^{ea}, h_1^{ea} for the EA model) in monetary policy rules characterise this coordination feature. h_0^i (where $i = us, ea$) indicates the elasticity of the instrument rate's responses to the contemporaneous real exchange rate; h_1^i (where $i = us, ea$) indicates the elasticity of the instrument rate's responses to the lagged real exchange rate. In agreement with the rule of thumb of exchange rate rules in Obstfeld and Rogoff (1995), h_0^i and h_1^i are both sign-restricted. An increase in the value of the real exchange rate indicates a real appreciation of the home currency (the US dollar), or equivalently a real depreciation of the foreign currency (the Euro). Following that, US monetary authority decreases the interest rate in response to a contemporaneous contractionary impact (i.e. an increase of the real exchange rate Q) and raises the interest rate against the same real exchange rate change in the following period for offsetting the effect from contemporaneous policy responses as such change happens; meanwhile, the EA monetary authority reacts in an opposite manner to the US policy in response to an increase of the real exchange rate, with which inflationary pressure is created for the EA economy. Therefore, the coefficient for the elasticity of US policy rate responses to the contemporaneous real exchange rate is limited to be negative ($h_0^{us} \prec 0$), and that to the lagged real exchange rate is limited to be positive ($h_1^{us} \succ 0$), while the EA counterpart takes a positive value for the former ($h_0^{ea} \succ 0$) and a negative value for the latter ($h_1^{ea} \prec 0$), respectively. For a CB targeting real exchange rate changes, the absolute values of the elasticity for contemporaneous and lagged real exchange rate simply need to be set equally ($h_1^{us} = -h_0^{us}, h_1^{ea} = -h_0^{ea}$). Moreover, for a non-coordination case to be considered in such formation, the values of these coefficients simply need to be restricted to zero ($h_0^{us} = h_1^{us} = h_0^{ea} = h_1^{ea} = 0$).

Different calibrations of these parameters distinguish them farther from each other within one category of coordination model. There are eleven models (see Table 4.2) in this category, including three 'US coordination only' models (Model C-3.1 to C-3.3), three 'EA coordination only' models (Model C-3.4 to C-3.6), three 'both US and EA coordination (to the same degree, $h_0^{us} = h_0^{ea}$ and $h_1^{us} = h_1^{ea}$)' models (Model C-3.7 to C-3.9) and two models in which both the US and the EA coordinate but to different degrees (Model C-3.10 and C-3.11). The reason for this wide selection of coordination models lies in the fact that within this well-developed DSGE framework it is possible to examine the robustness of the proposed open economy policy rules from a new angle by looking at the closeness of model-simulated data and actual data. And hence, it would be better to find out the possible existence of monetary coordination between economies by searching across diverse cases.

Models	Parameter Combinations
C-3.1 USFull	$h_0^{us} = -1, h_1^{us} = 1, h_0^{ea} = 0, h_1^{ea} = 0$
C-3.2 USSvensson	$h_0^{us} = -0.45, h_1^{us} = 0.45, h_0^{ea} = 0, h_1^{ea} = 0$
C-3.3 USTaylor	$h_0^{us} = -0.25, h_1^{us} = 0.15, h_0^{ea} = 0, h_1^{ea} = 0$
C-3.4 EAFull	$h_0^{us} = 0, h_1^{us} = 0, h_0^{ea} = 1, h_1^{ea} = -1$
C-3.5 EASvensson	$h_0^{us} = 0, h_1^{us} = 0, h_0^{ea} = 0.45, h_1^{ea} = -0.45$
C-3.6 EATaylor	$h_0^{us} = 0, h_1^{us} = 0, h_0^{ea} = 0.25, h_1^{ea} = -0.15$
C-3.7 BothFull	$h_0^{us} = -1, h_1^{us} = 1, h_0^{ea} = 1, h_1^{ea} = -1$
C-3.8 BothSvensson	$h_0^{us} = -0.45, h_1^{us} = 0.45, h_0^{ea} = 0.45, h_1^{ea} = -0.45$
C-3.9 BothTaylor	$h_0^{us} = -0.25, h_1^{us} = 0.15, h_0^{ea} = 0.25, h_1^{ea} = -0.15$
C-3.10 USFull,EATaylor	$h_0^{us} = -1, h_1^{us} = 1, h_0^{ea} = 0.25, h_1^{ea} = -0.15$
C-3.11 USTaylor,EAFull	$h_0^{us} = -0.25, h_1^{us} = 0.15, h_0^{ea} = 1, h_1^{ea} = -1$

Table 4.2: A list of exchange rate response coefficients for Type 3 coordination models

The coordinating parameters here are selected from the early literature that focused on the role of the exchange rate and had discussed the sensible degrees of response to real exchange rate changes. The earlier work by Ball (1999b) first introduced a new open economy Taylor rule with responses to real exchange rate changes. He found the parameter set of $h_0 = -0.37$, $h_1 = 0.17$ to be optimal in a small open economy with sticky prices[12]. The following study by Svensson (2000) found the optimal parameter set to be $h_0 = -0.45$, $h_1 = 0.45$. Moreover, the result showed the inflation variance was narrowed down, but the output performance deteriorated in terms of having a larger variance. Finally, a set of coefficients $h_0 = -0.25$, $h_1 = 0.15$ was suggested in Taylor (1999), in which he examined a Taylor rule within a multi-country framework and found that adding the real exchange rate would improve some countries' performances, while some would deteriorate. An additional pair of parameters $h_0 = -1$, $h_1 = 1$ is also considered in this study – central banks have the target interest rate fully responding to the current real exchange rate but also fully offset by the same amount of adjustment in the subsequent period. Although some empirical studies have concluded that the macroeconomic performance worsened when CBs reacted to the exchange rate strongly (Taylor, 1993b, 2001), the importance of the real exchange rate in the transmission mechanism is undeniable. This study would like to evaluate the effect of a strong reaction in a DSGE framework, and possibly identify the cause of the deterioration in the macroeconomic performance.

The fourth category of models is also structured in a fixed-but-adjustable-exchange-rate context (DOM_C-4), in which the leader economy sets the monetary policy rule reacting to common factors such as the output gap and the inflation deviation, as well as the real exchange rate. That is, the leader country is also coordinating in the means of reacting to the real exchange rate. Meanwhile, the follower's interest rate, determined according to the leader's interest rate, varies to keep the nominal exchange rate stable around a certain target rate. Therefore, this category of models is coded as DOM_C-4, indicating the co-existence of cooperation under the fixed-exchange-rate policy and coordination

[12]This study does not report the indirect inference testing result for this set of parameters as the DSGE model's rank condition is not verified given the complete set of parameters used in this study. Further study for finding whether there is one optimal set of values close to the finding in Ball (1999b) can be done by using indirect inference estimation.

through the real exchange rate.

In the first three of these models (DOM_C-4.1 to DOM_C-4.3), the US monetary policy rule responds to the real exchange rate with the selected set of parameters consistent with Type 3 models (model list in Table 4.3), whilst EA inflation follows US inflation and the real exchange rate differential[13]. The latter three models (DOM_C-4.4 to DOM_C-4.6) are the exact opposite cases, and have an EA-leader-US-follower type of monetary coordination. Again, one monetary policy shock is included in each of the follower's inflation determination equations for catching changes in the nominal exchange rate target.

Models	Parameters set
DOM_C-4.1 USd_Full	$h_0^{us} = -1, h_1^{us} = 1$
DOM_C-4.2 USd_Svensson	$h_0^{us} = -0.45, h_1^{us} = 0.45$
DOM_C-4.3 USd_Taylor	$h_0^{us} = -0.25, h_1^{us} = 0.15$
DOM_C-4.4 EAd_Full	$h_0^{ea} = -1, h_1^{ea} = 1$
DOM_C-4.5 EAd_Svensson	$h_0^{ea} = -0.45, h_1^{ea} = 0.45$
DOM_C-4.6 EAd_Taylor	$h_0^{ea} = -0.25, h_1^{ea} = 0.15$

Table 4.3: A list of exchange rate coefficients for Type 4 coordination models

4.3 Data

4.3.1 Data Resources

The two-country model is simulated and compared with a $VAR(1)$ using 7 key macroeconomic time series for each region – real GDP, real consumption, real investment, labour (represented by hours worked), real wage, inflation and short-term nominal interest rate as well as 3 trade related time series – US imports and exports and the real exchange rate between US dollars and the euro (see Table 4.4).

This study uses the same data in SW (2003) and SW (2007), although the data length is extended and some observations may be subject to revisions. Key data

[13] Also note that model DOM-2.1 can also be one special case of the fourth type of model, with $h_0^{us} = 0, h_1^{us} = 0$.

	Variables		Variables		Variables
y^{us}	US output	y^{ea}	EA output	ex^{us}	US export to EA
c^{us}	US consumption	c^{ea}	EA consumption	im^{us}	US import from EA
i^{us}	US investment	i^{ea}	EA investment	Q	USD/EUR real EX
l^{us}	US labour	l^{ea}	EA labour		
w^{us}	US real wages	w^{ea}	EA real wages		
π^{us}	US inflation rate	π^{ea}	EA inflation rate		
r^{us}	US short time interest	r^{ea}	EA interest rate		

Table 4.4: A list of key macroeconomic variables

series used for constructing seven US macroeconomic time series are obtained mainly from the US Federal Reserve Bank of St. Louis (FRED) and the US Bureau of Labor Statistics (BLS). A list of these data series are tabulated in Appendix B, Table B.6. Real GDP is expressed as billions of chained 2005 dollars by its origin[14]. The real consumption and real investment are constructed by deflating personal consumption expenditure and fixed private investments using a GDP deflator. Inflation is taken as the first difference of the logarithm of GDP implicit price deflator. The labour variable is expressed by working hours adjusted by civilian employment (16 years and over) [15]. Real wages are represented by the hourly compensation deflated by GDP deflator. The Effective Federal Funds Rate (EFFR) is taken as the short-term nominal interest rate. Real GDP, real consumption, real investment, hours and real wages are adjusted by population index to per capita level. Apart from the interest rate, all time series take the form of 100 times their logarithmic value (formulae are shown in Appendix B, Table B.7).

The Euro Area data are obtained from the Area-Wide Model (AWM) database established by the ECB, which covers a wide range of quarterly Euro Area macroeconomic time series. The time series in the AWM database are constructed by aggregating available country information – mainly from Eurostat, OECD na-

[14]It differs from the data used in SW (2007) paper, where the data were expressed in billions of chained 1996 dollars.

[15]Both the average weekly hours and the hourly compensation obtained from BLS are for the non-farm business sector for all persons. The population of the non-farm business worker only takes account of 80% of workers who produce the gross domestic product in the US.

tional accounts, OECD main economic indicators, BIS and AMECO databases[16]. The aggregation method is mainly 'Index method'[17], while some variables are simply weighted sum (such as interest rate) or are simply summed (such as employment). In this study, the definition of the Euro Area follows the way that the dataset defines. A list of the exact time series used can be found in Appendix B, Table B.8. Real GDP is in millions of ECU/Euros, and is re-scaled to the corrected level of the reference year 1995. Consistent with the US dataset, the first difference of the logarithm of GDP deflator is taken as an indicator of inflation. Real wages are presented as the wage per head deflated by GDP deflator. To be in line with US time series, Real GDP, real consumption, real investment and labour (hours) are all adjusted to per capita level by the population index calculated by the same method as the US index. The interest rate is the short-term nominal interest rate. Apart from the interest rate, all variables take the form of 100 times their log value (see Appendix B, Table B.9).

Additionally, the US dollar to the euro exchange rate time series is obtained from the Datastream. It is then inverted and adjusted by the US Consumer Price Index (CPI) and EA Harmonised Index of Consumer Prices (HICP) to be a real exchange rate series. An increase in the real exchange rate represents a real appreciation of the US dollar or a real depreciation of the euro. US imports from the EA and US exports to the EA are taken from the time series used in Le et al. (2010).

4.3.2 Time Series Properties

To begin with, these seventeen key macroeconomic time series are individually tested for their non-stationarity. For each variable, both Augmented Dickey-Fuller (ADF) tests and Phillips-Perron (PP) tests at level and first order difference

[16] Eurostat is the Statistical Office of the European Union; OECD is the Organisation for Economic Co-operation and Development; BIS stands for Bank for International Settlements; and AMECO is the annual macroeconomic database of the European Commission.

[17] The log-level index for any series X is defined: $\ln X_z = \sum_z w_i * \ln X_i$, where w_i is the weight of X_i in the aggregate X_z.

are conducted if the time series is not stationary at level. Full details of the non-stationarity test result can be found in Appendix B, Table B.10, B.12 and B.11. As the length of the time series varies from one to another, the individual length of the time series is used in non-stationarity tests.

All seven time series for the US economy range from 1947Q1 to 2010Q3 (255 observations in total). The test results show stationarity of US inflation and real wages at the 1% significance level; while both ADF and PP tests report non-stationarity in US output, consumption, investment, labour and interest rate at level, but stationarity at their first difference (i.e. they are $I(1)$ processes). All seven time series for EA economy range from 1970Q1 to 2009Q4 (160 observations in total). Both ADF and PP tests report non-stationarity at level, but stationary at the first difference in all seven time series (i.e. they are all $I(1)$ processes). US imports from the EA and exports to the EA range from 1970Q1 to 2008Q3 (155 observations in total). Taken from Le et al. (2010), these two time series are already linearly detrended, which will be in line with the detrending method taken in this study. Therefore, tests are carried out and reported at level only. Finally, the time series for the real exchange rate between the US dollar and euro is also shown to be $I(1)$.

According to the results of the non-stationarity test, all $I(1)$ time series are linear-detrended by individually taking deviation of each variable from its own mean and linear trend. Those stationary time series, US inflation, real wages, imports, and exports, are kept in their original forms. The experimental findings in Le et al. (2010) are consulted for the choice of detrending methods. In their study, various methods for filtering data – SW's filter, log-differencing, Hodrick-Prescott (HP) filter and linear detrending were carried out for testing the effect of changing filters on the indirect inference testing efficiency. The results did not differ significantly according to the Wald test on both $VAR(1)$ coefficients and data variances. Therefore, the log-linear detrending was used in order to sufficiently stationarise time series while keeping as much information as possible.

Thirteen linear-detrended time series are then re-tested for their non-stationarity.

Variables	ADF test	PP test
c^{us}	−2.415256(0.0155)	−2.012042(0.0426)
i^{us}	−3.261644(0.0012)	−2.401457(0.0161)
l^{us}	−3.186995(0.0015)	−2.521925(0.0116)
π^{us}†	−2.218320 (0.0258)	−3.029959 (0.0025)
r^{us}	−2.442378(0.0144)	−2.335998(0.0191)
w^{ea}†	−11.20522 (0.0000)	−9.414113 (0.0000)
y^{us}	−2.758494(0.0059)	−2.410950(0.0157)
c^{ea}	−1.583393 (0.1065)	−2.487046 (0.0129)
i^{ea}	−3.453894 (0.0006)	−2.250749 (0.0240)
l^{ea}	−2.633401 (0.0086)	−1.854073 (0.0609)
π^{ea}	−4.035019(0.0001)	−6.249280(0.0000)
r^{ea}	−2.795602(0.0054)	−2.335908(0.0193)
w^{ea}	−1.622117(0.0987)	−3.884375(0.0001)
y^{ea}	−1.851255 (0.0613)	−2.419604 (0.0155)
im^{us}†	−2.412372 (0.0158)	−1.974060 (0.0466)
ex^{us}†	−2.034836 (0.0405)	−2.246027 (0.0243)
Q	−1.832334(0.0638)	−2.282334(0.0221)

The second column reports the t-statistics of ADF tests and the corresponding probability. The third column reports the adjusted t-statistics of Phillips-Perron tests and the corresponding probability. †indicates that the time series is stationary at level, and that test statistics are obtained from its non-stationarity test at level.

Table 4.5: The result of non-stationarity tests for the linear-detrended data

Table 4.5 reports the results of the non-stationarity test for all seventeen time series that are in their final forms – they are used directly in the model evaluation and estimation. Overall, linear-detrending has taken out non-stationarity from the time series successfully; the stationarity of detrended time series is not rejected either by the ADF test or PP test, or even both.

4.4 Testing Using Indirect Inference

4.4.1 Obtaining Actual Errors

In the simulation of SW's US and EU models, parameters describing properties of the error structure, coefficients and variances of exogenous shock, are based on Bayesian estimates conditional on the chosen individual priors. Instead of imposing exogenous assumptions on the shock dynamics and volatility, this study extracts the real world information of shock's dynamics and volatility from actual data – structural errors are derived from the calibrated structural model and hence, regressions can be conducted on the individual structural shock to quantify the distinct autoregressive behaviour and its associate exogenous shock component for each individual shock.

For those equations that do not have forward-looking variables (expectations) involved in the determination process, structural errors can be derived simply by obtaining the residual from equations. For those equations involving unobserved expectations, an instrumental variable procedure first publically discussed in McCallum (1976) was used.

Theoretically, unobserved expectation terms should be endogenously determined, reflecting anticipations on the economic development by market participants with rational expectations. Estimates from models are traditionally taken as an approximation to these forward-looking behaviours. Even so, some statistical concerns have been raised on the consistency and the efficiency of these expectation estimates in order to ensure the efficiency of estimations, in particular on the model with rational expectations. Mills (1962) first introduced a method of 'implicit expectations', with which expectations could be derived from observable behaviours that were thought to have considerable relation with the underlying observable condition. If economic agents know better in predicting their next movements (economists have no clear idea on the explicit expectation formation used by economic agents), the implicit approach would have advantages over explicitly specifying an expectation formation with exogenously imposed hypotheses.

In an extended work, McCallum (1976) clearly demonstrated that a simultaneous equation system with rational expectations can be estimated consistently with expectation terms instrumented by their 'predicted' values obtained from a Least Squares (LS) regression on the related variables from the entire available information set[18]. Compared to a substitution method, which is an alternative for tackling this issue, the proposed method avoids the additional nonlinearity, and gives asymptotically efficient estimators using Full Information Maximum Likelihood (FIML) given some requirements on econometric models (Wickens, 1982). Based on the algorithm of FIML, the procedure of getting consistent and asymptotically efficient estimates can be interpreted as replacing forward-looking variables by the associated predictions from a restricted reduced form before estimating the model using Maximum Likelihood (ML). Predicting the expectation from restricted reduced form preserves the rationality, which would be transited into the estimation, and hence provide consistent and efficient estimates.

The choice of instrumental variables is based on past values of endogenous variables that appear to be foreseen rationally in the structural model, namely, consumption, investment, inflation, rate of return on capital and real wages for both the US and the EA, and additionally US labour supply. An eleven-variable $VAR(1)$ on these selected variables is then used to obtain predictions in line with rational expectations[19]. Hence the structural errors in those equations

[18] According to the concept of Rational Expectation (RE), the available information would include the past value of all the variables that are involved in the equation.

[19] A comparison of $VAR(1)$ predicted forward-looking variables to actual time series is pre-

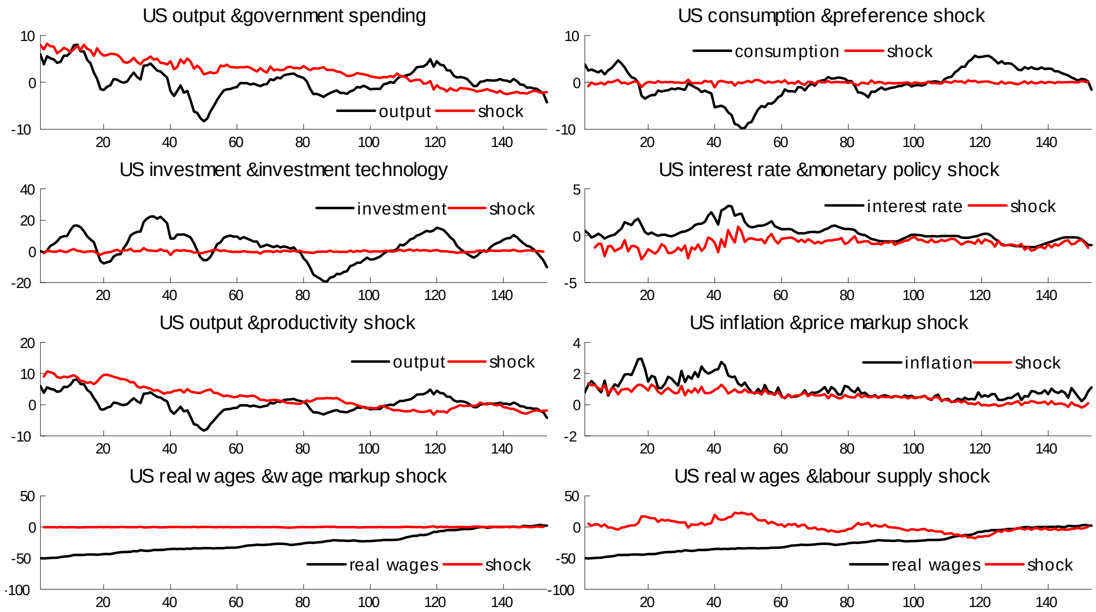


Figure 4-1: US - the actual data & structural errors from model NonC

with forward-looking property can be estimated with these $VAR(1)$ expectations. There are eight structural errors estimated for each region from the market clearing condition $(\varepsilon^{g,us}, \varepsilon^{g,ea})$, consumption Euler equation $(\varepsilon^{b,us}, \varepsilon^{b,ea})$, investment Euler equation $(\varepsilon^{i,us}, \varepsilon^{i,ea})$, monetary policy rule $(\varepsilon^{r,us}, \varepsilon^{\pi,ea})$, production function $(\varepsilon^{a,us}, \varepsilon^{a,ea})$, price setting equation $(\varepsilon^{\pi,us}, \varepsilon^{p,ea})$, wage setting equation $(\varepsilon^{w,us}, \varepsilon^{w,ea})$ and additional labour supply shocks from the NC model wage setting equation $(\varepsilon^{wNC,us}, \varepsilon^{wNC,ea})$[20]. A comparison of actual data and the derived structural shocks is shown in Figure 4-1 and 4-2.

Once structural shocks are reversely derived as residuals from the structural model, regressions in accordance with the presumed innovative structure of shocks can be carried out to quantify the dynamic and volatility property of each shock – coefficients of innovative structure and variance of exogenous innovations. Twelve

sented in Appendix Figure B-1 and Figure B-2.

[20] These two shocks appear in the context of no wage stickiness. Therefore, it can be explained as the pure labour supply shock.

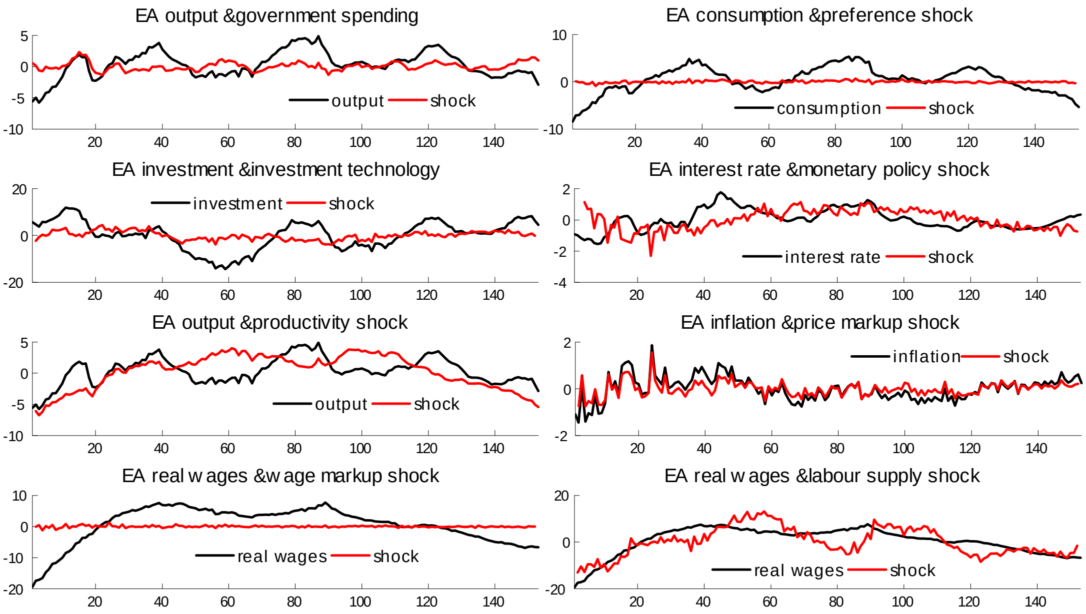


Figure 4-2: EA - the actual data & structural errors from model NonC

shocks out of sixteen, including all EA shocks and four US shocks, are assumed to follow $AR(1)$ processes. The US price mark-up shock, wage mark-up shock, and labour supply shock are assumed to be following the $ARMA(1,1)$ process. Additionally, the US government spending shock consists of an $AR(1)$ process as well as a cross-effect term from technology shock.

Table 4.6[21][22].presents a comparison of innovation standard errors in this study to previous analyses. Overall, standard errors of exogenous innovations are relatively close to those estimated in the SW's US model, with the exception of the US monetary policy shock, which appears to be more volatile when it is derived from actual data. There is, however, less similarity in the EA. That is, standard

[21] † In addition to the shock to interest rate that is quoted here, there is as shock to inflation objective in SW (2003) with estimated variance 0.017. The monetary policy shock (Taylor rule shock) in this study - the same as definition of monetary policy shock in SW (2007) - is a joint product of those two shock in SW (2003).

[22] ‡ The labour supply shock in SW (2003) is defined in representative agent's utility; while labour supply shock in this study is defined separately within a flexible wage setting environment.

Standard error for innovations in US								
	Gov.	**Cons.**	**Inv.**	**Taylor**	**Prod.**	**PriceM**	**WageM**	**LabS**
This study	0.5424	0.2495	0.5632	0.4612	0.478	0.1371	0.3195	2.7818
SW(2007)	0.52	0.24	0.45	0.24	0.45	0.14	0.24	–
Le et al.(2010)	0.673	0.371	0.704	0.344	0.553	0.239	0.311	–
Standard error for innovations in EA								
	Gov.	**Cons.**	**Inv.**	**Taylor**	**Prod.**	**PriceM**	**WageM**	**LabS**
This study	0.3663	0.2401	1.0102	0.4184	0.3918	0.2952	0.3093	2.0937
SW(2003)	0.325	0.336	0.085	0.081†	0.598	0.16	0.289	3.52‡
Le et al.(2010)	0.3755	0.5099	1.2329	0.4764	0.3017	0.0265	0.5273	–

† ‡ see footnote

Table 4.6: Standard errors of innovations - a comparison to SW(2003,2007)

errors of EA shocks deviate from the previous analyses to some extent. Notably, standard errors of the EA investment shock and the EA monetary policy shock are exceptionally large compared to those estimates in the SW's EU model. Although it can be argued that the monetary shock in this study is defined to include both shocks to the interest rate and inflation objectives in the SW's EU model, its variance is still substantially larger than overall variances in the monetary policy rule estimated by SW. On the other hand, their restrictions on the prior mean and the standard error may have imposed additional information that results in the extremely low variance. For EA investment shock, prior mean is set at 0.1 with a standard error of 2, which allows a narrow corridor at a really low rate for the Bayesian estimator. Despite their large divergence to SW's estimates, these two innovation standard errors are generally consistent with the findings in Le et al. (2010), which are also generated from data. Two shocks whose standard errors are noticeably larger than either of these earlier studies are the US monetary policy shock and the EA price mark-up shock.

The $AR(1)$, $ARMA(1,1)$ and cross-effect coefficients are quantitative representations of the shock dynamics in each economy. A comparison of these coefficients obtained here to those reported in previous studies is shown in Table 4.7. Overall, there is a rather large divergence in the shock dynamics across these three studies. The most significant divergence emerges in the dynamics of consumer preference shocks for both the US and the EA, US monetary policy

Coefficients for innovative dynamic in US shocks								
	Gov.	**Cons.**	**Inv.**	**Taylor**	**Prod.**	**PriceM**	**WageM**	**LabS**
This study								
$AR(1)$	0.9768	0.0632	0.4349	0.8766	0.9803	0.9883	0.9672	0.9642
$MA(1)$	0.3845					−0.7419	−0.749	−0.174
SW(2007)								
$AR(1)$	0.97	0.22	0.71	0.15	0.95	0.89	0.96	
$MA(1)$						−0.69	−0.84	
Le et al.(2010)								
$AR(1)$	0.944	−0.064	0.530	−0.062	0.971	0.925	0.915	
$MA(1)$						−0.709	−0.848	
Coefficients for innovative dynamic in EA shocks								
	Gov.	**Cons.**	**Inv.**	**Taylor**	**Prod.**	**PriceM**	**WageM**	**LabS**
This study								
$AR(1)$	0.8348	0.1757	0.8193	0.758	0.9858	0.2700	−0.205	0.9236
SW(2003)								
$AR(1)$	0.949	0.855	0.927	–	0.823	–	–	0.889
Le et al.(2010)								
$AR(1)$	0.751	−0.101	0.063	0.565	0.940	0.154	−0.038	

Table 4.7: Coefficients for shock processes - a comparison with previous analyses

shock, EA investment technology shock, although differences are also noticeable in other shocks.

This study finds that consumption preference shocks across both regions evolve positively but less persistently. In contrast, SW's estimations found high persistence in consumption preference shocks, whereas Le et al. (2010) reported negative, but rather low $AR(1)$ coefficients. US monetary policy shock, by this study, is suggested to be highly persistent, whereas both estimates from SW (2007) and Le et al. (2010) appear to be really low, or even to be negatively evolving. Furthermore, EA investment technology is shown to be close to a random walk in Le et al. (2010), whereas estimates both in this study and in SW (2003) show significantly high persistence.

4.4.2 Evaluating Models by Seven Key Indicators

Subject to the data availability, indirect inference testing is applied over the period of 1971Q1 to 2008Q3 (153 observations). Starting with a regression on the dataset of target variables, one can obtain parameters representing the actual macroeconomic behaviour of two regions using the auxiliary model, $VAR(1)$.

The main target variable dataset, although varied when the focus of the study changes, consists of seven key macroeconomic time series – output, inflation and interest rate for both the US and EA as well as the real USD/EUR exchange rate. Therefore, an auxiliary parameter set from actual data (actual data auxiliary parameters), α_T, includes 49 $VAR(1)$ coefficients and 7 variances.

Meanwhile, data simulation is carried out on the basis of a reduced-form policy and transition matrix from the structural model, accompanied by bootstrapped exogenous innovations that are derived in the previous section. Within this dynamic and stochastic framework, covariance of innovations is as important as parameters that determine the relative movement of variables. Therefore, in order to preserve this covariant property in the analysis, a vector-bootstrapping is used instead of normal methods that individually bootstrap each shock in every process[23].

With vector-bootstrapping, all shocks that strike the economies, both the US and EA, within one particular period of time (here defined as one quarter) are taken as a whole sample. The bootstrap sample size, hence, equals the number of observations (148 in total after losing some observations in processes). In each random drawing, vector-bootstrapping takes a sample of 16 shocks where each innovation will be kept in line with the others consistently at a certain point of time. Hence, as a full sample vector-bootstrapping is performed, an entire shock profile for 148 periods (quarters) will be ready for simulating one dataset. Finally, a thousand datasets are simulated by combining the given structural model and bootstrapped innovations (number of bootstrapping $N = 1000$). And correspondingly, a thousand sets of 'simulated data auxiliary parameters', $\alpha_S^n\left(\bar{\theta}\right)$, $n = 1, ..., N$, are generated in the same way as the 'actual data auxiliary parameter set' is generated.

[23] There are some concerns about the use of bootstrapping, particularly the robustness of the method when the leading process is a unit root (or near unit root). To address such a concern, Le et al. (2011) conducted a Monte Carlo experiment to check the asymptotic distribution of the AR coefficients in SW's models. The result suggested that the bootstrap was reasonably accurate in small samples; the distribution converged asymptotically to a χ^2 distribution.

For statistical analysis, the 'actual data auxiliary parameter set' is being compared with those 'simulated data auxiliary parameter sets' using Wald statistics presented in the methodology section. For each Wald statistic WS_S^n (or WS_T) computed, as a representation of closeness, a particular auxiliary parameter set α_S^n (or α_T) is compared against the mean of the one thousand simulated auxiliary parameter set, $\bar{\alpha}_S\left(\bar{\theta}\right) = \frac{1}{N}\sum_{n=1}^{N}\alpha_S^n\left(\bar{\theta}\right)$. The percentile location of WS_T in the distribution of WS_S^n (Equation 3.6) becomes an indication of how well the model-simulated parameters can embrace true parameters that describe the dynamics and volatility property of actual data.

In Table 4.8, a list of 'actual data auxiliary parameters' ($VAR(1)$ parameters and variances from actual data) and their corresponding 95% bootstrapped upper-bound and lower-bound obtained from model-simulated data is reported for both the non-coordination (NonC) model as well as the best performing coordination model referring to model C-3.6 – in which the US has no direct responses to the real exchange rate, while the EA fully coordinates under a floating-exchange-rate regime. The overall testing results, including the actual Wald statistic (WS_T), the Wald percentile, and the normalised MD for each model, are also shown at the bottom of the table.

The actual Wald statistic (WS_T) measures the distance between actual auxiliary coefficients and the corresponding mean of model-simulated auxiliary coefficients. The simulated Wald statistic WS_S^n, where $n = 1, \ldots, N$, measures the distance between an individual set of model-simulated auxiliary coefficients and the corresponding mean of model-simulated auxiliary coefficients. Therefore, the distribution of WS_S is a Wald statistic spectrum that profiles every single bootstrap-simulated sample. The Wald percentile labels the exact position of the actual Wald statistic (WS_T) in the distribution of the simulated Wald statistics (WS_S). And finally, the normalised MD is a normalised representation of the actual Wald statistic – its value coincides with 1.645 when the actual Wald statistic is exactly at the 95% percentile of the whole simulated Wald statistics spectrum. Hence, similar to Wald statistics, the smaller the value of normalised MD, the better the model-simulated coefficients can describe actual data dynamics and volatility.

Moreover, to avoid random sampling bias, the testing exercise is repeated 1000 times[24]. Therefore, the reported actual Wald statistics and nominalised MDs are the means of a large number of resamples (see Appendix B Figure B-3 and B-4 for statistical distributions).

Actual $VAR(1)$ Coefficients and Their Policy Implications

The actual $VAR(1)$ coefficients (α_T) are tabulated in the first column of Table 4.8, labelled A_I^D, where D and I are dependent and independent variables, respectively; and they can be any of the target variables in the testing. All variables generally exhibit a high level of persistence, except for EA inflation ($A_{\pi^{ea}}^{\pi^{ea}}$), which exhibits by 0.5831 in response to its lagged value. The US monetary policy instrument ($A_{r^{us}}^{r^{us}}$) appears to have even stronger inertia (0.9788) relative to the high level of persistence in the US policy rate reported in the literature. In contrast, the monetary policy inertia in the EA appears to be more moderate and is consistent with some studies focusing on the Euro Area.

Both policy rates react to macroeconomic changes weakly, but generally in line with theory, except for the response of the US policy rate to the EA monetary policy rate ($A_{r^{ea}}^{r^{us}} = -0.019$). Theoretically, an extended US output gap from its potential output level or a higher inflation deviation from the authority's inflation target induces a tightened monetary policy in the US; the same economic variations that occur in its foreign counterparty, in contrast, induce a relaxation in US monetary policy. Similarly, EA monetary policy responds positively to domestic output expansion and inflation increases, but negatively to US inflation. It, however, appears to be almost insular to US output spillover. Furthermore, US policy rate reacts weakly, but negatively, to the increasing interest rate in

[24] In one testing exercise, for each actual Wald statistic (W_T) to be computed, 1000 samples of bootstrapped innovations, and hence, simulated datasets are needed. This testing process is exercised 1000 times to achieve a distribution of the actual Wald statistic (W_T) and its associated normalised MD.

the EA. This may be a contradiction with presumed uncovered interest parity (UIP), which requires co-movement in interest rates to restore exchange rate stabilisation. A graph of both policy rates and real exchange rate is shown in Figure 4-3, which suggests an overall violation of UIP in the past three decades.

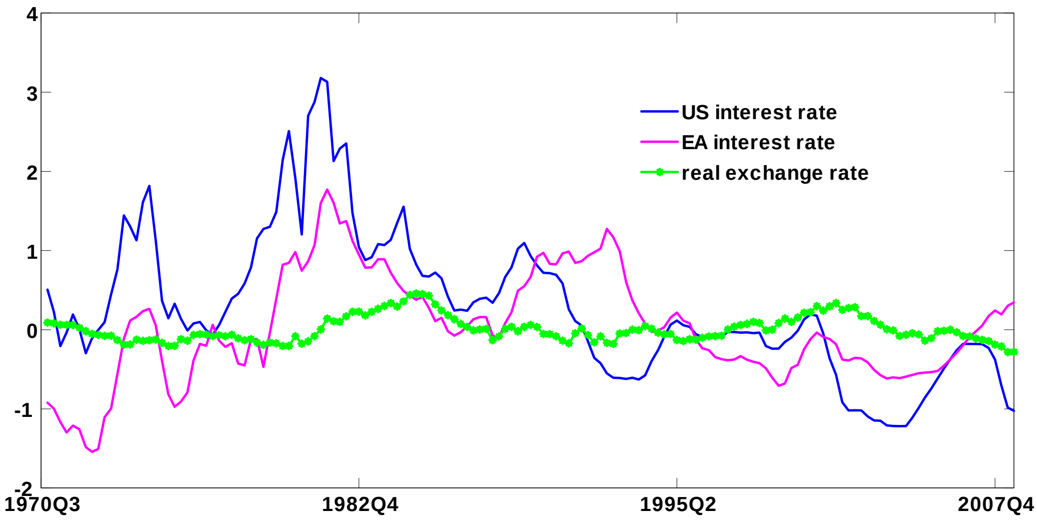


Figure 4-3: Nominal interest rates vs. real exchange rates

More interestingly, although the real exchange rate is more influential to monetary policies than other macroeconomic variables, responses of the US and EA policy rate to the real exchange rate follow a different rationale. The EA policy rate is lowered reacting to a lagged euro depreciation – a possible adjustment to the tightened monetary policy previously. On the contrary, the US policy rate, which will otherwise be tightened up as an adjustment to relaxing policy previously, is even lower in response to a lagged dollar appreciation. It implies a further extension, rather than presumably a reverse adjustment to its instantaneous reaction to the real exchange rate in the earlier period.

Impacts of the real exchange rate on output appear to be unconventional – a home currency appreciation tends to boost rather than to depress the domestic output growth. In particular, US output grows strongly by 2.67% following a 10% real dollar appreciation, whilst US inflation goes down by nearly 1%. One factor contributing to the output growth may be the strong and prolonged monetary policy relaxation in response to the real exchange rate. The very low, though correctly signed, exchange rate pass-through to US inflation is a potential demonstration of the argument insisting that LCP and VCP are extensive in international trade. In contrast, a 10% euro depreciation (Q increases by 10%) lowers EA output by 1% and EA inflation by 2.63%. This phenomenon contradicts the conventional argument that a home currency depreciation switches the expenditure towards home goods and has an expansionary impact on the domestic inflation. Moreover, the argument of the incomplete exchange rate pass-through, particularly the PTM case in Krugman (1987), may interpret the unexpectedly falling EA inflation as the euro depreciates.

The monetary spillover appears to be strong across two economies. A doubled EA interest rate brings down US output by 83.1%, while a doubled US interest rate boosts EA output by 20.9%. Moreover, a 10% increase in EA inflation brings down US output by 4.51%, while US inflation has a fairly small, but negative impact on EA output ($A^{y^{ea}}_{\pi^{us}} = -0.061$).

In addition to the dynamic property, the actual variances of the target variables are listed below the coefficients in the first column. Apart from volatile output in both the US and EA, the volatility of inflation and interest rates in both regimes is relatively low. The volatility of the real exchange rate appear to be really low at 0.02599.

Comparing the Non-Coordination and Coordination Models

In terms of 7 target variables, indirect inference testing is in favour of the coordination model C-3.6 (Note that, in the following section, the term 'coordination model' refers to the coordination model C-3.6 in particular, unless it is stated separately). Both non-coordination and coordination models are 100% rejected by the joint Wald test on the models' ability to replicate data dynamics and volatility (see the Wald percentile). However, the normalised MD indicates that the coordination model can replicate properties of the data 15% more closely than the non-coordination model. The actual Wald statistic drops from 15569.08 to 11574.36 when the model incorporates monetary coordination (model C-3.6).

Both models tend to over-predict $VAR(1)$ coefficients when they fail to embrace the true value. For coefficients that have unusual values, there is no surprise that both models are unable to capture those features. For example, the $VAR(1)$ regression shows that US inflation reacts to US interest rate positively at a low rate of 0.018; whereas, both models produce relatively strong and negative elasticity to be in line with the economic theory. Moreover, the $VAR(1)$ regression shows that the real exchange rate weakly reacts to inflation and the interest rate in both economies. Whereas for the model setup, both models undoubtedly produce high values of elasticity since the real exchange rate is assumed to absorb the information quickly and abundantly from the economy.

As a whole, the coordination model outperforms the non-coordination model in terms of its ability to replicate data volatility. Taking data dynamics alone, the coordination model C-3.6 is the best expression for data dynamics in this study. Nevertheless, the non-coordination model also performs relatively well compared to some other coordination models. The hypothesis of the existence of monetary coordination cannot be rejected, since the model's performance can be improved in the presence of monetary policy coordination in the real exchange rate.

What Makes the Coordination Model Better?

One of the advantages of using the Wald statistic is that the squared deviation is weighted against its relative contribution towards the variability of prediction. The larger the variance of a simulation, the smaller the scalar it has in the weighting matrix. As a result, if a model extends prediction variances in order to embrace the true value of coefficients, it will be penalised by a smaller weight towards the final score of the Wald statistic. Compared to analyses focusing on merely impulse response functions (IRFs), the Wald statistic takes both the VAR impulse response and the variance of simulation into account, avoiding possible compromises of the prediction variance in order to enlarge the success of catching impulse responses.

Given these robust features, key factors that bring down the joint Wald statistic are first, a smaller deviation of simulated means to actual $VAR(1)$ coefficients $\left[\alpha_T - \bar{\alpha}_S\left(\bar{\theta}\right)\right]$; and second, a weighting matrix $W\left(\bar{\theta}\right)$ specified as the inverse variance-covariance matrix of predicted coefficients (see the Wald statistic in Equation 3.2). From a statistical perspective, an improvement of the model's performance from coordinating monetary policy may lie in the higher simulation precision (dynamics aspect) or the lower simulation uncertainty (variability aspect), although multiple reasons can be explored extensively.

Firstly, model simulation precision is, to a degree, higher in the coordination model. Overall, only 24 true parameters out of 49 are captured by the coordination model's simulated bounds – less than the 28 parameters captured by the non-coordination model. Nonetheless, some true values are marginally missed out as a result of narrower simulated bounds in the coordination model. Furthermore, the mean of a simulated parameter from the coordination model can be closer to the true value even when it fails to capture the true impulse response in bounds. For instance, the simulated bounds for $A^{y^{ea}}_{r^{ea}}$ are reported as $[-0.262, 0.3122]$ with a mean of 0.0279 by the coordination model, while the corresponding bounds produced by the non-coordination model are $[-0.364, 0.4233]$ with a mean at 0.0675 compared to the true value at -0.299. Graphically, data dynamics is well captured by 5% and 95% impulse response bounds in the non-coordination model; whereas, the coordination model has a more accurate mean and a smaller simulation variance.

From the data volatility aspects, the time series variances, simulated by the coordination model, generally are smaller than those by the non-coordination model; yet they are still over-predicted relative to their true values. In particular, by incorporating monetary coordination, the mean of simulated variances for the real exchange rate is narrowed down by nearly 30% from 119.58 to 84.99; and that for EA output is narrowed down by more than a quarter from 27.97 to 20.67, despite the fact that they both deviate hugely from the actual values. As a consequence, even though the simulated VAR impulse response seems to capture the actual VAR impulse response better in the non-coordination model (in terms of number of impulse responses being embraced), the actual Wald statistic for the coordination model can be reduced remarkably, *ceteris paribus*.

Secondly, model prediction uncertainty is significantly reduced in the coordination model. Produced by the coordination model, 34 out of 49 $VAR(1)$ coefficients have smaller simulation variances. In particular, the simulation variance of real exchange rate volatility (simulation variance of σ_Q^2) has a dramatic drop from 8982.04 in the non-coordination model to 3924.84 in the coordination model (more than a 56% drop). Evidence also shows in simulated bounds – those narrower bounds are generally produced by the coordination model.

In the Wald statistic computation, large variances enlarge the multi-dimensional space represented by the variance-covariance matrix. Consequently, once the matrix is inversed to be a weighting matrix, the values of each matrix element are larger in general, although the penalty for being highly volatile in the simulation is still preserved as a relatively low weighting value. When the Wald statistic of a non-coordination model is calculated, squared deviations are weighted over much higher scalars resulting in a high actual Wald statistic.

The aforementioned large simulated bound can be an exact case of high prediction precision as well as high prediction uncertainty. Seemingly, the non-coordination model encloses actual $VAR(1)$ estimates better than the coordination model; however, largely due to the larger error bands it produces that marginally capture actual values. If its simulated mean is closer to the actual value, the Wald statistic can be improved by a smaller deviation (higher prediction precision); but it will be penalised by a larger simulation variance (higher prediction uncertainty). Nonetheless, the coordination model can still produce a simulated mean closer to the actual value even though it marginally misses out on embracing certain impulse responses. The actual Wald statistic is worsened by a larger deviation as well as a higher penalty from the higher prediction uncertainty – with one example being the coefficient for the response of EA output to EA interest rate ($A^{y^{ea}}_{r^{ea}}$).

For these reasons, simply looking at the ability to simulate an impulse response that embraces the actual impulse response cannot be seen as the only criterion for judging the overall performance of a DSGE model. The bias towards catching the dynamic property tends to result in compromising the predictive or simulative variance and even the mean value.

Furthermore, the coordination model's performance with respect to the real exchange rate, surprisingly, exhibits a mixture of improvements and deteriorations. Determinants of the real exchange rate are better illustrated in the coordination model. Not only can the coordination model deliver about an equivalent level of performance from the data dynamics perspective, but it successfully narrows down the simulation variances of the real exchange rate elasticity to the other variables (A^{Q}_{I}, where I can be any other target variable), by more than 40% on average (23% at minimum and 56% at maximum).

Yet the functioning of the real exchange rate channel, through which exchange rate fluctuations can be transmitted into key aggregate variables, retains no progress or even deteriorates. The simulated elasticities of output, inflation, and interest rate with regard to the real exchange rate (A^{D}_{Q}, where D can be any other target variable) fail to capture any actual effect of an explicit exchange rate channel.

		Non-coordination				**Coordination**			
	Actual	**Mean**	**LB**	**UB**		**Mean**	**LB**	**UB**	
$A^{y^{us}}_{y^{us}}$	0.8172	0.9307	0.8612	0.9936	OUT	0.9385	0.879	0.9915	OUT
$A^{y^{us}}_{y^{ea}}$	0.0592	0.0923	−0.063	0.2565	IN	0.0835	−0.049	0.2128	IN
$A^{y^{us}}_{\pi^{us}}$	−0.016	−0.223	−0.493	0.0613	IN	−0.325	−0.625	−0.009	IN
$A^{y^{us}}_{\pi^{ea}}$	−0.451	0.1873	−0.486	0.8286	IN	0.3525	−0.216	0.8979	OUT
$A^{y^{us}}_{r^{us}}$	0.0967	0.0474	−0.348	0.4596	IN	0.1938	−0.246	0.6304	IN
$A^{y^{us}}_{r^{ea}}$	−0.831	−0.322	−1.029	0.3417	IN	−0.483	−0.961	0.0012	IN
$A^{y^{us}}_{Q}$	0.2672	−0.060	−0.147	0.0187	OUT	−0.064	−0.139	0.0139	OUT
$A^{y^{ea}}_{y^{us}}$	0.0186	−0.008	−0.049	0.0302	IN	−0.009	−0.041	0.0255	IN
$A^{y^{ea}}_{y^{ea}}$	0.9828	0.9989	0.9163	1.0766	IN	1.0010	0.937	1.0638	IN
$A^{y^{ea}}_{\pi^{us}}$	−0.061	−0.051	−0.248	0.1390	IN	−0.096	−0.288	0.0981	IN

$A^{y^{ea}}_{\pi^{ea}}$	-0.268	0.0611	-0.353	0.5009	IN	0.0728	-0.263	0.4085	OUT
$A^{y^{ea}}_{r^{us}}$	0.2085	0.0567	-0.197	0.3164	IN	0.1160	-0.151	0.3946	IN
$A^{y^{ea}}_{r^{ea}}$	-0.299	0.0675	-0.364	0.4233	IN	0.0279	-0.262	0.3122	OUT
$A^{y^{ea}}_{Q}$	-0.099	-0.015	-0.059	0.0279	OUT	-0.011	-0.0545	0.0312	OUT
$A^{\pi^{us}}_{y^{us}}$	0.0235	0.0003	-0.037	0.0404	IN	-0.003	-0.036	0.0304	IN
$A^{\pi^{us}}_{y^{ea}}$	0.0053	-0.007	-0.095	0.0852	IN	-0.001	-0.073	0.0722	IN
$A^{\pi^{us}}_{\pi^{us}}$	0.9397	1.1169	0.9514	1.2765	OUT	1.0986	0.9123	1.2756	IN
$A^{\pi^{us}}_{\pi^{ea}}$	0.0308	0.0332	-0.335	0.3974	IN	0.1258	-0.189	0.4583	IN
$A^{\pi^{us}}_{r^{us}}$	0.0178	-0.380	-0.598	-0.158	OUT	-0.345	-0.606	-0.095	OUT
$A^{\pi^{us}}_{r^{ea}}$	0.0091	-0.002	-0.356	0.3517	IN	-0.1	-0.4	0.1858	IN
$A^{\pi^{us}}_{Q}$	-0.094	0.0009	-0.044	0.045	OUT	0.0005	-0.044	0.0412	OUT
$A^{\pi^{ea}}_{y^{us}}$	0.0135	-0.006	-0.028	0.0167	IN	-0.001	-0.019	0.0169	IN
$A^{\pi^{ea}}_{y^{ea}}$	-0.005	0.0233	-0.025	0.0722	IN	0.0114	-0.024	0.0476	IN
$A^{\pi^{ea}}_{\pi^{us}}$	0.0264	-0.042	-0.141	0.0644	IN	-0.107	-0.220	0.0042	OUT
$A^{\pi^{ea}}_{\pi^{ea}}$	0.5831	0.5514	0.3206	0.7664	IN	0.6046	0.3945	0.7910	IN
$A^{\pi^{ea}}_{r^{us}}$	0.0362	0.0584	-0.085	0.1964	IN	0.1484	-0.002	0.3045	IN
$A^{\pi^{ea}}_{r^{ea}}$	0.0746	0.0677	-0.142	0.2851	IN	-0.008	-0.17	0.159	IN
$A^{\pi^{ea}}_{Q}$	-0.263	-0.013	-0.037	0.0105	OUT	-0.039	-0.063	-0.018	OUT
$A^{r^{us}}_{y^{us}}$	0.0120	0.0039	-0.013	0.0209	IN	0.0017	-0.014	0.0176	IN
$A^{r^{us}}_{y^{ea}}$	-0.003	-0.037	-0.076	-0.0004	IN	-0.032	-0.064	0.0017	IN
$A^{r^{us}}_{\pi^{us}}$	0.0096	0.5196	0.4424	0.592	OUT	0.5463	0.4591	0.627	OUT
$A^{r^{us}}_{\pi^{ea}}$	-0.038	0.0098	-0.180	0.1855	IN	0.0060	-0.155	0.1659	IN
$A^{r^{us}}_{r^{us}}$	0.9788	0.2735	0.1688	0.3869	OUT	0.2394	0.1189	0.3603	OUT
$A^{r^{us}}_{r^{ea}}$	-0.019	0.0800	-0.092	0.2631	IN	0.0879	-0.062	0.2333	IN
$A^{r^{us}}_{Q}$	-0.291	0.0219	0.0046	0.0408	OUT	0.0272	0.0083	0.0457	OUT
$A^{r^{ea}}_{y^{us}}$	0.0001	-0.012	-0.034	0.0104	IN	-0.018	-0.043	0.0052	IN
$A^{r^{ea}}_{y^{ea}}$	0.029	0.0393	-0.005	0.0918	IN	0.0454	-0.002	0.0991	IN
$A^{r^{ea}}_{\pi^{us}}$	-0.032	-0.067	-0.165	0.026	IN	0.0345	-0.085	0.1561	IN
$A^{r^{ea}}_{\pi^{ea}}$	0.0148	-0.177	-0.39	0.0452	IN	0.0236	-0.198	0.2283	IN
$A^{r^{ea}}_{r^{us}}$	0.0817	0.0921	-0.036	0.2229	IN	-0.018	-0.194	0.1556	IN
$A^{r^{ea}}_{r^{ea}}$	0.8603	0.8795	0.6615	1.0779	IN	0.6342	0.4221	0.8414	OUT
$A^{r^{ea}}_{Q}$	-0.168	-0.023	-0.049	0.0003	OUT	-0.054	-0.088	-0.024	OUT
$A^{Q}_{y^{us}}$	-0.005	-0.028	-0.122	0.051	IN	-0.028	-0.092	0.0295	IN
$A^{Q}_{y^{ea}}$	0.0049	0.0076	-0.182	0.2043	IN	0.0134	-0.112	0.1448	IN
$A^{Q}_{\pi^{us}}$	-0.010	1.2094	0.7473	1.6584	OUT	1.2411	0.8486	1.6665	OUT
$A^{Q}_{\pi^{ea}}$	-0.007	-0.623	-1.588	0.2975	IN	-0.554	-1.236	0.1633	IN

$A^Q_{r^{us}}$	0.0245	−1.496	−2.121	−0.88	OUT	−1.521	−2.071	−0.982	OUT
$A^Q_{r^{ea}}$	−0.023	0.9279	0.0179	1.7846	OUT	0.8897	0.2669	1.4609	OUT
A^Q_Q	0.9368	0.9879	0.8869	1.0787	IN	1.0161	0.9312	1.0925	IN
$\sigma^2_{y^{us}}$	8.1212	63.940	16.321	153.86	OUT	64.963	18.076	157.03	OUT
$\sigma^2_{y^{ea}}$	3.6088	27.971	8.0136	65.806	OUT	20.669	6.4273	47.612	OUT
$\sigma^2_{\pi^{us}}$	0.3886	3.4624	1.9538	5.6678	OUT	3.4608	1.9247	5.8428	OUT
$\sigma^2_{\pi^{ea}}$	0.2386	0.5796	0.3613	0.8577	OUT	0.983	0.4500	1.8514	OUT
$\sigma^2_{r^{us}}$	0.8427	2.0674	1.1108	3.6190	OUT	2.0627	1.0578	3.6126	OUT
$\sigma^2_{r^{ea}}$	0.4319	1.0457	0.5650	1.7394	OUT	1.3488	0.6428	2.4698	OUT
σ^2_Q	0.0260	119.58	31.312	308.44	OUT	84.993	22.248	210.67	OUT
		Wald percentile: 100				Wald percentile: 100			
		Actual Wald stats: 15569.0814				Actual Wald stats: 11574.3650			
		normalised MD: 103.1941				normalised MD: 90.0273			

Table 4.8: Actual VAR parameters and model simulated bounds of the Non-Coordination model and the Coordination model(C-3.6)

The structure of the modern global economy contributes largely to the complication of exchange rate dynamics and its relationship with other macroeconomic aggregates. On the one hand, exchange rate determinants are presumably economic fundamentals, whereas the exchange rate exhibits a random walk empirically. On the other hand, classical models treat the exchange rate as a shock absorber that facilitates the international resource allocation; whereas, it is found that exchange rate pass-through to economic fundamentals, such as output and inflation, is not as efficient as the theory suggests. By incorporating monetary policy coordination, this study finds rather limited improvements to the models' ability to replicate exchange rate dynamics. Such compromise in the model structure potentially undermines the model's ability to replicate and even forecast dynamics of key macro-aggregates.

Is the Coordinating Economy More Volatile?

In terms of time series volatility, by incorporating monetary coordination (C-3.6), simulated variances of EA output ($\sigma^2_{y^{ea}}$) and the real exchange rate (σ^2_Q)

have been largely narrowed down towards their actual values, though they both still deviate from the true value to a great extent; yet variances of US output ($\sigma^2_{y^{us}}$) , inflation ($\sigma^2_{\pi^{us}}$) and interest rate ($\sigma^2_{r^{us}}$) remain unaffected, and variances of EA inflation ($\sigma^2_{\pi^{ea}}$) and interest rate ($\sigma^2_{r^{ea}}$) are both higher relative to the non-coordination model.

Intuitively, the EA's coordinating policy is effective in accommodating the impact from domestic shocks on both the domestic and foreign economies. Nonetheless, the EA economy is taking a higher risk of exposing itself to more foreign economic fluctuations, and a higher risk of stabilising the domestic output and real exchange rate at the expense of its own inflation and interest rate stability.

For instance, US monetary expansion may have a contractionary effect on the EA economy. Without coordination, the EA interest rate is forced to decline on a larger scale when impacts of the US policy are finally passed through into changes in bilateral trade flows. With a coordinating policy, the EA interest rate is cut to a smaller magnitude for consecutive periods in response to instantaneous movements in the real exchange rate[25]. Typically, when the transmission of shocks to the real exchange rate is more instantaneous, the EA interest rate takes actions even before the impact on output and inflation arrives, and hence, reduces the output and inflation volatility. Nonetheless, to achieve stability, a fairly accurate estimate is needed for impact from a one-off US monetary expansion. If the extent to which the monetary spillover can have effects on EA inflation is overestimated, EA monetary coordination, in contrast, creates more macroeconomic volatility by responding and adjusting unnecessarily aggressively.

Theoretically, the US monetary authority taking no account of a real exchange rate coordination can dampen the economic stabilisation of both economies, and may also amplify the impact of a beggar-thy-neighbour action by the US on the EA economy. The stabilising policy feedback from EA monetary coordination potentially weakens the effectiveness of a US devaluation policy intending to boost

[25] This is assuming that the interest rate response to the real exchange rate is relatively low, such as $h_0^{ea} = 0.25$ in model C-3.6.

US output and depress US unemployment. Thus, a more persistent expansionary policy in the US is needed to achieve a certain output and employment level. Consequently, persistent policy responses in the EA can potentially result in more volatile situations due to the US monetary authority's self-interest. US, individually, may not have such an intention since its output reacts positively to a real dollar appreciation, and hence, the competitive devaluation cannot be an answer to restore its current account deficit. However, such a conclusion can have a wider implication to other EA trading partners.

Altogether, the ability to replicate variances of target variables is poor in both models. The bounds simulated by both models fail to enclose any target variable's actual data variance. Even so, by and large, the majority of coordination models show stronger advantages over the non-coordination model in stabilising macroeconomic aggregates. Table 4.9 lists the models that produce 1^{st} and 2^{nd} closest mean of simulated variances to their associated actual value (3^{rd} and 4^{th} column). Although these 'closest' features scatter across a series of coordination models, distinguished by the independence of monetary policies and by the economy that coordinates, certain features can be identified.

	Actual	**NonC**	**Closest Mean**	2^{nd} **Closest Mean**
$\sigma^2_{y^{us}}$	8.1212	63.9403	C-3.10 60.0244	C-3.8 60.7012
$\sigma^2_{y^{ea}}$	3.6088	27.9706	C-3.6 20.6688	C-3.9 20.759
$\sigma^2_{\pi^{us}}$	0.3886	3.4624	DOM_C-4.4 1.331	DOM_C-4.5 2.151
$\sigma^2_{\pi^{ea}}$	0.2386	0.5796	DOM_C-4.5 0.4459	C-3.8 0.4598
$\sigma^2_{r^{us}}$	0.8427	2.0674	DOM_C-4.4 1.0276	DOM_C-4.5 1.1893
$\sigma^2_{r^{ea}}$	0.4319	1.0457	DOM_C-4.4 0.6103	C-3.7 0.7496
σ^2_{Q}	0.026	119.583	C-3.10 77.6854	DOM_C-4.6 80.5735

The first column reports variances of the actual time series; the second column reports the mean values of simulated variances; the third and fourth columns report the models that generate variances closest and 2^{nd} closest to the actual variance with values of the variance below.

Table 4.9: The closest simulated mean of variances

The EA's coordinating attitude towards the real exchange rate is crucial in cutting down the volatility for all variables except for US output, which has not been largely varied by any model[26]. Its low degree of coordination only lowers EA output to some extent, yet has marked ability to stabilise real exchange rate fluctuations. All four models with a low degree of EA coordination (model C-3.6, C-3.9, C3.10 and DOM_C-4.6) generate the lowest real exchange rate volatility. On the other hand, its moderate or high degree coordination tends to lower inflation and interest rate volatility in both regimes. Thus, stability of macroeconomic aggregates can be varying partly because of changes in the EA's manner of reacting to real exchange rate movements.

On the contrary, models with only US coordinates show no benefit from sole US responses to the real exchange rate, irrespective of exchange rate regimes. Rather, in terms of real exchange rate volatility, it is pretty costly for the US to have a low degree of monetary coordination. In particular, model DOM_C-4.3[27] produces the highest real exchange rate volatility (825.58) which is more than ten times the minimum. As a whole, among the three different degrees of US coordination, only the moderate response level enables models to produce relatively low variances for some target variables, such as US inflation and interest rate, even though these variances are not among the lowest. Either high or low degree of sole US coordination raises the volatility of all target variables.

Partial-coordination models, by and large, have blended results. No definitive conclusion can be made with regard to which model produces the lowest volatility that fits into the actual data property. However, given that the manner of coordination differs in these two economies, limited cases of partial-coordination might not be able to reveal the true monetary policy stance. Further investigation can be done by extending the number of partial-coordination cases, or by estimating

[26] Simulated means of US output variance varies from 60.02 by model C-3.10 to 68.93 by model DOM_C-4.3.

[27] In this model, the US responds to the real exchange rate with coefficients $h_0^{us} = -0.25$, $h_1^{us} = 0.15$; while the EA intends to fix the nominal USD/EUR exchange rate against the US dollar.

coefficients associated with monetary coordination.

4.4.3 Evaluating Models by US Output and Inflation

The volatility of output and the volatility of inflation are two essential targets in the policymaker's loss function. Many studies have been carried out, and various types of monetary policy rules have been proposed in the hope of finding an optimal monetary policy rule that minimises the volatility of the target variables and hence the loss function. However, the reliability of those findings may be undermined by the overall ability of a model used to estimate and predict these target variables. It will be informative to examine the robustness of those findings by evaluating the underlying models' overall performance, in particular, when the focuses are limited to output and inflation.

Model	**Wald percentile**		
	Dynamics	**Volatility**	**Dynamics+Volatility**
C-3.3 USTaylor	36.5% (−0.6101)	85.3% (0.2706)	56.8% (−0.3233)
C-3.11 USTaylor,EAFull	47.5% (−0.4403)	84.9% (0.3192)	56.7% (−0.2783)
C-3.9 BothTaylor	31.8% (−0.7293)	84.6% (0.3026)	62.1% (−0.1680)
C-3.5 EASvensson	76.1% (0.2016)	95.0% (1.6584)	95.9% (1.8187)
NonC (benchmark)	77.6% (0.2387)	94.0% (1.4219)	95.7% (1.8706)

This table reports the Wald statistics percentile, followed by the normlised MD in parentheses. The ranking is based on the normalised MD for dynamics and volatility.

Table 4.10: Best performing models by US output and inflation

Table 4.10 reports the four best performing models when both US output and inflation are jointly tested. Statistics for the non-coordination model are also included at the bottom of the table for comparison. Regarding the models' dynamics, a low degree of coordination in the US, suggested in Taylor (1999), seems to make positive progresses – in all three models with a low degree of US coordination normalised MDs (for Dynamics) fall into negative, regardless of whether there is coordination in the EA. Whereas, as the US monetary coordination gets stronger the models' dynamics are undermined.

The EA monetary coordination, even though not as decisive as the US coordination, does likewise. Models with a low degree of EA coordination tend to perform better than those with a medium to high degree of coordination, irrespective of whether the US is coordinating. Yet with both economies coordinating with a Taylor type (low degree) response to the real exchange rate, the dynamics of US output and inflation can be well captured. The partial-coordination model C-3.9 performs exceptionally well relative to the non-coordination model and other coordination models.

When both dynamics and volatility are accounted for, the coordination models C-3.3, C-3.11 and C-3.9 outperform the others[28]. The strength of these models lies in the coordination policy in both the US and EA that enables models to better interpret the dynamics of economic aggregates. In regard to the data volatility, however, they all perform poorly. It was previously mentioned that a low degree of US coordination has no benefit in lowering volatility. Apparently, the contradiction between fitting data dynamics and fitting data volatility becomes troublesome when identifying the model with the best performance.

4.4.4 Evaluating Models by EA Output and Inflation

Table 4.11 lists the five best performing models, ranked by normalised MDs on both models' dynamics and volatility when EA output and inflation are accounted for. Corresponding statistics for the non-coordination model, ranked 8^{th} place, are also listed at the bottom of the table for comparison. These models all marginally survive in the testing according to the actual Wald statistic (for both Dynamics and Volatility). Even though normalised MDs suggest that some coordination models can bring estimates closer to the actual data, there is no substantial improvement in closeness to distinguish any of these models from the non-coordination model.

[28] Taking account of the variability of testing statistics, these three models perform equivalently.

Certainly, with regard to the economic stability in the EA, although it has been shown that the EA monetary coordination has stabilising effects, its effectiveness is potentially balanced out by trade-offs between lowering inflation and interest rate variances and lowering output and real exchange rate variances. For instance, model C-3.10 produces the lowest output and real exchange rate variances, but relatively high inflation and interest rate variances; whereas model DOM_C-4.4 produces the lowest inflation and interest rate variances, but relatively high output and real exchange rate variances. For the policy design, the choices can be made in accordance with the policy stance of a country; whilst for evaluating the model's performance, particularly when all aspects are included, this may create close scores that make an improvement indistinguishable from another.

	Wald statistics		
Model	**Dynamics**	**Volatility**	**Dynamics+Volatility**
C-3.5 EASvensson	99.3% (3.6117)	90.2% (0.8633)	98.9% (3.0036)
C-3.8 BothSvensson	99.1% (3.5713)	90.9% (1.0426)	98.8% (3.3604)
DOM_C-4.5 EAd_Svensson	99.2% (3.5343)	89.9% (0.9320)	99.0% (3.5676)
DOM_C-4.4 EAd_Full	99.6% (3.5352)	94.3% (1.5047)	99.5% (3.6135)
C-3.4 EAFull	99.9% (4.2566)	95.8% (1.8866)	99.6% (3.6669)
NonC (benchmark)	99.7% (4.1551)	93.1% (1.2883)	99.6% (4.0862)

This table reports the Wald statistics percentile, followed by the normlised MD in parentheses. The ranking is based on the normalised MD on dynamics and volatility.

Table 4.11: Best performing models by EA output and inflation - compared with model NonC

The dynamics of EA output and the dynamics of EA inflation, surprisingly, have not been affected by the additional real exchange rate channel. That is to say, coordination models have no substantial advantage over the non-coordination model. Judging by normalised MDs, a small margin between the best performing model DOM_C-4.5 and the non-coordination model suggests an equivalent level of performance if testing variations are also taken into account.

Most studies focusing on the optimal open economy monetary policy judge coordinating coefficients (h_0^i and h_1^i) by evaluating policymakers' loss functions, which commonly consists of the weighted volatility of inflation, output, and other relevant variables. This study sheds light on the properties of those results from a broader perspective; the fact that the non-coordination model is in the middle range of all models being tested raises concerns that the model's overall fitness to reality needs to be evaluated more generally from both dynamics and volatility perspectives. In some circumstances, models are improved in one aspect at the cost of compromising the other. The comparatively deteriorated fitness to data cannot describe reality well, and thus, cannot reflect the true value of coefficients that are appropriate for the monetary policy design.

4.4.5 Evaluating Models by Target Variable Combinations

Broadly speaking, the result of the indirect inference model evaluation is in favour of coordination models, even though the non-coordination model may not be far behind for some target variable combinations. Depending on the target variable combination focused on in a testing practice, the 'best performing' model can vary. That is, it is inconclusive in regard to which is the best reality-reflecting model when the focus of a testing practice is changing; or in other words, a model can be the 'best performing' model for one target variable combination, but perform badly when it is tested against the other variable combination. Nevertheless, investigations across a group of selected target variable combinations that hold more researchers' attention may bring wider and deeper implications.

Not surprisingly, for every variable combination, there are some coordination models that can outperform the non-coordination model. On average, coordination models outperform the baseline non-coordination model by around 35%, with the biggest success a 117% improvement. Regarding key macro-aggregates of the US, coordination models with weak (low degree) US coordination and strong (high degree) EA coordination tend to outstand the others. It is also worth noting that EA macro-aggregates exhibit strong co-movements with US macro-aggregates; and hence, fixed-exchange-rate models with US domination perform strongly relative to the others, regardless of whether the US is coordinating.

Under a fixed-exchange-rate regime, the leader country's authority designs its monetary policy according to its self-interests; whereas, implied by the real exchange rate identity, the follower has its inflation attached to the leader's inflation and real exchange rate differentials directly (see equation 4.3 and 4.2). Changes to the inflation rate in the leader country take a shorter time to have a direct impact on the follower, whose inflation reflects spontaneously the leader's inflation movements. Meanwhile, as the capital mobility is not controlled, the international arbitrage enforces an equivalent nominal interest rate level across borders. In other words, the follower has no monetary independence – their nominal interest rate moves one to one with the leader's nominal interest rate. This relationship is mathematically represented by the nominal UIP (equation 3.14).

Moreover, when combining the real UIP (equation 3.15) and the follower's inflation determination equation (take the EA as the follower), one can obtain[29]

$$rr_t^{ea} - rr_t^{us} = E_t \left(\pi_{t+1}^{us} - \pi_{t+1}^{ea} \right). \tag{4.4}$$

Hence, a real interest rate differential in the current period implies a future inflation differential across economies.

In short, under a fixed-exchange-rate regime, the follower's inflation and nominal interest rate are determined exogenously by the leader unless there are fundamental changes to the real interest rate differential. The effectiveness of the leader's monetary coordination hence indirectly affects the follower's nominal variables. More likely, if the leader's monetary coordination is effective, the volatility of the follower's inflation and nominal interest rate may be more moderate. Take model DOM_C-4.1 (US fully coordinates, EA acts as a follower) as

[29] Note that, it can also be obtained by combining the International Fisher Effect (IFE) and the equivalent nominal interest rates. The IFE implies $rr_t^{us} = R_t^{us} - E_t\pi_{t+1}^{us}$ and $rr_t^{ea} = R_t^{ea} - E_t\pi_{t+1}^{ea}$ for the US and EA, respectively. Subtracting one from the other, one can obtain $rr_t^{ea} - rr_t^{us} = R_t^{ea} - R_t^{us} - E_t\pi_{t+1}^{ea} + E_t\pi_{t+1}^{us}$. Knowing that $R_t^{us} = R_t^{ea}$, the equation can be further reduced to $rr_t^{ea} - rr_t^{us} = E_t\pi_{t+1}^{us} - E_t\pi_{t+1}^{ea}$.

an example, a negative monetary shock in the US lowers US nominal interest rate, which in turn pushes up US inflation in periods. With coordination in the US monetary policy rule, the actual decline in the interest rate is smaller than its initial movement; and its impact on US inflation is smaller[30]. Hence, although the EA economy still suffers from volatility transited from the US economy, the magnitude of fluctuation may be smaller depending on the manner of US policy coordination. However, one cannot rule out the possibility that the leader's excessive responses to the real exchange rate can also result in a negative impact on the follower.

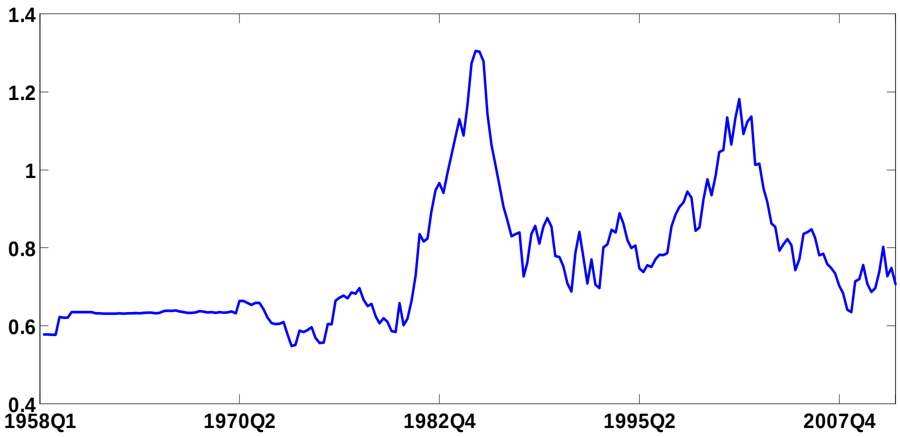


Figure 4-4: Nominal USD/EUR exchange rates

In reality, both monetary authorities in the US and EA label themselves with a flexible-exchange-rate regime. As shown in Figure 4-4, the nominal USD/EUR exchange rate[31] has fluctuated since the collapse of the Bretton Woods system in the early 1970s. The close co-movements between the US and EA macro-aggregates are unlikely to be the result of an intentional exchange rate intervention. However, it might shed light on a newly defined era – the 'Bretton Woods

[30] This is assuming a proper level of coordination. A sufficiently strong coordination can also turn the movement of the nominal interest rate in the opposite direction.

[31] The nominal Dollar to Euro exchange rate is the synthetic exchange rate taken from Datastream (Ref: USEURSN).

II' era. The US dollar may have retained its hegemony even long after the formal US dollar domination has ended.

Bretton Woods II originated from a paper by Dooley, Folkerts-Landau, and Garber (Dooley et al., 2003), in which they argued that the global monetary system has entered a 'revived Bretton Woods' era. Instead of Japan and Germany as in the Bretton Woods era, some Asian economies become the new 'peripheral' economies after the 1997-1998 Asian crisis. Just as during the Bretton Woods era, the new periphery is characterised by currency undervaluation, capital control and accumulated reserves; the center (the US) acts as a main source of demand for exports and financial intermediary[32]. Also, Bibow (2006) argued that 'Euroland' has in fact been behaving like a 'trade-account region' (a peripheral region), contributing to the deterioration of the US 'twin deficits'.

Either as a result of Bretton Woods II or the US activism in securing its dollar status, or both, the hegemony of the US dollar provides the privilege for the 'benign neglect' in regard to the US external balance; more importantly, it can be an explanation to the isolated US economy and to the close co-movements between EA and US macro-aggregates. On the other hand, the euro is involuntarily subject to external variations due to actions taken in response to the dollar hegemony; when the EA actively seeking an export-led strategy, the EA can also expose itself voluntarily to the external fluctuations – as suggested by the test result.

Furthermore, even though coordination models fit the actual data relatively well, they have little advantage over the non-coordination model when the real exchange rate is excluded from the joint Wald test. Table 4.12 shows the ranking of the best performing models when output, inflation and interest rate from both regions are jointly tested. The top four models are all coordination models and

[32] 'Bretton Woods II' is used to argue that that the US current account deficit is a result of bilateral affairs beneficial to both the centre and the periphery. Following that, the US current account imbalance may not be as unsustainable as it looks. Bibow (2006), on the other hand, argued that the US balance of payments imbalance is a 'benign neglect at the core'. Desipit the heated debate on the vulnerability of Bretton Woods II, the concept, coupled with the 'the benign neglect', is in fact a reasonable description of the global economy for the past decade.

Ranking	Model	normalised MD
1	DOM_C-4.4 EAd_Full	10.9787
2	C-3.7 EAFull	11.2144
3	C-3.8 BothSvensson	11.2168
4	DOM_C-4.5 EAd_Svensson	12.2780
9	NonC (benchmark)	14.4137

Table 4.12: Best performing models by output, inflation and interest rate in both regions

perform at a close range from 11 to 12.13 according to normalised MDs for both dynamics and volatility. Still, being ranked 9^{th} place, the non-coordination model does not fall behind substantially relative to the others.

Noticeably, comparing the joint test of 6 target variables with the joint test of 7 target variables, the inclusion of the real exchange rate deteriorates a model's performance heavily, irrespective of whether the tested model incorporates monetary coordination. The normalised MD is pushed up dramatically from just below 11 to 90 at best. Most importantly, the gap between the non-coordination model's performance and the coordination model's performance is largely widened. This phenomenon is widely found in the tested cases (see Table 4.13). Certainly, monetary policy coordination explains a part of the missing link, especially determinants of the real exchange rate; it also possesses an ability to stabilise economic fluctuations to a certain degree. Nevertheless, further investigation, such as in the transmission mechanism of the exchange rate to macroeconomic aggregates, is needed in order to improve the model's ability to fit the actual data.

Note that the indirect inference test evaluates the DSGE model's performance from the perspective of the model's ability to replicate the properties of the actual data (in-sample forecast). It differs from the other statistical tests, such as the LR test focusing on the model's predictive ability (out-of-sample forecast); put differently, these two measurements of 'fit' are not statistically correlated for a given model (Le et al., 2011)[33]. Moreover, Monte Carlo experiments also

[33] Le et al. (2011) also found that the Del Negro-Schorfheide DSGE-VAR weight is correlated to the LR test; thus, these two tests are more or less testing the same aspect of the model performance - the predictive ability.

Target Variables	$Diff\ ^{Best\ performing}_{NonC}$	Target Variables	$Diff\ ^{Best\ performing}_{NonC}$
y^{us}, y^{ea}	0.6527	y^{us}, y^{ea}, Q	3.962
π^{us}, π^{ea}	0.1497	π^{us}, π^{ea}, Q	12.1254
r^{us}, r^{ea}	2.0425	r^{us}, r^{ea}, Q	34.5987
y^{us}, π^{us}	2.1939	y^{us}, π^{us}, Q	3.6543
y^{ea}, π^{ea}	1.0826	y^{ea}, π^{ea}, Q	21.8213
$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}$	0.2171	$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}, Q$	10.8138

This table lists the differentials of normalised MDs (dynamics and volatility) between the non-coordiantion model and the best performing model from each testing practice on the associated target variable set (normalised MD^{NonC} – normalised MD$^{Best\ Performing}$);

Table 4.13: Gaps between the non-coordination and the coordination model (measured by the differences in normalised MDs)

suggested that the power of the indirect inference test was considerably higher than that of the LR test. Hence, for the purpose of detecting the efficacy of the model's in-sample forecast, the indirect inference test is an appropriate but more demanding test. For a detailed discussion on this issue, one can refer to Le et al. (2012). Accordingly, the test result in this study should be considered to be reliable as judged by its high statistical power; but it should not be mistaken as a justification for the DSGE model's predictive ability due to its different focal point from other statistical tests.

4.4.6 Variance Decomposition

To understand the change in the international transmission mechanism, this section compares the impact of a shock in the non-coordination model with that in the best performing coordination model (C-3.6). To derive the variance decomposition, all shocks are simply treated as deterministic and orthogonal to each other: in each simulation, the economy is only hit by one shock in the first period with one unit of standard error. The volatility of each target variable in response to this particular deterministic shock is calculated over a time horizon of 20 periods. The relative impact of this shock on a target variable (TV) can then be calculated as a ratio of the target variable's volatility due to this shock over its total volatility:

$$VD_{\varepsilon^i}^{TV} = \frac{\sigma^2 \left(TV \mid \varepsilon^i\right)}{\sigma^2 \left(TV\right)} \tag{4.5}$$

where ε^i can be any shock specified in the model setting.

Little spillover effect is found in the baseline non-coordination model, which is consistent with the finding in Le et al. (2010), though the entire structure of shock impacts significantly differs. Wage mark-up shocks in both economies have no significant impacts on any key macroeconomic aggregate. Shocks are transited into the real exchange rate variation and the net export variation from both economies, but with a strong US domination. In particular, the US mark-up shock contributes to about 80% volatility of the real exchange rate and net exports. And this finding is common to both the non-coordination model and coordination models.

Instead of a balanced impact structure, US economic volatility, especially output and interest rate, is found to be dominated by the US price mark-up shock. In particular, when the time horizon is extended, a domestic price-mark up shock may take up more than 98% of the US output volatility. The productivity shock and monetary policy shock have certain impacts on US inflation and interest rate, but the scale is smaller than the findings in Le et al. (2010).

In contrast with the US economy, EA's economic volatility has more diverse sources. Output volatility in the EA is attributed largely to its productivity shock and investment shock. The EA price mark-up shock is pretty trivial in explaining EA output volatility, yet it contributes to EA inflation and interest rate rather significantly. Apart from the wage mark-up shock, government spending shock, and labour supply shock, all other EA shocks have large impacts on EA inflation volatility. Noticeably, the EA monetary policy shock is strongly influential to inflation, but not interest rate. EA interest rate volatility, more similar to its output volatility, is largely impacted by the productivity shock and the investment shock, though the preference shock and the price mark-up shock also affect the EA interest rate by 13% in total.

Table 4.14 shows a comparison of the non-coordination model and the coordination model (C-3.6) by the percentage effect of each US shock to eight macro-variables (7 target variables and US net exports to EA). The last row adds up the total effect from US shocks on each variable. Unsurprisingly, the effect of US shocks on the EA macro-aggregate is trivial in the non-coordination model; whilst with EA monetary coordination, US shocks have a remarkable impact on the total fluctuation of EA macro-aggregates. In particular, US shocks now have an unexpectedly high domination on the EA economic volatility – 31.2%, 53.6% and 53.4% of EA output, inflation and interest rate, respectively. As expected, the US shock that takes a major role in the EA volatility is the US price mark-up shock.

Moreover, compared to the non-coordination model, there is a substantial increase of impacts on the EA economy from the US productivity shock and government spending shock, even though the international transmission of these two shocks to the real exchange rate and trade balance is barely altered. This is possibly raised by the magnified impact on the coordinating economy through both the interest rate channel and the direct exchange rate channel. Such an impact can lead to too much volatility in the coordinating economy when either its counterparty is not coordinating or it has an over-aggressive response to the real exchange rate. Given the low degree of EA coordination in model C-3.6, the chance that the EA interest rate over-reacts to the real exchange rate is small. Whereas, it is more likely that a US shock is delivered entirely to the EA economic variation through both direct and indirect exchange rate channels. Without coordination, the US monetary policy will not counter-balance its domestic shocks until the associated impact hits US inflation and output; on the other hand, the entire shock impact on the real exchange rate puts immediate pressure on the contemporaneous EA interest rate and its movements in subsequent periods[34]. And with time lags, when the expenditure-switching effect takes

[34] The complete interest rate pass-through is assumed here in the example, as this is not the concern of this study at this moment.

place in both economies, the EA monetary policy will need to take both actual changes in the domestic economy and potential changes in the US policy into consideration. With both of these effects, US shocks are more likely to induce additional fluctuations in the EA interest rate and hence other aggregates in the case of sole EA coordination rather than partial coordination.

Table 4.15, similarly, shows a comparison of the non-coordination model and the coordination model (C-3.6) by the percentage effect of each EA shock to eight key variables. As mirrored from a large increase in the transmission of US shocks, the domestic contribution to the EA economic variation declines proportionally, but remains plausible. In particular, the EA productivity shock and investment shock are the major domestic forces. It is also worth mentioning that the EA preference and government spending shocks have even larger impacts on EA output in the presence of EA coordination. And again, the impact of EA shocks on the real exchange rate and trade balance is generally constant when moving from the non-coordination model to the coordination model.

Contrarily, hardly any impact from EA shocks is passed through to the US economy even though the scale of information reflected in the real exchange rate is not substantially changed after introducing monetary coordination. Simply by conducting the exercise again but with US coordination, it can be shown that this phenomenon is partially a result of no monetary coordination from the US. Yet even when the US coordinates to the same degree as the EA, EA shocks still have a relatively low impact on the US economy compared to the impact that the EA receives from US shocks. This result sheds light on other possible reasons that can cause 'two orthogonal continents'. For instance, an incomplete exchange rate pass-through and a weak expenditure-switching effect for various reasons can potentially isolate the US economy. Besides, by treating the ROW as exogenous, trade structures in the US and EA are partially truncated. And the information that the real exchange rate reflects may be far beyond that which a simple two-country relation can demonstrate.

		$\mathbf{y}^{us}$		$\mathbf{y}^{ea}$		$\boldsymbol{\pi}^{us}$		$\boldsymbol{\pi}^{ea}$		$\mathbf{r}^{us}$		$\mathbf{r}^{ea}$		**Q**		**nx**	
		NC	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**
	Prod	2.76	2.76	0	0.99	2.57	2.57	0	1.76	2.63	2.63	0	1.45	2.81	2.84	3.13	3.27
	Cons	0.12	0.12	0	0.02	0.68	0.68	0	0.05	0.87	0.87	0	0.36	0.39	0.52	1.31	2.0
	Inv	0.06	0.06	0	0.02	0.06	0.06	0	0.05	0.14	0.14	0	0.04	0.11	0.14	0.12	0.16
	Tayl	0.13	0.13	0	0.02	9.48	9.4	0	0.03	2.59	2.56	0	0.49	0.29	0.38	0.31	0.4
US	**WM**	0.01	0.01	0	0	0.01	0.01	0	0.004	0.01	0.01	0	0.00	0.01	0.01	0.01	0.01
	Gov	0.09	0.09	0	0.36	0.43	0.43	0	0.65	0.78	0.79	0	0.55	1.13	1.18	1.33	1.45
	PM	96.7	96.7	0	29.7	86.6	86.7	0	50.95	92.8	92.8	0	50.4	80.4	78.9	79.1	76.7
	LabS	0.18	0.18	0	0.07	0.19	0.19	0	0.127	0.19	0.19	0	0.1	0.21	0.22	0.18	0.18
	Total	100	100	0	31.2	100	100	0	53.62	100	100	0	53.4	85.3	84.2	85.5	84.1

Table 4.14: Variance decomposition (NonC vs. C-3.6) - US shocks

		$\mathbf{y}^{us}$		$\mathbf{y}^{ea}$		$\boldsymbol{\pi}^{us}$		$\boldsymbol{\pi}^{ea}$		$\mathbf{r}^{us}$		$\mathbf{r}^{ea}$		**Q**		**nx**	
		NC	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**	**NC**	**C-3.6**
	Prod	0	0	40.7	24.5	0	0.002	24.1	14.0	0.01	0.003	35.0	17.3	8.15	8.77	7.54	8.05
	Cons	0	0	1.80	2.18	0.003	0	9.47	5.08	0	0.001	6.34	3.1	0.15	0.2	0.66	1.03
	Inv	0	0	51.7	37.1	0	0.002	34.4	13.1	0.01	0.003	50.0	22.0	5.4	5.61	5.46	5.76
	Tayl	0	0	2.65	2.00	0.003	0	18.5	6.75	0	0	0.69	0.31	0.56	0.69	0.49	0.58
EA	**WM**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gov	0	0	1.65	2.04	0	0	0.34	0.34	0	0	0.42	0.28	0.09	0.11	0.07	0.09
	PM	0	0	0.31	0.28	0	0	12.7	6.64	0	0	6.9	3.28	0.14	0.19	0.14	0.19
	LabS	0	0	1.14	0.74	0	0	0.47	0.43	0	0	0.65	0.40	0.21	0.24	0.19	0.2
	Total	0	0	100	68.8	0.006	0.004	100	46.4	0.02	0.007	100	46.6	14.7	15.8	14.5	15.9

y^i, π^i, r^i – output, inflation and interest rate for economy $i = US, EA$, respectively;
Q – the real exchange rate between the US dollar and the euro; nx – net exports between the US and EA;
Prod – productivity shock; Cons – preference shock; Inv – investment technology shock; Tayl – monetary policy shock;
WM – wage mark-up shock; Gov – exogenous government spending; PM – price mark-up shock; LabS – labour supply shock;

Table 4.15: Variance decomposition (NonC vs. C-3.6) - EA shocks

More importantly, this result provides a demonstration of the EA's crucial role in the global economy – it effectively accommodates shocks from both economies. It is expected that the stabilising effect is generated from both internalising domestic shocks by reacting to the self-induced exchange rate fluctuation and counteracting foreign shocks by reacting to the external-induced exchange rate fluctuation. Nonetheless, its effectiveness relies on not only the degree of monetary coordination, but also the degree of pass-through from shocks and policies.

With EA monetary coordination, US shocks are more likely to be transmitted into the EA economy and stabilised before feeding back to the US economy. On the other hand, even when the US coordinates, EA shocks are less likely to be transited into the US economy; therefore, given the same level of self-accommodating actions, the stabilising effect given by the US is less effective than the EA. As a whole, EA monetary coordination is fast and effective, easing the impact of domestic shocks on the EA, as well as minimising the impact being transmitted into the US economy. Meanwhile, US monetary coordination plays a relatively small role (a trivial role especially in model C-3.6) in stabilising economies.

Conventionally, analyses on the propagation of the business cycle put considerable attention on TOT, international trade and interest rate effects; indeed, the implication was meaningful. Nonetheless, this exercise also raises the importance of monetary policy coordination, which opens up a direct exchange rate channel for modelling the international transmission mechanism of shocks. Provided that economic fundamental changes are reflected in the real exchange rate on the same scale across both the non-coordination and coordination models, it would be expected that any of the increased international transmission of shocks is facilitated by monetary policy coordination. It also implies that allowing trade in the good and financial markets is not sufficient in mimicking the international transmission mechanism if the representation of relative prices is unclear. The missing exchange rate channel might disable the propagation mechanism even if the trade channel and the interest rate channel are present.

4.5 Conclusion

This chapter evaluates a non-coordination model and various coordination models using the indirect inference method. The benchmark model, the non-coordination model, is a two-country DSGE model built on the influential work of Smets and Wouters (2003, 2007), with additional cross-country links. The featured international good and financial market enables the propagation of shocks across borders. Although the framework is found to perform better than other DSGE alternatives, especially in terms of the dynamic behaviour of key macroeconomic aggregates, it left a puzzle of surprisingly weak spillover between economies.

On the other hand, the modern economy witnesses a growing macroeconomic interdependence as a result of economic, technological, political and sociological developments. The call for macroeconomic policy coordination has increased during the years of global integration, particularly in periods of crises. Despite all that, the majority of the literature, including strategic game models and NOEM models, found an insignificant role played by monetary coordination. The interest of this study, therefore, lies in the existence of monetary coordination, embedded in the monetary policy rule as a direct response to the real exchange rate, and its impacts on the DSGE models' performance. Monetary authorities' coordination actions as a consequence of macroeconomic interdependence are unveiled by the policy instrument's direct response to the real exchange rate. Thus, the null hypothesis that monetary policy coordination exists holds if incorporating real exchange rate responses in a monetary policy rule can improve the DSGE models' ability to replicate data substantially closer to the actual data.

Indirect inference is used to draw a statistical inference from various DSGE models for model evaluation and comparison. To evaluate the overall performance of a model, coefficients of the auxiliary model (dynamics) and simulated variances (volatility) are both included in the testing object. Corresponding normalised MDs are also reported alongside the Wald statistic percentile. The testing period is extended relative to previous studies; ranging from 1970 to 2008 subject to data availability.

The testing result implies that coordination models generally outperform the baseline non-coordination model, due to improvements in both the prediction precision and the prediction uncertainty. Hence, the null hypothesis holds; monetary policy coordination, or such interdependent actions, exists over the past four decades within the sample period of this study.

By a close investigation of various coordination models, it is suggested that EA monetary coordination has a crucial role in stabilising both economies to some extent. However, there are trade-offs that potentially complicate the design of a coordination policy in the EA – the weak coordination tends to cut down the volatility of output and the real exchange rate, whilst the strong coordination is more effective at lowering inflation and interest rate variances. On the contrary, sole US coordination has no considerable benefit as an economic stabiliser; instead, it becomes one of the causes of high real exchange rate volatility as the degree of coordination rises.

When variables of interest are limited to output and inflation, which are essential in the CBs' loss function considered in most studies, the models' ability to replicate US data, but not EA data, is dramatically improved. Moreover, models' performance deteriorates heavily once the real exchange rate is included, irrespective of whether monetary coordination is present. This sharply widened gap implies that reproducing the real exchange rate is essential in improving DSGE models' in-sample performance.

Additionally, variance decomposition exercise justifies the importance of monetary coordination in illustrating real exchange rate dynamics and enhancing the transmission mechanism of shocks. The simple trade channel and interest rate channel are not sufficient in modelling the international transmission mechanism since a mis-illustrated exchange rate will disable the proper functioning of those conventional channels to some extent. As a whole, the model's propagation of shocks is enhanced by the direct exchange rate channel, but the benefits in terms of lowering variances of macroeconomic aggregates in either economy are ambiguous. Monetary coordination provides feedback routes to accommodate shocks and stabilise the economy, whilst it also implies a higher exposure of the coordinating economy to foreign shocks. In particular, when its counterparties have no intention of coordinating, the EA economy is more likely to suffer from instability transmitted from the US.

Chapter 5

Estimating the US-EA Two-Country DSGE Model

5.1 Introduction

Ever since the refinement of DSGE models that allows conventional econometric techniques to be applied, this theoretically attractive framework has drawn immense attention from researchers focusing on forecasting and quantitative policy analysis, and even gained itself a place in CBs and some multilateral institutions[1]. Its coherent and micro-founded properties enable researchers to identify sources of variations, predict impacts from policy adjustments and structural changes as well as perform counterfactual experiments. Moreover, its ability to link structural parameters to reduced-form parameters facilitates a large breakthrough in understanding structural behaviours of the economy. The progress of DSGE modelling is quickly absorbing and incorporating all of the different features of the economic reality, such as sectoral specifications, heterogeneities and the behavioural psychology and so forth.

Notwithstanding these advantages, a question remains on how well a DSGE

[1] Some central banks have already developed their own DSGE models. Examples are the Bank of Canada, the Bank of England, the European Central Bank, and the US Federal Reserve. Also, international institutions like the International Monetary Fund (IMF) also have their own DSGE model.

model is fitting the actual data, in other words, can it be empirically validated?

Smets and Wouters in 2003 (SW, 2003) and Christiano, Eichenbaum and Evans in 2005 (hereafter CEE (2005)) set forward the success of DSGE models. The evidence emerged that an elaborate DSGE model with nominal and real rigidities can forecast macroeconomic time series reasonably well, accounting for the effects of various structural shocks, especially monetary policy shock.

In 2010, the work of Le, Meenagh, Minford and Wickens (Le et al., 2010) presented a two-country DSGE model, which is a combined version of the individual models in SW (2003) and SW (2007). The method of indirect inference was conducted to evaluate the model's closeness to actual data properties from the perspective of traditional econometric inference. It was shown that a cross-country link by a good market and a financial market improved the open-economy DSGE model's performance to an extent, but a mystery remained as the cross-country interactions were still absent from the system. As demonstrated in Chapter 4, to restore the link between two economies and improve the model's performance, it is important to allow monetary coordination by means of a policy instrument's direct reaction to real exchange rate movements.

As an extension, this chapter goes one step further to estimate this US-EA two-country DSGE model with monetary policy coordination using the indirect inference methodology. In three main aspects, this attempt differs from previous studies.

First, despite the large amount of literature estimating or parameterizing DSGE models, only a few of them used the indirect inference estimation[2]. The most relevant method of this kind is the Minimum Distance Estimation (MDE) used in Rotemberg and Woodford (1997) and CEE (2005), in which parameters were chosen to minimise the difference between IRFs, estimated from a VAR, and the analogous objects in a model. Theodoridis (2011) also used this method

[2]Except for calibrations from the empirical evidence, other methods to parameterise models include estimations using Generalized Method of Moments (GMM), Full-Information Maximum Likelihood (FIML), Bayesian method as well as Minimum Distance Estimation (MDE).

to estimate a DSGE model, but has chosen to match both impulse responses and the reduced-form error covariance.

Second, this study is one of the few studies focusing on large open-economy DSGE models. The existing literature employing DSGE models is mainly focusing on closed-economy or small open-economy models. In contrast, by pooling the US and EA economies together, three quarters of the 'World' economy is then covered in this study. More importantly, there are strong bi-directional influences between markets and interactions between authorities in these two regions. It is such mutual dependence that enables the concept monetary policy coordination to be developed, and the potential welfare improvement to be realised.

Last but not least, the model incorporates monetary coordination specified by a monetary instrument's direct responses to real exchange rate movements. The incentives of a monetary authority adopting monetary policy coordination lie in the macroeconomic interdependence – their policy influences each other at an aggregate level. This specification opens up an additional exchange rate channel, hence, changes both the domestic and international propagation mechanism. The spillover between the two economies is hence clearly observed – shocks and policies are channelized not only through the traditional trade and interest rate channels, but also through a direct exchange rate channel and implicitly through policy adjustments.

5.2 Parameters in Estimation

The focus of the estimation lies in two parts: first, common parameters characterising economic fundamentals in both the non-coordination and coordination models; second, parameters characterising the monetary policy coordination feature in a coordination model.

There are thirty-three common parameters, including two capital share coefficients (α^{us}, α^{ea}), four consumption or labour supply elasticities (σ_c^{us}, σ_l^{us}, σ_c^{ea}, σ_l^{ea}), eight nominal rigidity and partial-indexation coefficients (ξ_w^{us}, ξ_p^{us}, ι_w^{us}, ι_p^{us},

ξ_w^{ea}, ξ_p^{ea}, γ_w^{ea}, γ_p^{ea}), six coefficients accounting for real economic frictions ($\bar{S}^{us\prime\prime}$, ϕ_p^{us}, ψ^{us}, $\bar{S}^{ea\prime\prime}$, ϕ^{ea}, ψ^{ea}), nine monetary policy rule coefficients (ρ^{us}, r_π^{us}, r_y^{us}, $r_{\Delta y}^{us}$, ρ^{ea}, r_π^{ea}, r_y^{ea}, $r_{\Delta y}^{ea}$, $r_{\Delta\pi}^{ea}$), and finally four New Keynesian weighting parameters in the wage and price setting equations (Φ_w^{us}, Φ_p^{us}, ϕ_w^{ea},ϕ_p^{ea}). These parameters and their initially calibrated values are listed in Table 5.1.

By searching for the optimal values for a broad range of parameters, it will be interesting to see what a well-established DSGE framework can imply for economic behaviours, from an explorative rather than inspectoral aspect.

The first category of these parameters defines a real side of the economy regarding the production and consumption preferences. The capital share, reflecting the production input structure in an economy, is closely linked to the status of the economic development. Elasticities of intertemporal substitution and labour supply, directly affecting the effectiveness of both the monetary and fiscal policies, are reflections of a household's preferences regarding timing and leisure.

The second category of parameters reveals economic rigidities both from nominal and real aspects. Coefficients for the Calvo setting and the partial indexation form the price and wage setting behaviours in both forward and backward looking manners. Weights of the NK behaviour are the additional elements used in Le et al. (2010), which permit an investigation on the scope of the NK behaviour in an economy. In addition to the price and wage setting equations, Le et al. (2010) also characterised the scope of the NK behaviour in both monetary policy rules. However, for the purpose of finding a single monetary policy rule that prevails in each individual economy, the NK weights in the monetary policy rule are laid aside in the estimation.

Costs of capital adjustment and utilization, characterising real economic friction, are put forward to form more realistic links between investment, output growth and technological developments. The share of fixed costs in the production to some extent determines the production capacity and future economic growth. Last but not least, a set of parameters features monetary policies prevalent over four decades in these two largest economies in the world.

	Initial	**Descriptions**
α^{us}	0.19	share of capital in production
$\bar{S}^{us\prime\prime}$	5.74	steady state elasticity of capital adjustment cost
ϕ_p^{us}	1.5	one plus the share of fixed costs in production
ψ^{us}	0.54	elasticity of capital utilization cost
σ_c^{us}	1.38	coefficient of relative risk aversion of households
σ_l^{us}	1.83	inverse of elasticity of labour supply with respect to the real wage
ξ_w^{us}	0.7	degree of nominal wage stickiness
ξ_p^{us}	0.66	degree of nominal price stickiness
ι_w^{us}	0.58	degree of indexation to past indexation in wage setting
ι_p^{us}	0.24	degree of indexation to past indexation in price setting
Φ_w^{us}	0.1*	weights of NK in wage setting equation
Φ_p^{us}	0.2*	weights of NK in price setting equation
ρ^{us}	0.81	degree of interest rate smoothing in monetary policy rule
r_π^{us}	2.04	coefficient of inflation deviation in monetary policy rule
r_y^{us}	0.08	coefficient of output gap in monetary policy rule
$r_{\Delta y}^{us}$	0.22	coefficient of short-run output gap in monetary policy rule
α^{ea}	0.3	share of capital in production
$\bar{S}^{ea\prime\prime}$	7	steady state elasticity of capital adjustment cost
ϕ^{ea}	1.487	one plus the share of fixed costs in production
ψ^{ea}	0.175	elasticity of capital utilization cost
σ_c^{ea}	1.608	coefficient of relative risk aversion of households
σ_l^{ea}	1.188	the inverse of elasticity of labour supply with respect to the real wage
ξ_w^{ea}	0.758	degree of nominal wage stickiness
ξ_p^{ea}	0.909	degree of nominal price stickiness
γ_w^{ea}	0.663	degree of indexation to past indexation in wage setting
γ_p^{ea}	0.425	degree of indexation to past indexation in price setting
ϕ_w^{ea}	0.08	weights of NK in wage setting equation
ϕ_p^{ea}	0.06	weights of Nk in price setting equation
ρ^{ea}	0.931	degree of interest rate smoothing in monetary policy rule
r_π^{ea}	1.661	coefficient of inflation deviation in monetary policy rule
r_y^{ea}	0.143	coefficient of output gap in monetary policy rule
$r_{\Delta y}^{ea}$	0.173	coefficient of short-run output gap in monetary policy rule
$r_{\Delta \pi}^{ea}$	0.221	coefficient of short-run inflation deviation in monetary policy rule

Table 5.1: Parameters in the estimation

Aside from the conventional coefficients[3], four parameters characterizing monetary policy coordination are also estimated in the coordination model. h_0^{us} and h_0^{ea} represent the degrees to which monetary authorities respond to the contem-

[3]Depending on the monetary regime, a conventional monetary policy rule may consist of some, or all, of the factors including the interest rate smoothing (policy inertia), the inflation deviation from the authority's inflation targets, the output gap between the current output and the output level that prevails in the corresponding flexible economy, the short-run inflation deviation from its lagged inflation rate, the short-run output gap between the current output and the lagged output level, etc.

poraneous real exchange rate (Q_t), while h_1^{us} and h_1^{ea} are the degrees to which monetary authorities respond to the lagged real exchange rate; in other words, they represent the adjustments to the previous policy response regarding the real exchange rate.

Theoretically, a real depreciation (a decline in the value of Q_t for the US, or an increase in the value of Q_t for EA) will be balanced instantaneously by a tightening monetary policy that raises the short-run nominal interest rate. That is to say the US nominal interest rate is negatively influenced by the current real exchange rate, whilst the EA nominal interest rate is positively responsive to the current real exchange rate. Meanwhile, the nominal interest rates adjust to the lagged real exchange rate in an opposite manner to the way they react to the current value. Depending on the elasticity of responses, the adjustments to the lagged real exchange rate help to balance out the previous monetary policy effect, preventing excessive fluctuations.

Most of the common parameters are estimated subject to 50% upper and lower bounds around the initial values[4]. The coefficients for monetary coordination are set within a $[0, 1]$ interval ensuring a wider range for searching for the best fit monetary policy rule. The initial values of parameters are partially adopted from the original closed economy SW (2003) and SW (2007) models, and partially estimated in the two-country version in Le et al. (2010).

5.2.1 Objectives of the Estimation

The aim of an indirect inference estimation is to find out a set of parameters that minimises the distance between the simulated and actual data. Such a distance is measured by an actual Wald statistic (W_T) computed according to the outputs from an auxiliary model.

In an open-economy DSGE model, the cross-country interactions are also

[4]For the weighting coefficient such as degrees of the nominal price stickiness and NK's weights in the price and wage equations, the value of upper bound is manually set to 1 if its 50% upper bound value exceeds 1.

mimicked along with the other real and nominal properties. By seeking parameters that best describe the economic reality in such a DSGE model, this study can (1), further evaluate how well a DSGE model can perform providing the existing structural setting and optimised parameters; (2), better understand the way that economies behave from a more globalised perspective, providing the model evaluation is supportive towards a substantial improvement.

Additionally, the thirty-three common parameters, providing a source of comparison, are estimated using the non-coordination model. In the previous chapter, the existence of monetary policy coordination is proved robustly. Nonetheless, the fact that structural parameters are mostly calibrated according to some closed-economy models can be held against this result.

Parameters that can describe the behaviour of a closed economy reasonably well may not be appropriate for describing an open economy. Inappropriate calibrations may well be the main factor that fails the non-coordination model, rather than the lack of monetary policy interaction in the model structure. In such a case, the monetary policy coordination may be unnecessary or even counterproductive. Thus, the estimation of the non-coordination model serves to clarify the issue of calibration, by comparing the actual Wald statistics of the non-coordination and the coordination model when both are at their estimated optimum. The lower the actual Wald statistic, the closer the actual data is to the model-simulated mean, hence, the better the model can replicate economic reality.

In actual practice, nevertheless, the specific objective to be minimised may vary subject to the difference in research interests, such as variables of interest (target variables) and the number of variables in joint interest as well as the aspects of performance that are focused upon.

To be consistent with the model evaluation in the previous chapter, a target variable set consists of seven variables across both economies, including output, inflation, interest rate and the real USD/EUR exchange rate. The actual Wald statistic for both dynamics and volatility is used as a criterion.

5.2.2 Estimation Particulars

The method used for estimating models is the method of indirect inference as specified in Chapter 3, assisted by the Simulated Annealing (SA) algorithm for searching for the value of parameters within set boundaries.

Simulated Annealing (SA) is a generic probabilistic algorithm for approximating global optimisation of a given function across a large spatial area. In order to avoid being trapped in the local optimum, SA algorithm allows jumps that shift away from the set of parameters that seems to be optimal by an assigned probability. Compared with an exhaustive search that enumerates all possible solutions, the SA algorithm keeps the computation to a minimum. And it is more suitable here as long as the number of iterations is sufficiently large to allow for a thorough search over a restricted space.

An iteration in the estimation begins with a set of parameter values generated by the SA algorithm. The following process is carried out in the exact order as the model evaluation – deriving shocks and the associated coefficients for the shock dynamics and volatility; generating bootstrap-simulated datasets; obtaining auxiliary parameters from the actual and model-simulated data; and finally computing Wald statistics and the associated statistics. One actual Wald statistic (W_T) is produced by each iteration, and is taken as a criterion for judging the optimal estimates. The estimation process repeats until a certain criterion is matched – for example, the estimation has converged or the maximum number of iterations is reached.

For a computational reason, the maximum number of iterations is pre-set at 2300, considering the possibility of unsolved cases. As there is no additional parameter restriction, it is possible that the model cannot be solved by Dynare. To guarantee a creditable estimating result, the same exercise is conducted again with initial values being the indirect inference estimates from the first estimation.

5.3 Estimation Results

5.3.1 A Comparison of the Non-Coordination and Coordination Models

Two models, one benchmark non-coordination model and one partial-coordination model, are estimated. The partial-coordination model with initial coordinating elasticity $h_0^{us} = -h_0^{ea} = -0.5$ and $h_1^{us} = -h_1^{ea} = 0.5$ is selected given that the model evaluation shows a mixed implication from the diverse coordination specifications. By allowing the absolute values of coordinating elasticities to vary within a $[0, 1]$ interval, the cases of single country coordination or even a case of non-coordination are not excluded.

Taking the non-coordination model with original calibrations as a benchmark model[5], this section compares the performance of the estimated non-coordination and the estimated partial-coordination model with the performance of a calibrated benchmark. Insomuch that both models show better performances after the estimation, parameters adopted from a closed economy are not capable of describing economic reality in the context of global interactions. More importantly, it is confirmed by an outstanding performance of the partial-coordination model that monetary policy coordination plays an important role regardless of what the official label says.

Table 5.2 lists the actual Wald statistics across models before and after estimations and their corresponding test results. Though the case for benchmark is drawn randomly, the reported actual Wald statistics for the estimated non-coordination and partial-coordination models are the average of 1000 simulations in order to avoid bias by random sampling (see Appendix C Figure C-2 and C-1 for statistical distribution).

Clearly, even without coordination policy, the actual Wald statistic has fallen

[5] All other calibrated values are kept the same as in the model evaluation, except for two coefficients for the NK weights in the monetary policy rules (Φ_m^{us}, ϕ_m^{ea}). They are both set to one for specifying an effective monetary policy rule. This is for the purpose of comparing with indirect inference estimates in this chapter.

dramatically to 2001.97 with estimated parameters, suggesting a possible 93.6% drop in the actual Wald statistic value compared to its analogic version using original calibrations.

The test result[6] also shows a substantial improvement in the model's performance after the estimation. There are substantial changes in parameters, within which half move away from the calibrated value by around 20%. A large divergence of an estimated value from its initial calibration may suggest a high level of parameter sensitivity to the changing data[7], or more likely, inappropriate calibrations adopted from the previous closed economy studies. After all, the majority of calibrated values are originally from the individual closed-economy models. Merely adopting parameters from a closed-economy model and presuming the way that an economy, government or monetary authority responds may no longer be sufficient in an open economy case.

Such a result is not too surprising knowing that the economic agents are constantly adjusting their optimisations according to all the available information – imposed by the Rational Expectation Hypothesis (REH). As defined by John Muth (1961), the information set included all the exogenous variables, all past values of endogenous variables and the structure of the model. Changes in the monetary policy rule should alter the structure of the model accordingly – as suggested by Lucas Critique. Therefore, the reduced form of the model should also be changed; and suggested by the statistics, fit the actual data better in this case.

Meanwhile, regardless of the improvement in the baseline model, the partial-coordination model is fitting the actual data significantly better than the baseline

[6] For the benchmark case, the test result is obtained from the sample that generates the actual Wald statistic $W_T = 31299.21$. While for estimated models, since the reported actual Wald statistics are the average values, their corresponding test results are taken from the case that produces the closest actual Wald statistic to the mean. For the estimated non-coordination model, the test result is obtained from the simulation that gives an actual Wald statistic $W_T = 2001.855$. For the estimated partial-coordination model, the test result is taken from the simulation that gives an actual Wald statistic $W_T = 600.925$.

[7] Although the selected datasets are consistent with those in SW (2003), SW (2007), and Le et al. (2010), they are subject to revisions. Also, the data length is extended to cover a period between 1970 and 2008.

	Wald stats (actual W_T)	**Wald percentile**
		Dynamics+Volatility
Baseline non-coordination	$31,299.21$	100% (147.8)
Estimated non-coordination	$2,001.97$	100% (33.64)
Estimated partial-coordination	600.9	100% (15.15)

The first column shows actual Wald statistics of the individual model; The second column shows the joint test results concerning all seven variables using the corresponding parameter set. The figures in parenthesis are the corresponding normalised MDs.

Table 5.2: The estimation result (7 variables)

non-coordination model and even to the estimated non-coordination model. The actual Wald statistic falls more than 98% to 600.9 relative to the baseline non-coordination model, and about 70% relative to the estimated non-coordination model – even though the magnitude of the fall is still not sufficient for its value to be in the acceptance range.

The comparative improvement of the estimated non-coordination model relative to the estimated partial-coordination model can be illustrated through the improvement in (1) the model's ability to replicate data dynamics ($VAR(1)$ coefficients); (2) the model's ability to replicate data volatility (variance of a target variable).

From a dynamic perspective, 34 out of 49 actual $VAR(1)$ coefficients (70%) fall between bounds simulated by the estimated partial-coordination model. Specifically, the dynamics of US aggregates and the real exchange rate are well mimicked. Only 3 out of 21 simulated bounds associated with the US aggregate dynamics ($A_I^{y^{us}}, A_I^{\pi^{us}}, A_I^{r^{us}}$) fail to capture actual $VAR(1)$ coefficients in the partial-coordination model. The model's ability to capture real exchange rate dynamics (A_I^Q) is remarkably improved – only an autoregressive coefficient for the real exchange rate is marginally missed out by the simulated bounds (see Table 5.3; notations are the same as in Table 4.8). Also, the transmission of impacts from the real exchange rate to each target variable is better captured compared with the estimated non-coordination model, even though the improvement is marginal

		non-coordination				partial-coordination			
	Actual	**Mean**	**LB**	**UB**		**Mean**	**LB**	**UB**	
$A_Q^{y^{us}}$	0.2672	−0.062	−0.154	0.0179	OUT	−0.147	−0.558	0.2841	IN
$A_Q^{y^{ea}}$	−0.099	−0.019	−0.073	0.0349	OUT	−0.003	−0.219	0.1955	IN
$A_Q^{\pi^{us}}$	−0.094	−0.013	−0.097	0.0568	IN	−0.259	−0.501	−0.012	IN
$A_Q^{\pi^{ea}}$	−0.263	0.0254	−0.027	0.0794	OUT	−0.021	−0.139	0.0913	OUT
$A_Q^{r^{us}}$	−0.291	0.028	−0.037	0.0905	OUT	−0.089	−0.284	0.1075	OUT
$A_Q^{r^{ea}}$	−0.168	−0.007	−0.025	0.0103	OUT	0.0159	−0.111	0.1369	OUT
$A_{y^{us}}^Q$	−0.005	−0.059	−0.175	0.0472	IN	−0.0007	−0.022	0.0209	IN
$A_{y^{ea}}^Q$	0.0049	0.0876	−0.037	0.223	IN	−0.017	−0.076	0.0335	IN
$A_{\pi^{us}}^Q$	−0.010	1.5374	1.0645	2.0324	OUT	0.2425	−0.071	0.5454	IN
$A_{\pi^{ea}}^Q$	−0.007	−0.661	−0.954	−0.373	OUT	−0.188	−0.373	0.0013	IN
$A_{r^{us}}^Q$	0.0245	−1.832	−2.376	−1.314	OUT	−0.206	−0.566	0.1927	IN
$A_{r^{ea}}^Q$	−0.023	0.6934	0.2507	1.1116	OUT	−0.176	−0.563	0.1723	IN
A_Q^Q	0.9368	0.9111	0.7675	1.0303	IN	0.7764	0.6	0.9272	OUT
$\sigma_{y^{us}}^2$	8.1212	31.35	10.309	64.418	OUT	50.94	15.27	111.28	OUT
$\sigma_{y^{ea}}^2$	3.6088	21.646	6.608	47.129	OUT	5.7173	2.2587	11.038	IN
$\sigma_{\pi^{us}}^2$	0.3886	2.3626	1.3899	3.8845	OUT	2.7086	1.4617	4.4029	OUT
$\sigma_{\pi^{ea}}^2$	0.2386	3.172	1.7699	5.234	OUT	0.3747	0.2054	0.616	IN
$\sigma_{r^{us}}^2$	0.8427	2.3449	1.4826	3.5737	OUT	2.2274	1.2027	3.591	OUT
$\sigma_{r^{ea}}^2$	0.4319	2.3752	1.0606	4.1871	OUT	0.3627	0.2207	0.5705	IN
σ_Q^2	0.0260	28.96	10.361	66.221	OUT	0.7207	0.3415	1.3035	OUT

Table 5.3: VAR parameters, simulated means and bounds for the estimated non-coordination and partial-coordination models

(considering both the error band and the simulated mean).

Compared to the previous studies finding random walks in the exchange rate, the partial-coordination model connects the real exchange rate dynamics to macroeconomic fundamentals. In particular, the influence of monetary policies on the exchange rate is well captured. Although partly due to a lower level of inflation persistence ($A_{\pi^{us}}^{\pi^{us}} = 0.7713$, $A_{\pi^{ea}}^{\pi^{ea}} = 0.2626$), the replicated real exchange rate is less persistent than the actual data. On the contrary, the 'exchange rate disconnect' puzzle remains as the real exchange rate does not appear to explain the dynamics of macroeconomic fundamentals.

Nevertheless, the improvement comes at the expense of the deteriorating ability to capture EA aggregate dynamics, especially EA inflation. It is also worth noting that the simulation volatility is exaggerated in the estimated partial-coordination model, which widens its simulated bounds in order to capture the actual data dynamics.

Contrasting with the worsening EA aggregate dynamics, the estimated partial-coordination model has overwhelming success in replicating the volatility of EA output, inflation and interest rate – the simulated bounds embrace the actual time series variance reasonably well (see Table 5.3). Most remarkably, the simulated variance of the real exchange rate has gone down to 0.72, a 97.5% improvement even when comparing with the simulated variance produced by the estimated non-coordination model. Interestingly, despite a slight downward movement, the partial-coordination model fails to bring down the volatility of US aggregates substantially.

By and large, this estimation result is consistent with the testing finding in Chapter 4 that the monetary coordination property enables the open-economy DSGE model to describe reality better. Therefore, monetary coordination by means of reacting directly to the real exchange rate plays an important role between these two economies over the period since the 1970s, regardless of what is claimed by the officials. However, it is also clear that even finding suitable parameters through the indirect inference estimation cannot develop this model well enough to be accepted by the statistical test jointly on seven key macro-indicators.

5.3.2 Estimated Parameters from the Partial-Coordination Model

As mentioned previously, there are 37 parameters involved in the estimation of the partial-coordination model – 33 of which are common parameters regardless of whether countries are coordinating with each other, and 4 of which are particularly specified for characterising the coordination feature. All of the common parameters are estimated within 50% upper and lower bounds around the initial calibrations. Four parameters featuring coordination are estimated within a $[0, 1]$ interval, with starting coefficients all at 0.5. Intuitively, a monetary authority is able to specify its policy rule responding to the contemporaneous real exchange rate at a degree between 0% and 100%. Meanwhile, a lagged adjustment to policy impacts from the previous policy action is also limited within the same interval.

The calibrated parameters and their estimated values from the partial-coordination model are compared in Table 5.4. The last column of the table shows how significant an estimated parameter differs from its associated calibration by presenting a percentage change of the estimate relative to its initial value. Most parameters differ from the associated initial values to an extent – after all, the calibrations are mainly taken from closed-economy models, and are for a period not covering the entire sample period in this estimation. Yet it is still surprising to find that the way these two economies behave has exhibited such a large deviation from the previous studies. Given 50% estimation bounds, 17 out of 33 common parameters (51.5%) shift away from their initial values by 20% at least.

Capital Share, Risk Aversion and Labour Supply Elasticity

The share of capital (or factor share in general) in production function is always in the frontline studies on economic growth and trade. It has been particularly

	Initial	**Estimated from Coordination model**	**% changes**
h_0^{us}	$--$	0.537412404	$--$
h_1^{us}	$--$	0.188682261	$--$
h_0^{ea}	$--$	0.916113347	$--$
h_1^{ea}	$--$	0.380882356	$--$
α^{us}	0.19	0.18099328	-4.74
$(S^{us})''$	5.74	3.718443232	-35.219
ϕ_p^{us}	1.5	1.040320152	-30.645
ψ	0.54	0.588376843	8.959
σ_c^{us}	1.38	1.457612432	5.624
σ_l^{us}	1.83	1.168410138	-36.152
ξ_w^{us}	0.7	0.75707935	8.154
ξ_p^{us}	0.66	0.795572529	20.541
ι_w^{us}	0.58	0.497532053	-14.219
ι_p^{us}	0.24	0.237827833	-0.905
Φ_w^{us}	0.1	0.078627618	-21.372
Φ_p^{us}	0.2	0.204074451	2.037
ρ^{us}	0.81	0.49276564	-39.165
r_π^{us}	2.04	2.624063542	28.63
r_y^{us}	0.08	0.082510137	3.138
$r_{\Delta y}^{us}$	0.22	0.216930262	-1.395
α^{ea}	0.3	0.315276978	5.092
$\bar{S}^{ea\prime\prime}$	7.0	9.48270622	35.467
ϕ^{ea}	1.487	1.859896947	25.077
ψ^{ea}	0.175	0.119606142	-31.654
σ_c^{ea}	1.608	2.218967882	37.996
σ_l^{ea}	1.188	1.120739279	-5.662
ξ_w^{ea}	0.758	0.880001682	16.095
ξ_p^{ea}	0.909	0.970792531	6.798
γ_w^{ea}	0.663	0.836072184	26.104
γ_p^{ea}	0.425	0.426825108	0.429
ϕ_w^{ea}	0.08	0.047234646	-40.957
ϕ_p^{ea}	0.06	0.045662162	-23.896
ρ^{ea}	0.931	0.662154512	-28.877
r_π^{ea}	1.661	1.634455747	-1.598
r_y^{ea}	0.143	0.193813819	35.534
$r_{\Delta y}^{ea}$	0.173	0.116835092	-32.465
$r_{\Delta \pi}^{ea}$	0.221	0.20517139	-7.162

Table 5.4: Estimated parameters from the partial-coordination model

puzzling for researchers in terms of the 'stylised fact' of its long-term stability and short-term variability. Since the early studies date back to the 1950s, conventional wisdom considers a relatively constant factor share over time and space, which has been deeply embedded in economic models thereafter.

For instance, it is particularly invoked by the economic modelling justifying the use of the Cobb-Douglas production function and its similar kinds, which explicitly presume a constant factor share. Nevertheless, some recent studies have not only heavily criticised the conventional approach for measuring factor shares, but also documented a time-varying (or trendy) pattern over time and across industries, in particular, in the US whose factor shares in production were taken as smooth in much literature.

In SW's models, intermediate good producers are assumed to have a Cobb-Douglas production function and hence the value of factor shares is assigned taking into account previous empirical findings.

The EA capital share was calibrated at 0.3, well within the bounds suggested by the empirical evidence. The US capital share was estimated using Bayesian estimation. The estimate fell much lower than its initial value to 0.19, though it is still on the edge of the past empirical finding.

As a result of indirect inference estimation, the average capital share across EA countries is estimated to be around 0.315 over the past four decades, implying a share of labour income in the total output at just below 70%. This estimate of capital share is fairly in line with the SW's calibration, and is consistent with previous studies that found estimated capital shares vary between 0.2 and 0.4 across countries[8]. In contrast, an average capital share of 0.181 in the US over the same period indicates a mild decline relative to the SW's Bayesian estimate[9]. This figure implies a labour income share above 80%, which is touching the ceiling

[8] For example, Bernanke and Gurkaynak (2001) estimated labour shares for 53 countries, of which 11 countries are members of the Euro Area. The exception of Cyprus, Estonia, Luxembourg, Malta, Slovakia and Slovenia together only accounts for 2% of total EA nominal GDP. They found that the average labour shares across countries was 0.65 even when taking different approaches.

[9] The SW's estimate of the US capital share was 0.19 over a period between 1980 and 1999.

of the literature findings as well as the conventional assumptions in economic models.

Some early studies suggested that the US capital share can represent the level of capital share in other countries to some extent[10]. The moderate discrepancy of capital shares between the US and EA does not largely contradict this statement. Nonetheless, it might be informative on the difference of openness, nominal rigidities and economic developments between these two economies.

The second investigated aspect is the behaviour of the utility function, including coefficients of the risk aversion and elasticities of the labour supply with respect to real wages.

The household risk aversion (or the inverse elasticity of intertemporal substitution) reflects sensitivity of the consumption growth to the real interest rate. Accompanied by coefficients of the habit formation, it forms the interest rate semi-elasticity of consumption demand, which is crucial in a policy transmission mechanism. The higher it is, the lower the consumption responsiveness to the interest rate, hence, the lower the degree of policy effects in terms of the consumption stimulation.

Both SW's EA and US models reported the Bayesian estimates of the risk aversion to be close at around $1.35-1.40$, suggesting that households are slightly insensitive to the real interest rate. The indirect inference estimate for EA risk aversion is higher than the SW's estimate by more than 50%, and is also higher than the calibrated value in Le et al. (2010) by nearly 37%. The corresponding real interest rate semi-elasticity is about 0.142[11], significantly lower than the suggested value of 0.65 in Casares (2001)[12]. The suggested direct monetary policy

[10] For example, Bernanke and Gurkaynak (2001) reported that labour share across 53 countries is 0.65, lying between 0.60 and 0.8. Collin (2002) used an alternative measurement, and also found labour shares generally fall into the range of the US.

[11] The nominal interest rate is adjusted by the expected inflation rate, hence the real interest rate semi-elasticity is $\frac{1-h^{ea}}{\sigma_c^{ea}(1+h^{ea})}$. Given the coefficient of habit formation is kept constant at the calibrated value of 0.522. The rise of household risk aversion lifts sensitivity of the EA consumption growth to the direct policy change in the real interest rate.

[12] Casares (2001) estimated the structural consumption equation using data pre-dating the Euro Area (1970Q1-1998Q4). The data were the weighted averages over member countries.

impacts are hence much smaller than what would be expected from previous empirical studies.

US household risk aversion has a slight increase compared to the calibrated value, yet it is still lower than the EA by more than half. Comparatively, it is not that costly for US households when consumption is volatile. Hence, although US households save more for the future depending upon the magnitude of the increased real interest rate, the consumption smoothing is not as strong even though the interest rate fluctuates over time. However, given a high level of habit formation in the US[13], the real interest rate semi-elasticity remains low at 0.116. That is, the US consumption growth is still less likely to be influenced by a monetary policy relative to its EA counterpart[14].

The habit formation here captures real frictions on the household consumption growth, suggesting that households are more likely to track back their past consumption, instead of adjusting savings and consumption in accordance with real interest rate fluctuations or monetary policies. As more of a domestic factor, its value is adopted from the previous study. In short, in terms of lowering interest rate for the purpose of stimulating consumption demand, monetary policies are not very effective, especially in the US. On the other hand, consumption demand may not be dampened too much even when a contractionary monetary policy is needed.

The elasticity of the labour supply has a critical role in economic policy analysis, especially in the area of fiscal policies. Its high value represents a larger policy effect on employment, leading to a higher excess burden when policies such as tax and benefit reforms are imposed.

However, empirical studies evaluating labour supply elasticity took various approaches and reached dispersive results; and hence, there is no definitive con-

Their findings suggested that the direct policy impact on consumption was high on average.

[13] The coefficient for the habit formation was estimated in SW's US model to be 0.71.

[14] The coefficient of habit formation is set to be high at 0.71, suggesting that US households keep their consumption in line with the past to a high degree, rather than follow what is happening with the interest rate contemporarily.

clusion on the value that should be used in a policy analysis[15]. Meanwhile, the general equilibrium model tends to adopt a high elasticity value for the purpose of evaluating policy implications, contradicting the relatively low value found in the micro-level data. Similar to SW's models, the inverse of labour supply elasticities are estimated to be lower than the initial calibrations, suggesting a higher level of labour supply elasticities in both economies.

The US inverse elasticity declines to 1.168 – 36% lower than SW's estimate of 1.83, and much lower than the range reported by SW (2005) using a longer time series up to 2002. Meanwhile, the EA inverse elasticity also declines slightly to 1.121, and is significantly lower than the SW's estimation. Accordingly, labour supply elasticity in the US has risen by more than half to 0.856, and in the EA has risen by a tiny amount to 0.892. This result is less in line with the recent empirical studies that found a low to moderate level of labour supply elasticities. Together with other estimated parameters, the coefficient of impacts from real wage changes on labour supply climbs to 0.929 in the US, and 0.936 in the EA[16].

Stickiness in the Economies

Researchers have been seeking ways to incorporate certain features of macroeconomic observables into the modelling, for instance, the inertial inflation and persistent output in response to a monetary shock. There are considerable studies on nominal rigidity following Taylor (1980) and Calvo (1983). But mostly, there have been difficulties in matching the high level of rigidity required in macroeconomic models and a relatively short observed duration in the actual data.

In some studies of the US and EA, nominal wage rigidity is found to be a critical tribute to the output persistence in models; on the other hand, nominal price rigidity solely was not sufficient to generate the same result. Some discussions

[15] Blundell and MaCurdy (1999) summarised four 'core' wage elasticities existing in the empirical literature. They also concluded that the elasticity suitable for policy analysis should also measure responses to a parametric shift in the lifecycle profile itself.

[16] Other factors influencing this coefficient consist of the risk aversion, nominal wage stickiness, and the weight of NK wage setting.

dated back to the late 1980s hence turned to identify the real economic frictions that might alter the functioning of a lower nominal rigidity in macroeconomic models[17]. More recently, CEE (2005) studied this issue quantitatively by estimating a nominal rigidity model with and without the real rigidity. The finding confirmed that the key real friction that enables a model to match the observed features of inflation and output was the variable capital utilization, while the other real frictions accounted for the dynamics of the other variables.

Nominal Rigidities

Adopted from SW's models, the models in this study also specify nominal rigidities by embedding a Calvo price and wage setting, complemented with a past inflation indexation. The Calvo price setting transforms a price setting equation into a pure forward-looking function of the expected inflation. Meanwhile, the partial indexation allows the price to be updated according to the past inflation partially when the price is not subject to re-optimisation in the current period[18]. This setting allows backward-looking behaviour – as described by a traditional Phillips curve.

Accordingly, the price setting equation consists of both forward-looking and backward-looking behaviours, and so does the wage setting equation. Empirically, the price responses to the lagged inflation rate, represented in a traditional Phillips curve with a number of lags, are proven to be robust. The combination of the backward-looking and forward-looking features plays an important role in producing the aggregate output and inflation persistence. Moreover, it also illustrates its key role in replicating a hump shape response of inflation to monetary shocks (Dixon and Bihan, 2012).

Additionally, the model is weighted over an NK price setting, where prices are subject to a Calvo sticky price and partial indexation, and an NC price setting,

[17] For example, Ball and Romer (1990) argued that with the combination of real rigidities, particularly when combined with good market imperfection and the labour market imperfection, a small nominal rigidity can generate substantial persistence.

[18] This differs from the indexation in CEE (2005), in which a full indexation is used and the price is adjusted fully to the past inflation rate.

where prices are perfectly flexible and are adjusting instantaneously to the market demand and supply condition.

Comparing the indirect inference estimates with the estimates in Meenagh et al. (2009) and Le et al. (2011), the coefficients for price partial indexation are fairly stable in both economies; the EA economy exhibits a lower degree of NK price setting behaviour, while the US economy agrees with the assigned degree; and coefficients of Calvo price setting behaviour are both significantly higher.

Relative to the estimate in SW (2007), the US price rigidity is 20% higher at 0.796, which indicates an average price duration of 4.9 quarters. This result is just above the observed empirical evidence from microeconomic data that prices are generally changed every 3 to 4 quarters. Both coefficients of price partial indexation and the weights for the NK price setting have been fairly stable compared to the original calibrated values.

In general, the New-Keynesian behaviour has only a slightly wider scope in the US economy than what was considered and the degree of the backward-looking and forward-looking manner is fairly stable over time. Even coupled with other changing parameters, the impact from the past and future inflation on the contemporaneous inflation rate remains constant at 0.19 and 0.81, respectively. The only significant change in the inflation dynamics is that inflation becomes less sensitive to the rental rate of capital.

In contrast to a moderate level of price rigidity in the US market, the coefficient for the EA price rigidity rises to 0.971, even higher than what was suggested in the SW's Bayesian estimation. Such a result implies that almost the entire EA market is maintaining a constant price over a long period. Accordingly, the price duration is approximately 8.6 years, which is far beyond what was suggested in empirical findings. The EA price partial indexation is barely changed at 0.427, suggesting a similar backward-looking manner, *ceteris paribus*. The weight for the NK pricing in the EA, however, is about a quarter lower than the original calibration, that is, less EA market behaviour can be described by the NK property.

Overall, EA inflation becomes highly insensitive to both past inflation and rental rate of capital, but more sensitive to real wages and productivity shock, while its forward-looking behaviour remains strong at 0.7. Noticeably, it is real factors – predominantly changes in real wages – that cause fluctuations in EA inflation. This is the same as the US but with almost three times the responsiveness. Also, EA inflation is nearly four times as sensitive as US to technology shocks.

The staggered wage (or wage stickiness) is crucial in the macroeconomic modelling for two reasons – it not only accounts for the persistence in the aggregate output and inflation, but also provides a channel for the real effect of a monetary shock to be passed through to the real side of the economy. As shown in CEE (2005), an inertial inflation is a result of the inertial marginal costs, depending positively on the wage, rental rate of capital and interest rate. According to the discussion above, the impact of real wage dynamics on inflation outweighs the other factors notably. In particular, such an impact is exaggerated when inflation becomes more sensitive to real wages as a result of changes in nominal price rigidity. In other words, nominal wage rigidity is one of the main factors responsible for the inflation persistence.

The coefficient for the Calvo wage setting in the US is higher than what was estimated in an individual closed-economy context. The suggested wage contract duration is approximately 4 quarters, which is generally in agreement with the US price duration. There is a lower degree of backward-looking wage setting among US households that cannot reoptimise their wages. Noticeably, there is also a good 20% decline to 0.079 in the weight of the NK wage setting in the US. The scope of the NK wage setting, which itself exhibits more a forward-looking but less a backward-looking manner, is much narrower. Accordingly, wage elasticities to various factors drop in the US, except for a tiny increase in the elasticity to the expected real wage due to the joint effect of higher wage stickiness and lower NK wage setting weight.

Both coefficients for Calvo wage setting and for wage partial indexation in the

EA are higher than the initial calibration. Hence, the model produces a longer EA wage contract duration at 8.3 quarters relative to the empirical observation in previous studies. That is to say, even though this partial-coordination model produces a reasonable EA wage contract duration, the implied EA price contract duration is not only far beyond the empirical observation, but also mis-matched with the wage contract duration. Also, the EA wage is more responsive to past inflation accounted for by the increased past indexation. In contrast, the EA economy exhibits fewer New-Keynesian wage setting behaviours – its NK weight for wages drops almost 41% to 0.047. As a whole, the EA wage elasticities move exactly the same way as the US – all fall slightly with the exception of a tiny increase in the response to the expected real wage.

Broadly, wages are less sensitive, while prices are more sensitive to their own domestic economic conditions, especially the real wage and productivity shocks. Additionally, the actual impact of real wages on labour supply has been raised markedly to 0.929 for the US and 0.936 for the EA. As the decline of labour supply elasticity outweighs the change in the elasticity of intertemporal substitution, the labour supply in both regions is more sensitive to the change in consumption and the associated expectation. To some extent, these two economies are acting in line with each other. Such a result is consistent with the similarities stated in SW (2005), where they applied an EA model setting on both the US and EA data over a sample period from 1974 to 2002.

Real Frictions

Two coefficients featuring real frictions in each economy are estimated – a parameter for steady state elasticity of capital adjustment costs and an elasticity of capital utilization cost[19].

The models with a neoclassical investment accelerator impose a strong assumption of perfect capital mobility among firms and countries, and predict neg-

[19] The coefficients for habit formation are left out due to the change in value causing problems in solving the structural model. Further research in estimating the coefficient of habit formation may be done by imposing some appropriate restrictions on structural parameters.

atively correlated international factor comovements. On the contrary, variable capital utilization allows a change in output to be realised by an adjustment of the capital utilization rate rather than solely by changing investments. Therefore, impacts of an output fluctuation on the rental rate of capital will be eased, and so will the strong hypothesis on capital mobility. It may also enable a model to produce positive comovements of macroeconomic aggregates without requiring a very high negative correlation between productivity shocks in the two economies.

The implied steady state elasticity of capital utilisation cost function takes the form of $\sigma_u = \frac{\Psi(1)''}{\Psi(1)'} = \frac{\psi}{1-\psi}$[20], in which the coefficient ψ is estimated. Accordingly, a rise in the coefficient ψ results in an increase in the steady state elasticity of capital utilization costs, and vice versa. The initial calibrations of ψ are quite different, leaving the efficiency of capital usage significantly divergent in two economies. The estimation brings up its value for the US even further to 0.588, implying a rise in the steady state elasticity to 1.429. On the other hand, although the base value of ψ for the EA is small, the indirect inference estimation implies an even lower value (a 32% decline) for ψ. As a result, there is an almost 36% decline in the EA steady state elasticity of capital utilisation costs to only 0.136. This large divergence between two economies contradicts the finding in SW (2005), particularly in terms of the efficiency of the capital application in the US.

The household optimization implies that a household will use capital more intensively up to the point where the cost of an increase in the capital utilisation rate is equivalent to the cost of employing one more unit of capital. Hence, σ_u plays a role in the model's dynamics for stabilising the rental rate of capital from the output volatility. When output increases as a result of an expansionary policy, households raise their capital utilisation up to the point where $r_t^k = \sigma_u z_t$, rather than further pumping capital into production, seeing that the cost of capital is already higher up and given the presence of the capital adjustment cost. As a result, capital in service is increased to catch up with the output increase without

[20] The cost of variations in the capital utilization rate takes the form of $\Psi(z_t)$, where z_t is a rate of capital utilization. It is assumed that $z_t = 1$ and $\Psi(1) = 0$ in the steady state.

pushing up the rental rate of capital.

On the whole, a lower σ_u implies that EA households can raise the capital utilisation rate even further to keep the rental rate of capital, and hence, inflation stabilised without incurring too much cost. Contrarily, a very high σ_u in the US dampens the effectiveness of variable capital utilisation. For the need of raising output, US households are left with smaller room to adjust their capital utilisation, but have to adopt more capital (invest). The rising demand for capital will then push up the rental rate of capital. Intuitively, the US rental rate of capital is more volatile in response to output fluctuations; and furthermore, US inflation can be even more volatile if it is sensitive to changes in the rental rate of capital. Although knowing this, US inflation, benefiting from its lower nominal rigidity, has a lower sensitivity to the productivity shock than EA inflation does.

As stated in CEE (2005), the dynamics of inflation and output may not be very sensitive to capital adjustment costs and other real frictions. Nevertheless, capital adjustment costs are crucial in understanding the dynamics of investment and other variables.

The capital adjustment cost takes on the neo-classical assumption of a convex adjustment[21], in which the adjustment cost function $S(\cdot)$ is a positive function of changes in investment rather than the level of investment. The model's dynamics, hence, are influenced by the steady state second order derivative $\bar{S}'' = S''(1) > 0$. The presence of a capital adjustment cost forces economic agents to be forward-looking when the price of capital changes persistently. Consequently, investment has higher sensitivity to capital price changes.

The initial value of $\bar{S}''$ is lower for the US at 5.74, and higher for the EA at 7. The indirect inference estimates show even larger divergence between the two economies – the value of $\bar{S}''$ is even lower at 3.718 for the US and higher at 9.483 for the EA. Accordingly, for the US, the elasticity of investment in response to

[21] Although some studies, for example Cooper and Haltiwanger (2006), criticised that the capital adjustment costs did not necessarily follow a convex function, the non-convexity might mimic the dynamics of the data better, especially at plant-level.

changes in the real value of capital $\frac{1}{\bar{S}''(1+\beta)}$ is more than 50% higher than what the initial calibration has implied; whilst for the EA, the elasticity is lower by more than a quarter.

That is, relative to US investment, EA investment will have a smaller percentage increase when its real value of capital is foreseen to be falling. Intuitively, when the steady state convexity of a capital adjustment function gets higher, the increase of costs for installing an extra unit of capital becomes faster. Economic agents are more reluctant to change their investment schedules in response to the changing real price of capital, unless the benefit of raising an extra unit of capital at a higher price or cutting the capital level in order to ease the high cost pressure can outbalance the cost of adjustments.

Such an implication is somehow echoing the previous implication on capital utilisation cost. In spite of a high capital adjustment cost, the EA economy has a relatively low steady state elasticity of capital utilisation costs. Hence, when encountering a sudden production expansion, the EA economy alters its capital utilisation rate primarily, whilst the US economy changes investment primarily since it has a high capital utilisation cost but a low investment adjustment cost. In other words, due to their heterogeneities in the investment cost structure, an investment shock may have a reasonable scale of impacts on the EA economy, while a shock on the capital price level may cause more economic variations in the US.

Monetary Policy Rules

Recall that the monetary policy rule in this two-country DSGE model may consist of interest rate smoothing, short-run responses to inflation deviation and output gap as well as real exchange rate coordination in addition to the original Taylor rule in Taylor (1993a). All of the parameters are estimated using indirect inference starting with initial calibrations mainly adopted from SW's models. Apart from the coordination coefficients for each economy, there are four parameters from the US monetary policy rule (one interest rate smoothing, two long-term responses and one short-term response) and five parameters from the EA monetary policy rule (one interest rate smoothing, two long-term responses and two short-term responses).

Monetary Policy Inertia

CBs' behaviours have been recognised by much of the literature as seeking to smooth nominal interest rate – characterised by CBs taking a series of actions in the same direction to adjust the short-term nominal interest rate to a desired level, rather than having a 'once-and-for-all' action in response to current economic conditions and real activities. Some researchers put together a certain rationale for justifying the optimality of CBs' gradualism, whilst some criticised that the policy inertia might result in an insufficient or delayed policy response to macroeconomic situations. Numerous empirical studies estimating policy rules tend to support the existence of interest rate smoothing (represented by ρ^i, $i = us, ea$), although some raise arguments against this.

Based on the historical data from the US, the estimate of ρ^{us} tends to range between 0.7 to 0.9. In particular, among early literature to find a strong policy inertia, Clarida et al. (2000) found the value of ρ^{us} to be approximately 0.8 in a forward-looking policy rule[22]. Fewer studies have investigated the EA policy inertia, though the public indeed observes a more or less stronger pattern. As one of the early explorers in this region, Castelnuovo (2007) reported a high degree of policy inertia at $\rho^{ea} = 0.84$[23].

The degrees of interest rate smoothing in both the US and EA are shown to be relatively high in SW's findings, but are both in agreement with the literature.

[22] Investigations on other countries' monetary rules also found a strong policy inertia. For example, Clarida et al. (1998) estimated various monetary policy functions for Germany, Japan, the US, the UK, France and Italy, and found the value of ρ ranged from 0.87 to 0.97. Noticeably, in their study, the US monetary policy rule, which took the form of a second-order partial adjustment, had the sum of partial adjustments $\rho_1 + \rho_2$ ranging from 0.90 to 0.97.

[23] The data used in Castelnuovo (2007) ranged from 1980Q1 to 2003Q4, within which the EA did not actually exist over a large period. Also, the target/desired interest rate was expressed as an original Taylor rule; hence, the short-run responses to inflation deviation and output gap were not accounted for.

The indirect inference estimates, however, reveal some deviations. The values of ρ^i have dropped by 39% to 0.493 for the US and by 29% to 0.662 for the EA, which are both in contrast with their high persistence previously shown by the strong autoregressive dynamics and are considerably lower than the literature findings. To achieve a certain interest rate target, possibly in response to a particular shock, a low degree of interest rate smoothing (or policy inertia) implies that the speed of interest rate adjustments is more radical, rather than at a 'sluggish pace'.

Disagreement with these findings from SW's closed-economy estimates may lie in the fact that the link via the good and financial market forces central bankers to think more beyond their domestic matters. In fact, the indirect inference estimates of ρ^i show an even higher degree of declines in the non-coordination model.

The endogenous macroeconomic aggregates influence each other simultaneously in a global economic system. Such relations create trade-offs between stabilising one or the other in a changing economic condition, making the open-economy monetary policy design much more comprehensive. Even though only one target, commonly domestic inflation, is officially announced, a CB that insists on a strict inflation targeting is rare. More commonly, a flexible inflation targeting is adopted – besides inflation, other multiple targets or issues will be taken into consideration when a monetary policy is designed.

As a consequence, the short-run nominal interest rate responds to address not only the domestic macroeconomic variation but also the differential between the domestic and foreign macroeconomic variations. The movement of the short-run nominal interest rate may be more frequent and radical, but less persistent and smooth.

The other potential factor propelling this disagreement is that the determinant of interest rate dynamics is portioned out by the real exchange rate coordination; put differently, that an additional link of the real exchange rate may have contributed to the lower persistence of interest rate dynamics. On one hand, the contemporaneous interest rate adjustments are needed to accommodate macroeconomic fluctuations as well as restore the real exchange rate. Hence, the backward-looking interest rate dynamics are weaker than we have ever estimated using however complex a monetary policy rule (without the exchange rate). On the other hand, a clearer link between the real exchange rate, the nominal interest rate and all the other macroeconomic variables either facilitates a more efficient policy transmission, or restricts CBs in taking sufficient actions due to an additional trade-off. The former enables CBs to minimise the nominal interest rate variations, the latter can cause excessive variations in the nominal interest rate.

Responses to Inflation Deviation and Output Gap

An interest rate response to economic fundamentals, typically inflation deviation and output gap, has been the centre of attention since Taylor (1993a) summarised the rationale for a monetary policy rule. Cited as the Taylor rule and Taylor principle later on, the objectives of the policy rules of this kind are grounded by a quadratic loss function, measured by an inflation deviation from the target rate and the real activity (the output gap relative to a potential level).

In the US, there is a nearly 29% rise in the long-run response of the nominal interest rate to an inflation deviation and a 3% rise in the long-run response of the nominal interest rate to an output gap. Together with a lower interest rate smoothing, coefficients of the net long-run response to an inflation deviation and an output gap have risen considerably to 1.331 and 0.042, respectively. On the contrary, the SW's finding of a strong response to the short-run output gap is slightly weakened here by a near figure at 0.217.

In the EA policy rule, the coefficient for the long-run reaction to an inflation deviation is only lowered to 1.634; while the coefficient for the long-run response to an output gap has risen dramatically to 0.194. Coupled with a lower interest rate smoothing, coefficients of the net long-run response to an inflation deviation and an output gap have risen to 0.552 and 0.065, respectively. Nevertheless, there are considerable declines in the responses to a short-run inflation deviation and a short-run output gap. In general, a 1% change in the inflation differential $\Delta\pi_t^{ea}$ or in the output differential Δy_t^{ea} can only induce 0.205% or 0.117% changes in the nominal interest rate.

Overall, both economies' policy rules obey the Taylor Principle since both values of r_π^i (where $i = us, ea$) are greater than unity ensuring a unique and stable equilibrium. Broadly speaking, both values are in line with empirical findings if not slightly higher[24], although the values of r_y^i (where $i = us, ea$) have not been able to match the criterion of either Taylor's original idea or an efficient weight being greater than 0.5 in Ball (1999a). There is quite a big discrepancy relative to the results in Castelnuovo (2007) and Peersman and Smets (1999). Nonetheless, the weak response to an output gap is reasonable when the results in Clarida et al. (1998) are taken into account[25]. Therefore, over the past four decades, monetary policies have been tight on stabilizing inflation, but fairly relaxed on narrowing the output gap.

Furthermore, there is substantial evidence that monetary policies have put more effort into the long-run stability of inflation and output, but have been less concerned about short-run issues. Put differently, the lower interest rate smoothing contributes partially to a higher degree of reactions to long-run fundamentals, while as a monetary policy becomes more radical, short-run deviations are less of a concern for CBs.

Monetary Coordination

The role of the real exchange rate in monetary policy rules has been subject to a long and heated debate. Few empirical studies have given support to the welfare benefit from monetary coordination. Theoretically, strategic game models provided a reasonable motive for internalising policy externalities; although an

[24] For instance, Castelnuovo (2007) reported the value of r_π in the EA mainly being between 1 to 1.3, but could be 1.8 in a forward-looking Taylor rule; Clarida et al. (1998) found the value of r_π ranged between 1.05 to 2.2 depending on various types of Taylor rule.

[25] Notes that both Castelnuovo (2007) and Peersman and Smets (1999) used the weighted average data over some EA countries for a period when the EA did not in fact exist. Clarida et al. (1998) used data from individual countries and reported that the values of r_y ranged from 0.25 to 0.35 for Germany, -0.07 to 0.88 for France and -0.03 to 0.22 for Italy.

application of the repeated game later on proved that it might not necessarily be the case. The NOEM stated that the globalisation process may have diluted the need for monetary coordination, while more efforts have been made to justify the optimality for the presence of the exchange rate in monetary rules from some other aspects.

To explore a wider range of possible coordination degrees, the bounds for coordination coefficients h_0^i and h_1^i $(i = us, ea)$ are set to be within an interval $[0, 1]$. Thus, monetary authorities can follow a policy that falls between a non-coordination (when coefficients are set to zero) and a full coordination policy (when coefficients approach unity).

Note that this chapter adopts the hypothesis from Chapter 4 that the exchange rate coordination exists when monetary policy coordination can better describe the actual economic behaviour, or specifically, when a model can produce certain macro-indicators that better fit the actual data. Put differently, the null hypothesis holds when the coordination coefficients are estimated to be non-zeroes.

The estimated coordination parameters are shown on the top rows of Table 5.4. The US reacts to the contemporaneous real exchange rate (h_0^{ue}) at the moderate degree of 0.5374; the corresponding coefficient for the lagged real exchange rate (h_1^{us}) is also relatively low at 0.1887. Accordingly, the short-run nominal interest rate has risen by 53.74% in response to a 100% real dollar depreciation (halved in the value of Q_t), but then lowered by 18.87% in the following period as an adjustment to the current policy action. The implied US policy rule is stable, respecting that the net effect of the real exchange rate is positive at 34.87%; and is consistent with the rationale proposed by Obstfeld and Rogoff (1995), Ball (1999b) and Taylor (1999) that the net interest rate response shall be non-positive in response to a real depreciation of the home currency[26].

[26] In Obstfeld and Rogoff (1995), they limited the absolute value of two parameters to be equal ($-h_1 = h_0$), and hence had an interest rate rule reacting to changes in the real exchange rate. In Ball (1999b) and Taylor (2001), the absolute value of h_0 is greater than the absolute value of h_1.

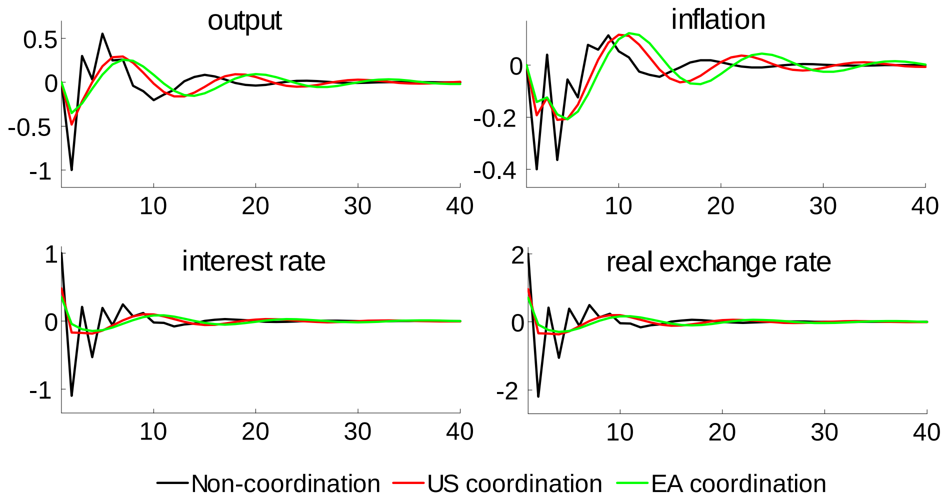


Figure 5-1: IRFs to a positive monetary policy shock by the model in Ball (1999b)

In contrast to the mild exchange rate policy in the US, the EA has shown to have a rather radical exchange rate policy, though it is also a stable and consistent policy in agreement with the literature. The EA policy response to the contemporaneous real exchange rate (h_0^{ea}) is exceptionally strong at 0.9161 and to the lagged real exchange rate (h_1^{ea}) is also high at 0.3809. Although the adjustment elasticity is well above some previous findings, it is comparatively low that the net policy response to 100% euro depreciation (double in the value of Q_t) is a 53.52% rise in the EA nominal interest rate. To achieve such a net response, the EA nominal interest rate has risen by 91.61% contemporarily and is cut by 38.09% in the following period as a counteraction to the temporary real exchange rate effect.

To demonstrate the mechanism that monetary coordination can, or is assumed to be able to, accommodate shocks and influence macroeconomic aggregates, the three-equation open-economy model in Ball (1999b) is stochastically simulated, coupled with exogenously defined Taylor rules (1) with no coordination specification, (2) with the estimated US coordination specification and (3) with the estimated EA coordination specification. All parameters are calibrated exactly the same as the original. Four shocks (to output, inflation, real exchange rate and monetary policy) are specified, assuming all to be white noise with one standard error. The steady state impulse responses of output, inflation, interest rate and the real exchange rate to a positive monetary shock are shown in Figure 5-1, and to a positive real exchange rate shock are shown in Figure 5-2.

The illustration begins by considering a case where a monetary shock strikes the economy leading to a rise in the nominal interest rate by 1 (shocked by one standard error) in the first period. By the model setting, the elasticity of the immediate real exchange rate response to an interest rate increase is 2[27]. Without coordination, the nominal interest rate and real exchange rate move fully in response to the monetary shock. With either the US or EA coordination, the magnitude of a nominal interest rate increase is reduced by an immediate real exchange rate feedback, as with the real exchange rate. With a mild coordination in the US, the US dollar appreciates only by 0.964; and thus, the observed US nominal interest rate rises only to 0.482. With a strong coordination in the EA, the euro appreciates only by 0.706 and the net EA nominal interest rate rises only by 0.353.

By a weaker starting variation in the nominal interest rate and real exchange rate, both coordination cases have considerably low output and inflation variations in the second period. In response to an initial monetary tightening (a rise in the US nominal interest rate), US output and inflation decline by 0.482 and 0.193, respectively; and in its analogic case, EA output and inflation decline by 0.353 and 0.141, respectively. Moreover, the negative interest rate movement in the second period is so strong that the initial increase is overturned to have a net decrease to -0.168 in the US and -0.042 in the EA – hence, a home currency depreciation occurs.

Subsequently, policy interventions set in to prevent further output and infla-

[27] The real exchange rate is defined in a way that its increases in value indicate real appreciation of the home currency. The elasticity of the real exchange rate in response to the domestic interest rate is assumed to be 2.

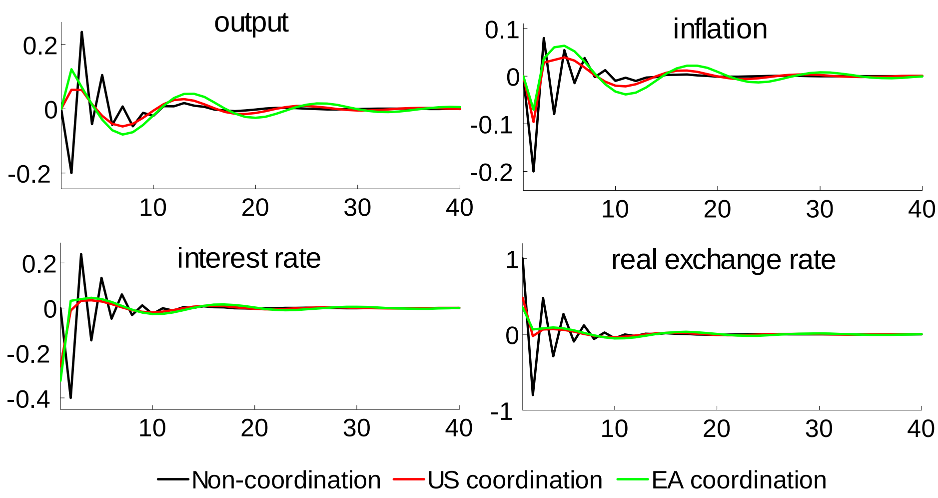


Figure 5-2: IRFs to a real exchange rate shock by the model in Ball (1999b)

tion drifts. As a whole, the impact of the initial shock dies out during a long period of oscillation, but with a much smaller volatility and in a much smoother manner.

On the contrary, failing to account for the instantaneous feedback from the real exchange rate, the non-coordination model produces extremely volatile impulse responses. In the first period, the nominal interest rate takes on the exact impact of the initial monetary shock leading to a strong real exchange rate appreciation by a scale of 2. In the subsequent period, output and inflation drop more than double relative to the case with coordination; the nominal interest rate has a remarkable swing from 1 to -1.1, and the real exchange rate swings from 2 to -2.2.

Overall, in the absence of a direct real exchange rate channel, the nominal interest rate needs to shift greater in order to counteract the impacts of a shock, such as a monetary shock or a real exchange rate shock. However, such reactions result in more volatile output, inflation, and real exchange rate as well as the nominal interest rate itself.

Even though the above example is plausible, the effectiveness of exchange rate coordination may still be subject to the type of shocks that hit the economy – this is in agreement with the finding in Adolfson et al. (2007). It is shown by the same simulation, neither an inflation shock nor an output shock can be accommodated properly by the additional exchange rate channel. Instead, monetary coordination causes excessive and prolonged economic fluctuations.

When inflation or output changes on the impact of a shock, the nominal interest rate responds promptly. However, the simultaneous counter-movements of the real exchange rate have an undermining effect – the aforementioned stabilising effect of the real exchange rate effectively mitigates the monetary policy effect on inflation and output. Thus, to eventually absorb the impact from an inflation or output shock, a prolonged monetary policy is needed. In fact, the time lag of a monetary policy impact is about 2 to 3 periods longer than the non-coordination case (see Appendix C, Figure C-3 and C-4). As a whole, the cumulated variance of inflation and output under monetary coordination can be even larger than the variation in a non-coordination context.

Therefore, whether an economy benefits, in terms of its economic stability, from monetary policy coordination can have implications on the major shocks that drive that particular economy. Put another way, whether an economy should coordinate monetarily, and to what extent monetary coordination can be welfare-improving are partially determined by the main drives of the economic volatility.

Turning to an evaluation of the estimated model, interestingly, the estimation has improved the model's performance in terms of both dynamics and volatility. Recall that Chapter 3 concludes that a moderate US coordination generates a relatively low time series variance, but a low US coordination enhances the model's dynamic performance; and that a weak EA coordination tends to cut down the volatility of output and the real exchange rate, whilst a strong EA coordination lowers inflation and interest rate variances. Given this contradiction between the testing conclusion and the estimation outcome, the source of the improvement in the estimated model can be multiple and quite comprehensive.

To get a rough idea about the possible causes, indirect inference model evalu-

	Alternative 1		Alternative 2	
	AW	**Wald**	**AW**	**Wald**
$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}, r^{us}, r^{ea}, Q$	5605.69	100% (63.63)	11348.77	100% (95.27)
y^{us}, π^{us}, Q	107.92	100% (8.56)	494.44	100% (17.72)
y^{ea}, π^{ea}, Q	993.62	100% (31.25)	5789.82	100% (70.39)
$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}, Q$	1818	100% (34.1)	2168.15	100% (38.28)

AW indicates actual Wald statisics; The column 'Wald' consists of Wald percentile for both model's dynamics and volatility on the top figure and the corresponding normalised MD at the bottom in bracket.

Table 5.5: Robustness check on the effectiveness of monetary coordination

ations are run on two alternative models (see Table 5.5 for test results). The first model (Alternative 1) is a partial-coordination model with estimated coordination parameters but with other common parameters being the initial calibrations. The second model (Alternative 2) is a non-coordination model with the common parameters taken from the estimated partial-coordination model.

The model performs reasonably well with the presence of monetary coordination even though the common parameters are taken from the initial calibration. On the contrary, without coordination, the second alternative model performs badly even with the estimated parameters taken from the partial-coordination model.

In other words, monetary coordination plays a considerably plausible role between the US and EA economies. It is the coordinating feature that brings the actual Wald statistic down from 15569.08 to 5605.69[28]; although undeniably, the refinement of common parameters also has a large contribution towards the final improvement in the model's performance.

It is noteworthy that coordination coefficients estimated for both economies

[28]The figure 15569.08 is the actual Wald statistic reported for an indirect inference testing on the coordination model C-3.6 (see Table 5.3). This model (Alternative 1) differs from model C-3.6 only in terms of their coordination parameters. Hence, their test results are comparable in order to identify the robustness of estimated coefficients. However, note that there is the possibility of a minor bias as a result of random sampling. The test result for Alternative 1 is drawn from a random sample, while the result for model C-3.6 is the mean value over 1000 simulations.

are well above some optimal or reasonable values proposed in the literature. Providing empirical evidence, Taylor (1999) and Taylor (2001) argued that a strong policy reaction to the real exchange rate could have an adverse effect on macroeconomic performances.

In spite of the observed accommodating impacts from simple model simulations, there is also the possibility that such aggressiveness in counteracting shocks can put the economy into the exact situation that a monetary policy is trying to address. Intuitively, a radical action of the nominal interest rate can induce excessive variations in the real exchange rate and thus the nominal interest rate itself. As a result, the output and inflation variations can even be larger than the non-coordination case.

Nonetheless, given the above model simulation, the volatility of major macroeconomic aggregates in the EA is not exaggerated by the radical monetary policy coordination. In fact, only when hit by a real exchange rate shock does the EA economy exhibit visibly higher output and inflation volatility than the US.

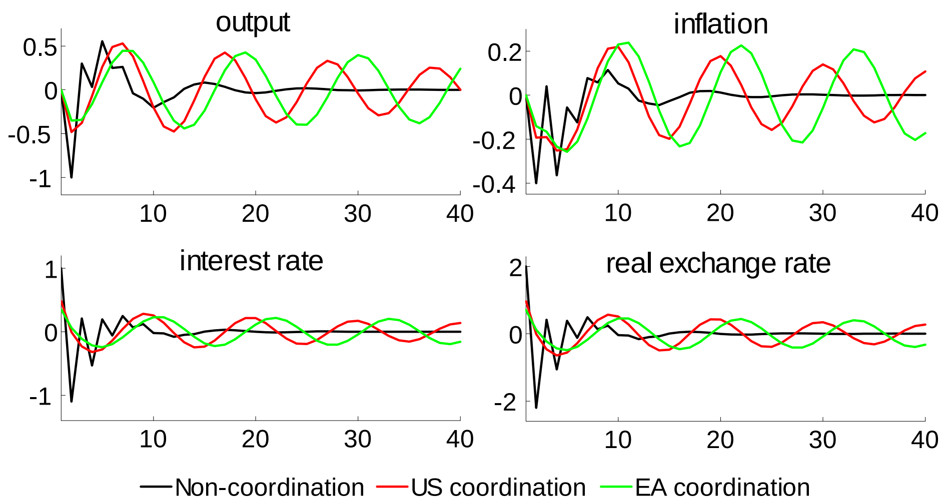


Figure 5-3: IRFs to an interest rate shock - by the model in Ball (1999b) with responses to real exchange rate changes

What may be causing a prolonged and large-amplitude oscillation is the level of a policy adjustment in response to the lagged real exchange rate. To illustrate this point, a model is simulated with a coordination specification $h\left(Q_t - Q_{t-1}\right)$[29] – the policy instrument responds to real exchange rate changes rather than the level real exchange rate. The simulated IRFs show a comparatively low starting variation, but rather prolonged and exaggerated swings from a few periods onwards (see 5-3 for IRFs to an interest rate shock[30]). Even with a weak response to real exchange rate changes, such as $h = -0.25$, the coordination model still produces prolonged variations, particularly in output and inflation.

This finding contradicts some proposals suggesting a policy rate to react to exchange rate changes rather than the level exchange rate. It is also somehow against the interpretation put forward by Ball (1999b) that policy rates should correct the temporary exchange rate effect in order to avoid an inefficient oscillation in output and inflation. By limiting the net responses to the exchange rate to be zero, the accommodating effect from a direct real exchange rate channel can only cover a really small time span. Given a reasonable time lag that a macro-economy requires to respond to the real exchange rate and interest rate, the benefit from such a monetary coordination can be nil, or even negative.

However, a more comprehensive analysis will be required. After all, such a simple model simulation can potentially miss out crucial information that is possessed by the comprehensive economic architecture. Whether this type of coordination policy is beneficial and whether more practical and effective proposals can be adopted are subject to a wide range of heterogeneities in economies; any structural or parametric changes can potentially overturn an initial conclusion. Further extension can be done by analysing an optimal coordination monetary policy using the prevailing welfare-based loss function.

[29] As an increase in the value of Q_t indicates a real domestic currency appreciation, h should be non-positive.

[30] IRFs to other shocks are shown in Appendix C, Figure C-5, C-6, and C-7.

5.3.3 Assessing Performance over Different Variable Combinations

In this section, the estimated non-coordination and coordination models are re-evaluated by indirect inference testing with regard to different macroeconomic aspects (Table 5.6). This exercise not only evaluates the model's overall performance across different target variable combinations, but also demonstrates the improvement of a model's performance from more specific aspects. For comparison, the first two columns list the test results from the baseline non-coordination model, in which the original calibrations are used. The third to sixth column report evaluations on the estimated non-coordination and partial-coordination models, respectively.

	NonC - original		NonC		C-HH	
	AW	**Wald**	**AW**	**Wald**	**AW**	**Wald**
$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}, r^{us}, r^{ea}$	830.859	100% (19.86)	775.48	100% (21.32)	373.9	100% (12.43)
$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}, r^{us}, r^{ea}, Q$	31299.21	100% (147.78)	2024.87	100% (37.25)	582.64	100% (17.2)
y^{us}, y^{ea}	41.83	99.3% (3.88)	35.55	99.6% (3.21)	58.36	100% (5.31)
y^{us}, y^{ea}, Q	609.48	100% (17.14)	209.3	100% (9.65)	54.48	99.7% (3.94)
π^{us}, π^{ea}	37.66	99.9% (4.95)	33.31	99.9% (3.84)	23.59	99.1% (2.90)
π^{us}, π^{ea}, Q	2418.26	100% (50.62)	409.47	100% (16.69)	73.94	100% (5.69)
r^{us}, r^{ea}	29.91	99.2% (3.26)	56.01	100% (5.97)	25.13	99.2% (3.07)
r^{us}, r^{ea}, Q	40064.12	100% (185.51)	1647.04	100% (38.64)	193.12	100% (10.76)
$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}$	123.23	99.9% (6.36)	141.41	100% (7.29)	63.48	99.7% (3.39)
$y^{us}, y^{ea}, \pi^{us}, \pi^{ea}, Q$	1547.85	100% (29.64)	316.27	100% (11.54)	118.78	100% (5.32)

AW indicates actual wald statisics; The column 'Wald' consists of Wald percentile for both model's dynamics and volatility on the top figure and the corresponding normalised MD at the bottom in bracket.

Table 5.6: Model evaluation after the estimation - by various combinations

To a great extent, the estimated partial-coordination model has better performances across different aspects concerned by monetary authorities. Except for the joint test on both the US and EA output, actual Wald statistics for various target variable combinations have fallen by 60% on average and the corresponding normalised MDs have fallen by 52% on average in the partial-coordination model.

The test result also agrees with the previous conclusion in Chapter 4 that when the real exchange rate is included in the joint Wald test, the coordination model significantly outperforms the non-coordination model. It can be observed in Table 5.6 that every single target variable set containing the real exchange rate has at least a 90% improvement in the model's performance when partial-coordination is incorporated. Moreover, although the inclusion of the real exchange rate still heavily deteriorates the model's performance, the gap has been narrowed down to a great extent. In other words, the property of the real exchange rate is better captured by the estimated coordination model.

Noticeably, the outperformance of the coordination model lies in its ability to represent both the dynamics and volatility of inflation, real exchange rate and potentially nominal interest rates. The model's performance for both the US and EA inflation is improved by more than 40% according to the normalised MD, mainly attributed to the improvement in the US inflation dynamics and volatility. There is no clear evidence that the model's performance for both the US and EA interest rate is higher in the partial-coordination model. The model's ability to reproduce both the US and EA output is, however, rather controversial. Compared to the baseline non-coordination model, the estimated coordination model can better reproduce US output dynamics, but not volatility; whilst the reproduced EA output is far more volatile partly due to a higher exposure to both the domestic and international shocks. On the other hand, since the real exchange rate is absent in the policy rule, the estimated non-coordination model is able to better reproduce EA output, especially in terms of volatility.

5.3.4 Impacts of a Monetary Shock on Output and Inflation - IRFs

Since the 1980s, researchers have been using both the univariate and multivariate analyses to study time series properties of some macroeconomic variables[31]. In particular, stylised facts of output and inflation have been extensively recorded by empirical studies. Contrasting to the short-run positive autocorrelation, output was found to have a potential negative autocorrelation over a long time horizon. Moreover, some components of the output fluctuation are permanent.

By examining long-run properties, Cochrane (1988) clearly stated that GNP had a trend-reverting manner following a shock. Campbell and Mankiw (1987) also concluded that shocks were persistent at least over a normal business cycle of two to three years. Thereafter, the traditional view about the output's persistent shock-driven fluctuations and temporary deviation from a 'natural rate' of output growth were questioned. For example, Cogley and Nason (1995) found a standard Real Business Cycle (RBC) model cannot reproduce those stylised facts without a persistent exogenous resource. Henceforth, whether a general equilibrium model can replicate the hump-shaped IRFs becomes one of the critical aspects for evaluating the models' performances.

SW's EU and US models were able to reproduce hump-shaped IRFs following the introduction of a large number of shocks. Additionally, CEE (2005) used a model of a similar kind, and successfully replicated hump-shaped IRFs following a monetary policy shock identified from a VAR.

To assess whether a model with cross-country interactions and monetary coordination can also replicate the main features of macroeconomic time series, IRFs of output and inflation for both economies are presented in Figure 5-4. IRFs of the estimated partial-coordination model following a US or EA monetary policy shock are presented in the upper panel (a) in Figure 5-4. The corresponding IRFs

[31] Examples for the univariate analyses are Nelson and Plosser (1982), Campbell and Mankiw (1987), and Cochrane (1988). Examples for the multivariate analyses are Blanchard and Quah (1989), Cochrane (1994), and Pesaran and Shin (1998).

generated from the estimated non-coordination model are presented in the lower panel (b) in Figure 5-4. Following definitions in Dynare, IRFs here represent deviations of the variable trajectory from its steady state values after the strike of an idiosyncratic shock. That is to say, a convergence of impulse responses to zero indicates a convergence of the economy back to a steady state.

Perceptibly, there are several characteristics in IRFs that are particular to the estimated partial-coordination model.

First of all, there is a hump-shaped pattern in IRFs generated from the estimated partial-coordination model. In particular, either a foreign or a domestic monetary policy shock hits the EA economy, EA output and inflation fall in the first period before growing and peaking at a level above the steady state value, where a weak reverting effect eventually sets in lowering both output and inflation over a long horizon. US output and inflation, however, behave in a slightly different way. They glide down further after the initial drop and pick up gradually back to the steady state level without overshooting.

Overall, domestic shocks have more persistent impacts on the domestic economy, while impacts from foreign shocks tend to die out quickly. Following a US monetary policy shock (see Figure 5-4, (a1)), US output and inflation converge over 35 to 40 periods; while EA output and inflation peak at about the 7^{th} and 4^{th} period, respectively. Following an EA monetary shock (see Figure 5-4, (a2)), US output and inflation converge within 20 periods, while EA output and inflation generally peak at the 20^{th} period before sliding down smoothly to a steady state.

The non-coordination model, on the other hand, produces rather different IRFs. When a domestic monetary shock hits the economy, output and inflation grow more rapidly back towards a steady state after an initial drop. When a foreign monetary shock hits the economy, both output and inflation rise and then drop sharply before a sudden pick-up to push them back to a steady state. The convergence normally takes about 10 periods for the former, while it only takes 4 to 5 periods for an economy to recover from a foreign shock.

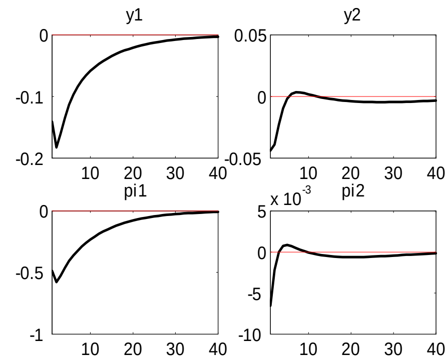
Second, the magnitude of impulse responses to a foreign shock is considerably higher in the estimated partial-coordination model. If IRFs from two models are put into one graph, by the exact scale, the changes of US output and inflation in response to an EA shock in the non-coordination model can almost be negligible. Put differently, the monetary spillover between two economies in the partial-coordination model is comparatively strong relative to the non-coordination model.

Moreover, the estimated partial-coordination model exhibits a high output and inflation persistence, particularly in the EA. It may be due to the fact that the estimated nominal rigidities are higher in the estimated coordination model. It may also be the result of a fair amount of exchange rate policy adjustments mentioned previously.

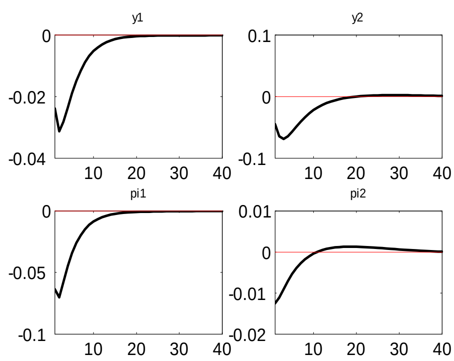
5.3.5 How Well are the Economies Linked?

Three relevant papers, in the sense of models and regions involved, all have studied the contribution of structural shocks to key macroeconomic variables. SW (2003) and SW (2007) both used historical decomposition, and were able to identify contributions from each structural shock according to both the quantity and time horizon. They concluded that in both economies output was mainly driven by demand shocks in the short run, but by supply shocks over a medium and long horizon. And at all horizons, supply shocks, mainly wage and price mark-up shocks, accounted for the majority of inflation variations. Moreover, neither output variations nor inflation variations were significantly affected by monetary policy shocks.

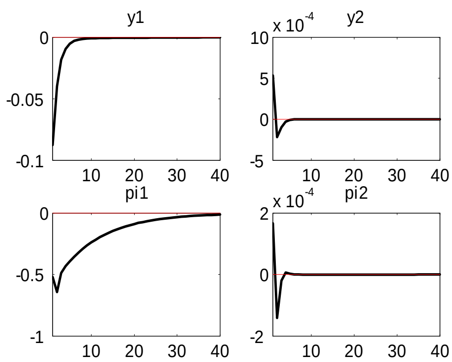
By treating shock to be orthogonal to each other, Le et al. (2010) reported a variance decomposition for a two-country DSGE model combining SW's EU and US models. They found a surprisingly weak spillover between economies, meaning that both economies were acting like closed economies, and were only driven by their own domestic shocks. Also, both economies were predominantly driven by supply shocks; only in the EA economy were monetary policy shocks important in determining output and inflation variations.



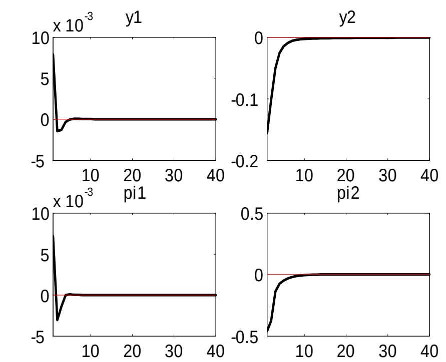
(a1) US monetary policy shock



(a2) EA monetary policy shock



(b1) US monetary policy shock



(b2) EA monetary policy shock

The upper and lower panels show IRFs from the estimated partial-coordination and non-coordination models, respectively; y1 and pi1 represent US output and inflation; y2 and pi2 represent EA output and inflation, respectively.

Figure 5-4: IRFs from estimated models

As shown in Chapter 4, EA monetary policy coordination changes the internal propagation mechanism of shocks. As a result, a substantial fraction of shocks striking in one economy will be channelled into the other economy through a monetary policy reaction to the real exchange rate. Hence, as an extension, it is expected that the estimated partial-coordination model can produce a certain degree of cross-country spillover as the coordination policy changes, but the fraction of shocks channelised and the impact structure from each shock also rely on the changes in other structural parameters.

Table 5.7 shows the impact contribution from each US shock to output, inflation, and interest rate in both economies as well as net exports and the real exchange rate. Similarly, Table 5.8 shows the impact contribution from each EA shock to all those listed endogenous variables.

Overall, the impact structure of shocks is more balanced – contributions to the economic volatility from shocks are more evenly spread out. Wage mark-up shocks remain unimportant in deciding the volatility in both economies. US shocks, especially the price mark-up shock and labour supply shock, vary net exports the most; while EA shocks are somewhat more responsible for the real exchange rate volatility.

Even though the real exchange rate volatility is driven by the EA economy to a great extent, the spillover from the EA to the US economy remains rather weak. In particular, US output is entirely insulated from EA shocks even within a model with multiple transmission channels. Note that, this failure of capturing a cross-country spillover cannot be purely pinned on the ineffectiveness of a monetary policy. Factors such as the trade structure, degree of openness, sensitivity of the economy to a particular type of shock, degree of exchange rate pass-through, policy stance, and preference differential can have rather decisive power over an economy's exposure to external influences.

The US dollar is the most common currency in international trade, especially in the trade of raw materials and crude oil, and for official reserves. Such an influential position may benefit the US dollar due to the fact that product prices

		y^{us}	y^{ea}	π^{us}	π^{ea}	r^{us}	r^{ea}	Q	nx
	Prod.	36.0518	32.6386	4.0883	7.04353	9.80381	8.02822	12.7851	5.07234
	Cons.	0.21601	0.36295	3.25792	0.12049	8.00319	10.452	4.76718	2.94617
	Inv.	0.16735	0.62835	1.06043	0.20899	3.17519	4.16097	1.85136	0.279
	Tayl.	0.15071	0.04173	64.0973	0.01002	40.7722	6.8029	3.22127	0.4075
US	**WM**	0.00496	0.00184	0.00272	0.00044	0.00427	0.00229	0.00189	0.0098
	Gov.	0.90715	18.6152	1.57274	4.43762	3.56422	1.14199	6.59286	0.8621
	PM	41.824	14.7324	7.97886	3.06094	9.4392	10.0478	4.94332	46.1492
	Lab.	20.6718	7.49337	13.4152	1.81931	21.3323	12.4493	9.20578	40.9293
	Total	99.9938	74.5144	95.4735	16.7013	96.0943	53.0855	43.3687	96.6555

Table 5.7: Variance decomposition - the partial-coordination model (US shocks)

		y^{us}	y^{ea}	π^{us}	π^{ea}	r^{us}	r^{ea}	Q	nx
	Prod.	0.00004	0.48491	2.49014	29.2298	2.37643	24.674	28.9139	1.27666
	Cons.	0.00002	1.15636	0.0025	0.28597	0.00497	0.26979	0.14233	0.67737
	Inv.	0.00135	19.6076	1.28824	16.455	1.25822	13.51	14.9379	0.65502
	Tayl.	0.00372	0.2299	0.57874	0.08797	0.15602	0.81553	9.65328	0.56279
EA	**WM**	0	0.00001	0.00001	0	0.00003	0.00312	0.00109	0.00007
	Gov	0.00001	3.94718	0.00619	0.11501	0.0041	0.07556	0.07986	0.00424
	PM	0.00097	0.03751	0.08005	26.6004	0.01536	1.93376	1.84793	0.11447
	Lab.	0.00011	0.02214	0.0807	10.5246	0.09056	5.63276	1.05498	0.05392
	Total	0.00622	25.4856	4.52657	83.2987	3.90569	46.9145	56.6313	3.34454

Table 5.8: Variance decomposition - the partial-coordination model (EA shocks)

are intentionally fixed to the US dollar – an LCP or VCP strategy. If the resulting exchange rate pass-through to the US price level is sufficiently low, the expenditure-switching effect cannot be triggered; and hence US output and other macro-variables are not responding to foreign shocks.

In general, the US economic volatility is mainly driven by the domestic supply shocks, such as the productivity, labour supply and price mark-up shocks. The monetary policy shock is not affecting output, but is the largest determinant of US inflation and interest rate variances. Only about 4% of US inflation and interest rate variance is accounted for by EA shocks – mainly the productivity and investment shocks.

The EA economic volatility has a wider range of resources, including a large portion of US shocks. About three quarters of EA output volatility comes from the US contribution, including US productivity, price mark-up, government spending and labour supply shocks; while, domestically, the EA investment and government spending shocks take responsibility for nearly one quarter of the output variation. EA inflation is more domestically determined by supply shocks, except for 16.5% by the investment shock. Given the radical coordination policy in the EA, it is not surprising that more than 50% of the EA interest rate volatility is driven by US shocks; while domestically the EA interest rate volatility is also subject to the productivity and labour supply shocks.

5.4 Conclusion

Extended from the model evaluation, this chapter applies indirect inference estimation on a US-EA two-country DSGE model (1), without monetary policy coordination and (2), with partial-coordination. In general, thirty-seven parameters are included in the estimation of the partial-coordination model. Thirty-three parameters are common in both the partial-coordination and non-coordination models and four parameters are specifically designed to characterize monetary policy coordination. The estimation of most parameters is typically limited within the 50% upper and lower bounds of their initial values. Coordination coefficients are, however, estimated within a $[0, 1]$ interval in order to investigate a full range of potential coordination policies. The exercise is eventually carried out by minimising the actual Wald statistic of 7 key macroeconomic time series, including output, inflation, and interest rate from both regions as well as the real exchange rate.

All in all, the partial-coordination model achieves the lowest actual Wald statistic at 600.9, significantly lower than the non-coordination model. Accordingly, the conclusion of this estimation agrees with the previous model evaluation that incorporating monetary coordination improves the model's performance in the sense that it better describes the property of the actual data. This progress can be threefold: a great improvement in the model's ability to replicate the dynamics of US time series; a great improvement in the model's ability to replicate the volatility of EA time series; and a great improvement in the model's ability to replicate both the dynamics and volatility of the real exchange rate. Nonetheless, even these improvements cannot develop this model well enough to be accepted by an indirect inference evaluation on 7 target variables.

The estimated fundamental parameters are not in great conflict with the literature findings. Nonetheless, they do reveal some differences between the US and EA economies in various aspects, such as openness, productivity and policy sensitivity. Interestingly, both the US and EA show a moderate to high degree of coordination with a relatively low level of policy adjustment to the lagged real exchange rate. Therefore, the net policy response to the real exchange rate is rather significant. Despite the surprisingly strong coordination, the coordinating property is a major contribution to the improvement in the model's performance. Moreover, depending on the type of shocks that hit the economy, the effectiveness of coordination can be diverse.

The model evaluation on smaller target variable combinations suggests that the partial-coordination model can fit the dynamics and volatility of inflation, real exchange rate and interest rate rather well. Nevertheless, its controversial ability to fit either US or EA output undermines the model's overall performance.

Moreover, the estimated partial-coordination model produces clear hump-shaped IRFs with a high persistence following a monetary policy shock. The greater scale of responses is also an indication of a significant monetary spillover. Finally, providing a moderate degree of coordination and a relatively high level of shock transmissions from the EA economy to the real exchange rate, the variance decomposition implies that the US economy is quite insular, particularly in terms of its output.

Chapter 6

Concluding Remarks and Future Prospects

This thesis began with a literature review on the exchange rate and its important role in monetary policy. The advance of macroeconomic modelling, such as the NOEM and DSGE models, integrates international misalignments into its comprehensive structure, permitting the possibility of large welfare gains from monetary coordination. Such misalignments can hinder the international relative price from adjusting effectively, and in turn, cause economic resource allocation to deviate from the efficient level. Even so, there is no definitive conclusion on whether monetary policy coordination is beneficial. On the other hand, it is challenging to ascertain monetary policy coordination when its appearances are rather diverse and are denied by most monetary authorities.

Motived by such an ambiguity, this thesis attempts to assess the existence and the extent of monetary coordination based upon a plausible two-country DSGE model of the US and EA. The null hypothesis is that the existence of monetary coordination holds if the model's performance is significantly improved by the presence of a policy instrument's direct responses to the real exchange rate. An additional interest of this thesis lies in the improvement on the DSGE model's performance and the scale of cross-country interactions in the presence of a direct exchange rate channel.

In Chapter 4, selected coordination models are compared with the benchmark non-coordination model with regard to their overall performances evaluated by indirect inference. In general, coordination models outperform the baseline non-coordination model. Among others, the coordination model C-3.6 performs exceptionally well in terms of its ability to replicate 7 key macroeconomic variables. In other words, the null hypothesis holds that monetary authorities are, to some extent, coordinating with each other by means of a policy instrument's direct responses to the real exchange rate.

The improvement associated with monetary policy is twofold: a higher prediction precision and a lower prediction uncertainty. The EA coordinating policy is crucial to the stabilisation of both the US and EA economies. Yet for all that, there is a trade-off between coordinating weakly to cut down output and exchange rate volatility, and coordinating strongly to lower inflation and interest rate variations. Contrarily, sole US coordination has no considerable benefit in terms of lowering economic variations; instead, an increasing degree of US coordination may serve as a destabiliser, particularly to the real exchange rate.

Additionally, an inclusion of the real exchange rate in indirect inference testing heavily deteriorates the models' performance no matter whether monetary coordination is incorporated. Yet the gap between the performances of the coordination and non-coordination models is sharply widened, reassuring the essential role of monetary coordination.

Extended from the model evaluation, Chapter 5 applies the indirect inference estimation on the US-EA two-country DSGE model both in a context of non-coordination and partial-coordination. Without doubt, the estimated partial-coordination model achieves the lowest actual Wald statistic at 600.9 – supporting the conclusion from the model evaluation that the monetary coordination specification improves the DSGE model's performance in the sense that it can better replicate properties of the actual data. The threefold progress lies in the model's ability to replicate the dynamics of US time series, the model's ability to replicate the volatility of EA time series and the model's ability to replicate both dynamics and volatility of the real exchange rate.

Overall, estimated fundamental parameters are in agreement with the literature, although the observed nominal price rigidities are comparatively high. Unexpectedly, both economies have a moderate to high degree of coordination in terms of the contemporaneous response. Coupled with a minor adjustment to the lagged real exchange rate, net policy responses to the real exchange rate are rather significant in both economies. Despite that monetary coordination in both economies is surprisingly strong, it is the major contribution to a model's sound performance. It is worth noting that depending on the type of shocks that hits the economy, the effectiveness of coordination can be diverse.

Furthermore, the estimated partial-coordination model produces considerably clear hump-shaped IRFs with high persistence following a monetary policy shock, especially for EA output and inflation. Beyond the first glance of the cross-country interaction in Chapter 4, there is clearer evidence of significant monetary spillovers between the two economies – from a larger scale of impulse responses in both economies and a shift in the impact contribution of the variance decomposition. In fact, the EA economy, especially its output and interest rate, is well affected by US shocks. Even though providing a moderate degree of coordination and a relatively strong shock transmission from the EA economy to the real exchange rate, the variance decomposition suggests that the US economy is quite insular, particularly in terms of its output.

Nonetheless, even these improvements cannot develop this model well enough to be accepted by the indirect inference evaluation on 7 target variables. Further research prospects can be broader and deeper.

Firstly, focusing on a positive aspect, this thesis assesses the existence and extent of monetary policy coordination. Further research can analyse if such an existence is welfare improving; and from a normative perspective, suggest an optimal degree of monetary coordination using utility-based welfare analyses.

Moreover, there are issues in evaluating fixed-exchange-rate models with all 7 target variables jointly tested. Intuitively, by assuming uncovered interest parity

(UIP), the follower country's interest rate or inflation have an almost identical comovement to the leader country's interest rate and inflation, with the assistance of the real exchange rate. The Wald statistic is not reliable in such cases, since variance-covariance matrices are near singular. There are two possible ways to go around this problem – by using a pseudo-inverse matrix as the weighting matrix in computing Wald statistics; or by introducing a risk premium shock in the UIP equation. In the former case, fixed-exchange-rate coordination models (such as DOM_C-4.1 and DOM_C-4.5) can possibly be equivalent to, or even outperform, the floating-exchange-rate coordination model C-3.6 in indirect inference testing. Nonetheless, such experiments need to be extended to ensure (1), the validity of the use of a pseudo-inverse matrix; (2), no bias in the random sample testing; and (3) a better performance even after estimations. In the latter case, the floating-exchange-rate coordination model, especially model C-3.6, is still the best performing model according to the indirect inference model evaluation (random sampling), although the fixed exchange rate model DOM-2.1 performs closely. Further investigation can be done to find out suitable representations of the long-run relation between the interest rate and exchange rate beyond UIP.

Bibliography

Adolfson, M., Laséen, S., Lindé, J. and Villani, M., 2007. Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through, *Journal of International Economics*, Vol. 72, 481-511.

Armington, P., 1969. A Theory of Demand for Products Distinguished by Place of Production. *IMF Staff Papers*, 16:1, 159-178.

Auboin, M. and Ruta, M., 2011. The Relationship between Exchange Rates and International Trade: A Review of Economic Literature, *WTO Staff Working Paper* ERSD-2011-17.

Backus, D., Gavazzoni, F., Telmer, C., and Zin, S., 2010. Monetary Policy and the Uncovered Interest Parity Puzzle, *National Bureau of Economic Research, working paper no. 16218.*

Backus, D., Kehoe, P., and Kydland, F., 1992. International Real Business Cycles, *Journal of Political Economy*, Vol. 100(4), 745-775.

Ball, L., 1999. Efficient Rules for Monetary Policy, *International Finance*, Vol. 2(1), 63-83.

Ball, L., 1999. Policy Rules for Open Economies, in Taylor J.B., ed., *Monetary Policy Rules*. Chicago: University of Chicago Pres, 127-44.

Ball, L. and Romer, D., 1990. Real Rigidities and the Non-Neutrality of Money, *The Review of Economic Studies*, Vol, 57(2), 183-203.

Baron, D., 1976. Fluctuating Exchange Rates and the Pricing of Exports, *Economic Inquiry*, Vol. 14(3), 425-438.

Batini, N., Harrison, R. and Millard, S., 2003. Monetary Policy Rules for an Open Economy, *Journal of Economic Dynamics & Control*, Vol. 27, 2059-2094.

Baxter, M., and Farr, D., 2005. Variable Capital Utilization and International Business Cycles. *Journal of International Economics*, Vol. 65, 335-347.

Benigno, G. and Benigno, P., 2003. Price Stability in Open Economies, *Review of Economic Studies*, Vol. 70, 743-764.

Benigno, G. and Benigno, P., 2006. Designing Targeting Rules for International Monetary Policy Cooperation, *Journal of Monetary Economics*, Vol. 53, 473-506.

Bernanke, B. and Gürkaynak, R., 2001. Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously. In: Bernanke, B. S., Rogoff, K. Eds., *NBER Macroeconomics Annual 2001.* MIT Press, Cambridge, MA.

Betts, C. and Devereux, M., 1996. The Exchange Rate in a Model of Pricing-to-Market, *European Economic Review*, Vol. 40, 1007-1021.

Betts, C. and Devereux, M., 2000. Exchange Rate Dynamics in a Model of Pricing-to-Market, *Journal of International Economics*, Vol. 50,215-244.

Bhundia, A. and Stone, M., 2004. A New Taxonomy of Monetary Regimes, *IMF Working Paper* 04/191, March.

Bibow, J., 2006. Global Imbalances, Bretton Woods II, and Euroland's Role in All This, *Working Paper No. 486, The Levy Economics Institute, December.*

Blanchard, O. and Galí, J., 2007. Real Wage Rigidities and the New Keynesian Model, *Journal of Money, Credit and Banking*, Vol. 39(1), 35-65.

Blanchard, O. and Quah, D., 1989. The Dynamic Effects of Aggregate Demand and Supply Distribution, *American Economic Review*, Vol. 79(4), 655-673.

Blundell, R. and MaCurdy, T., 1999. Labor Supply: A Review of Alternative Approaches. In Ashenfeter, O. and Card, D. Eds., *Handbook of Labor Economics*, Vol. 3A, Ch. 27, Amsterdam, North Holland.

Brischetto, A. and Voss, G., 1999. A Structural Vector Autoregression Model of Monetary Policy in Australia, *Reserve Bank of Australia Research Discussion Papers* No. rdp1999-11.

Calvo, G. A., 1983. Staggered Prices in A Utility-Maximizing Framework, *Journal of Monetary Economics*, Vol. 12, 383-398.

Calvo, G. and Reinhart, C., 2002. Fear of Floating, *The Quarterly Journal of Economics*, Vol. 117(2), 379-408.

Campa, J. and Goldberg, L., 2005. Exchange Rate Pass-through into Import Prices, *The Review of Economics and Statistics*, Vol. 87(4), 679-690.

Campa, J. and González-Mínguez, J., 2006. Different in Exchange Rate Pass-through in the Euro Area, *European Economic Review*, Vol. 50, 121-145.

Campbell, J. and Mankiw, N. G., 1987. Are Output Fluctuations Transitory? *The Quarterly Journal of Economics*, Vol. 102(4), 857-880.

Canova, F., 2005. *Methods for Applied Macroeconomic Research*. Princeton University Press, Princeton.

Canzoneri, M., Clark, P., Glaessner, T. and Leahy, M., 1984. The Effect of Exchange Rate Variability on Output and Employment, *International Finance Discussion Papers* No. 240, Provided by Board of Governors of the Federal Reserve System.

Canzoneri, M., Cumby, R. and Diba, B., 2005. The Need for International Policy Coordination: What's Old, What's New, What's Yet to Come? *Journal of International Economics*, Vol. 66, 363-384.

Canzoneri, M. and Gray, J., 1985. Monetary Policy Games and the Consequences of Non-Cooperative Behavior, *International Economic Review*, Vol. 26(3), 547-564.

Canzoneri, M. and Henderson, D., 1991. *Monetary Policy in Interdependent Economies: A Game-Theoretic Approach*, MIT Press, Cambridge, MA.

Canzoneri, M. and Minford, P., 1988. When International Policy Coordination Matters: An Empirical Analysis, *Applied Economics*, Vol. 20, 1137-1154.

Casares M., 2001. Business Cycle and Monetary Policy Analysis in a Structural Sticky-Price Model of the Euro Area. *European Central Bank Working Paper* 49, Frankfurt am Main, Germany.

Castelnuovo, E., 2007. Taylor Rules and Interest Rate Smoothing in the Euro Area. *The Manchester School*, Vol. 75(1), 1-16.

Chari, V., Kehoe, P. and McGrattan, E., 2002. Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates? *The Review of Economic Studies*, Vol. 69(3), 533-563.

Christiano, L., Eichenbaum, M., and Evans, C., 2005. Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*, Vol. 113(1), 1-45.

Clarida, R., Galí, J. and Gertler, M., 1998. Monetary Policy Rules in Practice: Some International Evidence. *European Economic Review*, Vol. 42, 1033-1067.

Clarida, R., Galí, J. and Gertler, M., 2000. Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory. *Quarterly Journal of Economics*, Vol. 115(1), 147-180.

Clarida, R., Galí, J. and Gertler, M., 2001. Optimal Monetary Policy in Open versus Closed Economics: An Integrated Approach, *American Economic Review*, Vol. 91(2), 248-252.

Clarida, R., Galí, J. and Gertler, M., 2002. A Simple Framework for International Monetary Policy Analysis, *Journal of Monetary Economics*, Vol. 49, 879-904.

Clarida, R. and Gerlter, M., 1997. How the Bundesbank Conducts Monetary Policy, in Romer C. and Romer D., eds., *Reducing Inflation: Motivation and Strategy, NBER Books*, No. rome97-1, 363-412.

Clark, P., 1973. Uncertainty, Exchange Risk, and the Level of International Trade, *Economic Inquiry*, Vol. 11(3), 302-313.

Clark, P., Tamirisa, N. and Wei, J., 2004. Exchange Rate Volatility and Trade Flows - Some New Evidence, *IMF Working Paper*, May 2004.

Cochrane, J., 1988. How Big Is the Random Walk in GNP? *Journal of Political Economy*, Vol. 96(5), 893-920.

Cochrane, J., 1994. Permanent and Transitory Components of GNP and Stock Prices, *The Quarterly Journal of Economics*, Vol. 109(1), 241-265.

Coenen, G., Lombardo, G., Smets, F. and Straub, R., 2008. International Transmission and Monetary Policy Cooperation, *European Central Bank Working Paper Series*, No. 858.

Cogley, T. and Nason, J., 1995. Output Dynamics in Real-Business-Cycle Models. *The American Economic Review*, Vol. 85(3), 492-511.

Cooper, R., 1969. Macroeconomic Policy Adjustment in Interdependent economies, *The Quarterly Journal of Economics*, Vol. 83(1), 1-24.

Cooper, R., and Haltiwanger, J., 2006. On the Nature of Capital Adjustment Costs. *Review of Economic Studies*, Vol. 73, 611-633.

Corsetti , G. and Pesenti, P., 2001. Welfare and Macroeconomic Interdependence, *The Quarterly Journal of Economics*, Vol. 116(2), 421-445.

Corsetti, G., Dedola, L. and Leduc, S., 2010. Optimal Monetary Policy in Open Economies, *Working Paper Series 2010-13, Federal Reserve Bank of San Francisco.*

Cushman, D., 1983. The effects of Real Exchange Rate Risk on International Trade, *Journal of International Economics*, Vol. 15, 45-63.

Cushman, D. and Zha, T., 1997. Identifying Monetary Policy in a Small Open Economy under Flexible Exchange Rates, *Journal of Monetary Economics*, Vol. 39, 433-448.

De Grauwe, P., 1988. Exchange Rate Variability and the Slowdown in Growth of International Trade, *IMF Staff Papers*, Vol. 35(1), 63-84.

Devereux, M. and Engel, C., 2003. Monetary Policy in the Open Economy Revisited: Price Setting and Exchange Rate Flexibility. *Review of Economic Studies*, Vol. 70, 755-783.

Dixon, H., and Bihan, H., 2012. Generalised Taylor and Generalised Calvo Price and Wage Setting: Micro-Evidence with Macro Implications, *The Economic Journal*, Vol. 122, 532-554.

Dooley, M., Folkerts-Landau, D., and Garber, P., 2003. An Essay on the Revived Bretton Woods System, *NBER Working Paper Series No. 9971.*

Dornbusch, R., 1976. Expectations and Exchange Rate Dynamics, *The Journal of Political Economy*, Vol. 84(6), 1161-1176.

Edge, R., Gürkaynak, R., 2010. How Useful Are Estimated DSGE Model Forecasts for Central Bankers? *Brooking Papers on Economic Activity*, Vol. 41(2), 209-259.

Either, W., 1973. International Trade and the Forward Exchange Market, *The American Economic Review*, Vol. 63(3), 494-503.

Fisher, R., 1928. *Statistical Methods for Research Workers.* Oliver and Boyd, London. Page 112-113.

Freedman, C., 1996. The Use of Indicators and of the Monetary Conditions Index in Canada, *Publication of Bank of Canada: The Transmission of Monetary Policy in Canada.*

Friedman, M., 1953. The Case for Flexible Exchange Rates, in *Essays in Positive Economics.* Chicago: University of Chicago Press, 157-203.

Galí, J., 2002. New Perspective on Monetary Policy, Inflation, and the Business Cycle, *NBER Working Paper, No. 8767.*

Galí, J. and Monacelli, T., 2005. Monetary Policy and Exchange Rate Volatility in a Small Open Economy, *Review of Economic Studies*, Vol. 72, 707-734.

Gerlach, S. and Smets, F., 2000. MCIs and Monetary Policy, *European Economic Review*, Vol. 44, 1677-1700.

Ghosh, A., 2009. Implications of Production Sharing on Exchange Rate Pass-Through, *International Journal of Finance & Economics*, Vol. 14, 334-345.

Gopinath, G., Itskhoki, O. and Rigobon, R., 2010. Currency Choice and Exchange Rate Pass-Through, *American Economic Review*, Vol. 100(1), 304-336.

Gourieroux, C., Monfort, A., Renault, E., 1993. Indirect Inference. *Journal of Applied Econometrics*, Vol. 8, S85-S118.

Guender, A., 2006. On Optimal Monetary Policy Rules and the Construction of MCIs in the Open Economy, *Open Economies Review*, Vol. 16, 189-207.

Hamada, K., 1976. A Strategic Analysis of Monetary Interdependence, *Journal of Political Economy*, Vol. 84(4), 677-700.

Henderson, D. and McKibbin, W., 1993. An Assessment of Some Basic Monetary Policy Regime Pairs: Analytical and Simulation Results from Simple Multi-Region Macroeconomic Models, in Bryant, R., Hooper, P. and Mann, C., eds, *Evaluating Policy Regimes: New Research in Empirical Macroeconomics.* The Brooking Institution, Washington, D.C., 45-218.

Hellerstein, R., Daly, D. and Marsh, C., 2006. Have U.S. Import Prices Become Less Responsive to Changes in the Dollar? *Current Issues in Economics and Finance, Reserve Bank of New York*, Vol. 6(2).

Hooper, P. and Kohlhagen, S., 1978. The Effect of Exchange Rate Uncertainty on the Prices and Volume of International Trade, *International Economics*, Vol. 8, 483-511.

IMF, 1993. Balance of Payments Manual (the 5^{th} edition), *International Monetary Fund.*

Jabara, C., 2009. How Do Exchange Rate Affect Import Price? Recent Economic Literature and Data Analysis, *Office of Industries Working Paper, U.S. International Trade Commission*, No. ID-21.

Kahn, G., 1987. Dollar Depreciation and Inflation, *Federal Reserve Bank of Kansas City Economic Review*, Vol. 72(9), 32-49.

Kim, S. and Roubini, N., 2000. Exchange Rate Anomalies in the Industrial Countries: A Solution with a Structural VAR Approach, *Journal of Monetary Economics*, Vol. 45, 561-586.

Kimball, M., 1995. The Quantitative Analytics of the Basic Neomonetarist Model. *Journal of Money, Credit, and Banking*, Vol. 27(4), 1241-1277.

Krugman, P., 1987. Pricing-to-Market When the Exchange Rate Changes, in Sven and Richardson, eds., *Real Financial Linkages Among Open Economies*, MIT Press, Cambridge, MA, 49-70.

Kydland, F. and Prescott, E., 1982. Time to Build and Aggregate Fluctuations. *Econometrica*, Vol. 50(6), 1345-1370.

Le, V., Meenagh, D., Minford, P., Wickens, M., 2010. Two Orthogonal Continents? Testing a Two-country DSGE Model of the US and the EU Using Indirect Inference. *Open Economies Reviews*, Vol. 21, 23-44.

Le, V., Meenagh, D., Minford, P., Wickens, M., 2011. How Much Nominal Rigidity is there in the US Economy? Testing a New Keynesian DSGE Model Using Indirect Inference. *Journal of Economic Dynamics and Control*, Vol. 35(12), 2078-2104.

Le, V., Meenagh, D., Minford, P., Wickens, M., 2012. Testing DSGE Models by Indirect Inference and other Methods: Some Monte Carlo Experiments, *CEPR Discussion Papers 9056, C.E.P.R Discussion Papers.*

Leitemo, K. and Söderström, U., 2005. Simple Monetary Policy Rules and Exchange Rate Uncertainty, *Journal of International Money and Finance*, Vol. 24, 481-507.

Lucas, R., 1976. Econometric Policy Evaluation: a Critique. *Carnegie-Rochester Conference Series on Public Policy*, Vol. 1(1), 19-46.

Masson, P. and Pattison, J., 2009. Financial Regulatory Reform: Using Models of Cooperation to Evaluate Current Prospects for International Agreement, *Journal of Economic Asymmetries*, Vol. 6(3), 119-139.

McCallum, B.T., 1976. Rational Expectations and the Natural Rate Hypothesis: Some Consistent Estimates. *Econometrica*, Vol. 44, 43-52.

McFadden, D., 1989. A Method of Simulated Moments for Estimation of Discrete Response Models without Numerical Integration. *Econometrica*, Vol. 57, 995-1026.

McKenzie, M., 1999. The Impact of Exchange Rate Volatility on International Trade Flows, *Journal of Economic Surveys*, Vol. 13(1), 71-106.

McKibbin, W., 1997. Empirical Evidence on International Economic Policy Coordination, in Fratianni, M., Salvatore, D. and Von Hagen, J., eds, *Macroeconomic Policy in Open Economies, Handbook of Comparative Economic Policies*, Vol. 5, Greenwood Press, Westport, CT, 148-176.

Meenagh, D., Minford, P., Wickens, M., 2009. Testing a DSGE Model of the EU Using Indirect Inference. *Open Economies Review*, Vol. 20(4), 435-471.

Meyer, L., Doyle, B., Gagnon, J. and Henderson, D., 2002. International Coordination of Macroeconomic Policies: Still Alive in the New Millennium? *International Finance Discussion Papers n. 723, Board of Governors of the Federal Reserve System.*

Minford, P. and Ou, Z., 2013. Taylor Rule or Optimal Timeless Policy? Reconsidering the Fed's Behavior since 1982, *Economic Modelling*, Vol. 32, 113-123.

Minford, P., Perugini, F., and Srinivasan, N., 2002. Are Interest Rate Regressions Evidence for a Taylor Rule? *Economics Letters*, Vol. 76, 145-150.

Mussa, M., 1986. Nominal Exchange Rate Regime and the Behavior of Real Exchange Rates: Evidence and Implications, *Carnegie-Rochester Conference Series on Public Policy*, Vol. 25, 117-214.

Muth, J., 1961. Rational Expectations and the Theory of Price Movements, *Econometrica*, Vol. 29(3), 315-335.

Nelson, C. and Plosser, C., 1982. Trends and Random Walks in Macroeconomic Time Series: Some Evidence and Implications, *Journal of Monetary Economics*, Vol. 10, 139-162.

Obstfeld, M. and Rogoff, K., 1995. The Mirage of Fixed Exchange Rates, *The Journal of Economic Perspectives*, Vol. 9(4), 73-96.

Obstfeld, M. and Rogoff, K., 1998. Risk and Exchange Rates, *NBER Working Paper* No. 6694.

Obstfeld, M. and Rogoff, K., 2000. New Directions for Stochastic Open Economy Models, *Journal of International Economics*, Vol. 50, 117-153.

Obstfeld, M. and Rogoff, K., 2001. The Six Major Puzzles in International Macroeconomics: Is There a Common Cause? *NBER Chapters, in: NBER Macroeconomics Annual 2000*, Vol. 15, 339-412.

Obstfeld, M. and Rogoff, K., 2002. Global Implications of Self-oriented National Monetary Rules. *Quarterly Journal of Economics*, Vol. 117, 503-535.

Obstfeld, M., Shambaugh, J. and Taylor, A., 2005. The Trilemma in History: Tradeoffs among exchange Rates, Monetary Policies, and Capital Mobility, *The Review of Economics and Statistics*, Vol. 87(3), 423-438.

Oudiz, G. and Sachs, J., 1984. Macroeconomic Policy Coordination among the Industrial Economies, *Brookings Papers on Economic Activity*, Vol. 1, 1-75.

Ozturk, I., 2006. Exchange Rate Volatility and Trade: A Literature Survey, *International Journal of Applied Econometrics and Quantitative Studies*, Vol. 3(1), 85-102.

Pesaran, H. and Shin, Y., 1998. Generalized Impulse Response Analysis in Linear Multivariate Models. *Economics Letters*, Vol. 58, 17-29.

Peersman, G. and Smets, F., 1999. The Taylor Rule: a Useful Monetary Policy Benchmark for the Euro Area? *International Finance*, Vol. 2(1), 85-116.

Pippenger, J., 2013. The Failure of Uncovered Interest Parity, Forward Bias and Related Puzzles, *Departmental Working Papers, Department of Economics, UCSB, UC Santa Barbara.*

Rogoff, K., 1985. Can International Monetary Policy Cooperation be Counterproductive? *Journal of International Economics*, Vol. 18, 199-217.

Rose, A., 1996. Explaining Exchange Rate Volatility: An Empirical Analysis of 'the Holy Trinity' of Monetary Independence, Fixed Exchange Rates, and

Capital Mobility, *Journal of International Money and Finance*, Vol. 15(6), 925-945.

Rotemberg, J. and Woodford, M., 1998. An Optimization-based Econometric Framework for the Evaluation of Monetary Policy: Expanded Version. *NBER Technical Working Papers* 0233.

Sims, C., 1980. Macroeconomics and Reality, *Econometrica*, Vol. 48(1), 1-48.

Smets, F., Wouters, R., 2003. An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association*, Vol. 1(5), 1123-1175.

Smets, F., Wouters, R., 2005. Comparing Shocks and Frictions in US and Euro Area Business Cycles: A Bayesian DSGE Approach. *Journal of Applied Econometrics*, Vol. 20, 161-183.

Smets, F., Wouters, R., 2007. Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review*, Vol. 97, 586-606.

Smith, A., 1993. Estimating Nonlinear Time-series Models Using Simulated Vector Autoregressions. *Journal of Applied Econometrics*, Vol. 8, S63-S84.

Srinivasan, N., Minford, P., and Perugini, F., 2002. The Observational Equivalence of Taylor Rule and Taylor-type Rules, *Royal Economic Society Annual Conference 2002*, 167, Royal Economic Society.

Stein, J., 1976. *Monetarism*. Amsterdam: North-Holland Publishing Co.

Sutherland, A., 2004. International Monetary Policy Coordination and Financial Market Integration, *CEPR Discussion Papers*, No. 4251.

Svensson, L., 2000. Open-Economy Inflation Targeting. *Journal of International Economics*, Vol. 50(1), 155-183.

Taylor, J., 1980. Aggregate Dynamics and Staggered Contracts, *Journal of Political Economy*, Vol. 88(1), 1-23.

Taylor, J., 1993. Discretion versus Policy Rules in Practice. *Carnegie-Rochester Conference Series on Public Policy*, Vol. 39(1), 195-214.

Taylor, J., 1993. *Macroeconomic Policy in a World Economy: from Econometric Design to Practical Operation.* W.W. Norton, New York.

Taylor, J., 1999. The Robustness and Efficiency of Monetary Policy Rules as Guidelines for Interest Rate Setting by the European Central Bank, *Journal of Monetary Economics*, Vol. 43, 655-679.

Taylor, J., 2000. Low Inflation, Pass-Through and the Pricing Power of Firms, *European Economic Review*, Vol. 44, 1389-1408.

Taylor, J., 2001. The Role of the Exchange rate in Monetary-Policy Rules. *American Economic Review*, Vol. 91(2), 263-267.

Theodoridis, K., 2011. An Efficient Minimum Distance Estimator for DSGE Models, *Bank of England Working Paper*, No. 439.

Warmedinger, T., 2004. Import Prices and Pricing-to-Market Effects in the Euro Area, *European Central Bank Working Paper Series*, No. 299.

Wickens, M.R., 1982. The Efficient Estimation of Econometric Models with Rational Expectations. *Review of Economic Studies*, Vol. 49, 55-67.

Wickens, M.R., 2012. How Useful are DSGE Macroeconomic Models for Forecasting? *CEPR Discussion Paper* 9049, C.E.P.R. Discussion Papers.

Wilson, E., Hilferty, M., 1931. The distribution of Chi-square. *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 17(2), 684-688.

Wollmershäuser, T., 2006. Should Central Banks React to Exchange Rate Movements? An Analysis of the Robustness of Simple Policy Rules under Exchange Rate Uncertainty, *Journal of Macroeconomics*, Vol. 28, 493-519.

Mills, E.S., 1962. *Price, Output and Inventory Policy: A Study in the Economics of the Firm and Industry*. John Wiley and Sons, Inc.

Appendix A

Chapter 2 Appendix

A.1 Derive the Real Exchange Rate

The CPI-based price level for the home and foreign economies are:

$$
\begin{aligned}
P_t &= \left[a_H P_{H,t}^{1-\phi} + (1-a_H) P_{F,t}^{1-\phi}\right]^{\frac{1}{1-\phi}} \\
P_t^* &= \left[(1-a_F^*) P_{H,t}^{*1-\phi} + a_F^* P_{F,t}^{*1-\phi}\right]^{\frac{1}{1-\phi}}
\end{aligned}
$$

where P_i $(i = H, F)$ indicates the price level of goods produced in the economy i; Asterisk indicates goods are consumed in the foreign economy (are priced in the foreign currency).

Define the deviations from LOOP as $\Delta_{H,t} = \frac{\frac{P_{H,t}^*}{\varepsilon_t}}{P_{H,t}}$ and $\Delta_{F,t} = \frac{\frac{P_{F,t}^*}{\varepsilon_t}}{P_{F,t}}$ for the home and foreign economies, respectively.

The real exchange rate hence can be derived in terms of TOT and the deviation:

$$
\begin{aligned}
Q^{1-\phi} &= \left(\frac{\varepsilon_t P_t}{P_t^*}\right)^{1-\phi} = \frac{a_H\left(\varepsilon_t P_{H,t}\right)^{1-\phi} + (1-a_H)\left(\varepsilon_t P_{F,t}\right)^{1-\phi}}{(1-a_F^*)\,P_{H,t}^{*1-\phi} + a_F^* P_{F,t}^{*1-\phi}} \\
&= \frac{a_H\left(\varepsilon_t P_{H,t}\right)^{1-\phi} + (1-a_H)\left(\varepsilon_t P_{F,t}\right)^{1-\phi}}{a_H^* P_{H,t}^{*1-\phi} + (1-a_H^*)\,P_{F,t}^{*1-\phi}} \\
&= \frac{a_H\left(\varepsilon_t P_{H,t}\frac{P_{H,t}^*}{P_{H,t}^*}\right)^{1-\phi} + (1-a_H)\left(\varepsilon_t P_{F,t}\right)^{1-\phi}}{a_H^* P_{H,t}^{*1-\phi} + (1-a_H^*)\left(P_{F,t}^*\frac{\varepsilon_t P_{F,t}}{\varepsilon_t P_{F,t}}\right)^{1-\phi}} \\
&= \frac{a_H\left(\frac{1}{\Delta_{H,t}}P_{H,t}^*\right)^{1-\phi} + (1-a_H)\left(\varepsilon_t P_{F,t}\right)^{1-\phi}}{a_H^* P_{H,t}^{*1-\phi} + (1-a_H^*)\left(\Delta_{F,t}\varepsilon_t P_{F,t}\right)^{1-\phi}} \\
&= \frac{a_H\left(\frac{1}{\Delta_{H,t}}\right)^{1-\phi} + (1-a_H)\left(\mathcal{T}_t^H\right)^{1-\phi}}{a_H^* + (1-a_H^*)\left(\Delta_{F,t}\mathcal{T}_t^H\right)^{1-\phi}}
\end{aligned}
$$

Based on the assumption of symmetric parameters across economies, coefficients for the home bias are $a_H = a_F^* = (1-a_H^*)$ and the deviations $\Delta_{H,t} = \Delta_{F,t} = \Delta_t$. The real exchange rate can be written as a log-linearised form:

$$
\begin{aligned}
Q &= -\left(2a_H - 1\right)\tilde{\mathcal{T}}_t^H - a_H\left(\hat{\Delta}_{F,t} + \hat{\Delta}_{H,t}\right) \\
&= -\left(2a_H - 1\right)\tilde{\mathcal{T}}_t^H - 2a_H\hat{\Delta}_t
\end{aligned}
$$

Appendix B

Chapter 4 Appendix

B.1 Consumer Maximization Over Home and Foreign Goods

The households in each regime maximise their consumption composite, subject to their consumption budget constraint. The Lagrangean can be written as

$$L = \left[\omega \left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t \left(C_t^f\right)^{-\rho}\right]^{\left(-\frac{1}{\rho}\right)} + \lambda \left(\tilde{C}_t - p_t^d C_t^d + q_t C_t^f\right)$$

The first order conditions (F.O.C.) with respect to the domestic good consumption, foreign good consumption and the total consumption composite are:

$$\frac{\partial L}{\partial C_t^d} = \left(-\frac{1}{\rho}\right)\left[\omega\left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t\left(C_t^f\right)^{-\rho}\right]^{-\frac{1}{\rho}-1}(-\rho)\,\omega\left(C_t^d\right)^{-\rho-1} - \lambda p_t^d = 0 \tag{B.1a}$$

$$\frac{\partial L}{\partial C_t^f} = \left(-\frac{1}{\rho}\right)\left[\omega\left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t\left(C_t^f\right)^{-\rho}\right]^{-\frac{1}{\rho}-1}(-\rho)(1-\omega)\varsigma_t\left(C_t^f\right)^{-\rho-1} - \lambda q_t = 0 \tag{B.1b}$$

$$\frac{\partial L}{\partial \tilde{C}_t} = \lambda \tag{B.1c}$$

where λ is the marginal increment in the utility index on the one unit change of the consumption composite. While at the maximum level $L = \tilde{C}_t$, hence $\frac{\partial L}{\partial \tilde{C}_t} = 1$. When combining with the F.O.C. (B.1c) the marginal utility of consumption composite is 1 as shown:

$$\frac{\partial L}{\partial \tilde{C}_t} = 1 = \lambda \tag{B.2}$$

Substituting B.2 into the F.O.C. with respect to the domestic good consumption (B.1a), we obtain

$$\left[\omega\left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t\left(C_t^f\right)^{-\rho}\right]^{-\frac{1}{\rho}-1}\omega\left(C_t^d\right)^{-\rho-1} = p_t^d$$

Re-arranging it using the total consumption composite, we have the home demand for home goods relative to the total consumption composite:

$$\left\{\left[\omega\left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t\left(C_t^f\right)^{-\rho}\right]^{\left(-\frac{1}{\rho}\right)}\right\}^{1+\rho}\omega\left(C_t^d\right)^{-\rho-1} = p_t^d$$

$$\left(C_t\right)^{1+\rho}\omega\left(C_t^d\right)^{-\rho-1} = p_t^d$$

$$\frac{C_t^d}{C_t} = \omega^\sigma \left(p_t^d\right)^{-\sigma} \tag{B.3}$$

Similarly, substitution of B.2 into the F.O.C. with respect to the foreign good consumption (B.1b) gives us:

$$\left[\omega \left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t \left(C_t^f\right)^{-\rho}\right]^{-\frac{1}{\rho}-1} (1-\omega)\varsigma_t \left(C_t^f\right)^{-\rho-1} = q_t$$

$$\left\{\left[\omega \left(C_t^d\right)^{-\rho} + (1-\omega)\varsigma_t \left(C_t^f\right)^{-\rho}\right]^{\left(-\frac{1}{\rho}\right)}\right\}^{1+\rho} (1-\omega)\varsigma_t \left(C_t^f\right)^{-\rho-1} = q_t$$

$$\left(C_t\right)^{1+\rho} (1-\omega)\varsigma_t \left(C_t^f\right)^{-\rho-1} = q_t$$

$$\frac{C_t^f}{C_t} = \left[(1-\omega)\varsigma_t\right]^\sigma \left(q_t\right)^{-\sigma} \tag{B.4}$$

Note that, we can transform the consumption composite 3.8 into unity by deviding through C_t:

$$1 = \left[\omega \left(\frac{C_t^d}{C_t}\right)^{-\rho} + (1-\omega)\left(\frac{C_t^f}{C_t}\right)^{-\rho}\right]^{\left(-\frac{1}{\rho}\right)} \tag{B.5}$$

Substituting B.3 and B.4 into B.5, we obtain the optimized consumption budget 3.12 and hence the log-linearized approximation 3.13 of the domestic price level.

B.2 Model Specification

B.2.1 United States (Home country)

Flexible economy

$$0*(1-\alpha^{us})\,\varepsilon_t^{a,us}=\alpha^{us}r_t^{k,usf}+(1-\alpha^{us})\,w_t^{usf}$$

$$z_t^{usf}=\frac{1-\psi}{\psi}r_t^{k,usf}$$

$$r_t^{k,usf}=w_t^{usf}+l_t^{usf}-k_t^{usf}$$

$$k_t^{s,usf}=k_{t-1}^{usf}+z_t^{usf}$$

$$i_t^{usf}=\frac{1}{1+\bar{\beta}\gamma^{us}}\left(i_{t-1}^{usf}+\bar{\beta}\gamma^{us}i_{t+1}^{usf}+\frac{1}{(\gamma^{us})^2\,(S^{us})''}q_t^{usf}\right)+\varepsilon_t^{i,us}$$

$$q_t^{usf}=-r_t^{usf}-0*\varepsilon_t^{b,us}+\frac{\sigma_c^{us}\left(1+\frac{h^{us}}{\gamma^{us}}\right)}{1-\frac{h^{us}}{\gamma^{us}}}\varepsilon_t^{b,us}+\frac{r_*^{k,us}}{r_*^{k,us}+1-\delta^{us}}r_{t+1}^{k,usf}+\frac{1-\delta^{us}}{r_*^{k,us}+1-\delta^{us}}q_{t+1}^{usf}$$

$$\begin{aligned}c_t^{usf} \quad = \quad & \frac{\frac{h^{us}}{\gamma^{us}}}{1+\frac{h^{us}}{\gamma^{us}}}c_{t-1}^{usf}+\frac{1}{1+\frac{h^{us}}{\gamma^{us}}}c_{t+1}^{usf}+\frac{(\sigma_c^{us}-1)\left(\frac{w_*^hL}{c_*}\right)^{us}}{\sigma_c^{us}\left(1+\frac{h^{us}}{\gamma^{us}}\right)}\left(l_t^{usf}-l_{t+1}^{usf}\right)\\ & -\frac{1-\frac{h^{us}}{\gamma^{us}}}{\sigma_c^{us}\left(1+\frac{h^{us}}{\gamma^{us}}\right)}\left(r_t^{usf}+0*\varepsilon_t^{b,us}\right)+\varepsilon_t^{b,us}\end{aligned}$$

$$y_t^{usf}=c_y^{us}c_t^{usf}+i_y^{us}i_t^{usf}+\varepsilon_t^{g,us}+crkky*z_t^{usf}+\frac{im_*^{ea}}{y_*^{us}}im_t^{eaf}-\frac{im_*^{us}}{y_*^{us}}im_t^{usf}$$

$$y_t^{usf} = \phi_p^{us}\left[\alpha^{us} r_t^{s,usf} + (1-\alpha^{us})\, l_t^{usf} + \varepsilon_t^{a,us}\right]$$

$$w_t^{usf} = \sigma_l^{us} l_t^{usf} + \frac{1}{1-\frac{h^{us}}{\gamma^{us}}} c_t^{usf} - \frac{\frac{h^{us}}{\gamma^{us}}}{1-\frac{h^{us}}{\gamma^{us}}} c_{t-1}^{usf}$$

$$k_t^{usf} = \left(1 - \frac{i_*^{us}}{k_*^{us}}\right) k_{t-1}^{usf} + \frac{i_*^{us}}{k_*^{us}} i_t^{usf} + \frac{i_*^{us}}{k_*^{us}} (\gamma^{us})^2 (S^{us})'' \varepsilon_t^{i,us}$$

$$im_t^{usf} = c_t^{usf} + \sigma_g^{us} Q_t^f$$

$$c_t^{usf} = \omega^{us} c_t^{usdf} + (1-\omega^{us})\, im_t^{usf}$$

$$Q_t^f = -r_t^{eaf} + r_t^{usf} + 0.99999 E_t Q_{t+1}^f$$

Sticky economy

Consumption Euler equation

$$\begin{aligned} c_t^{us} \quad = \quad & \frac{\frac{h^{us}}{\gamma^{us}}}{1+\frac{h^{us}}{\gamma^{us}}} c_{t-1}^{us} + \frac{1}{1+\frac{h^{us}}{\gamma^{us}}} E_t c_{t+1}^{us} + \frac{(\sigma_c^{us}-1)\left(\frac{w_*^h L}{c_*}\right)^{us}}{\sigma_c^{us}\left(1+\frac{h^{us}}{\gamma^{us}}\right)} \left(l_t^{us} - E_t l_{t+1}^{us}\right) \\ & - \frac{1-\frac{h^{us}}{\gamma^{us}}}{\sigma_c^{us}\left(1+\frac{h^{us}}{\gamma^{us}}\right)} \left(r_t^{us} - E_t \pi_{t+1}^{us}\right) + \varepsilon_t^{b,us} \end{aligned}$$

Investment Euler equation

$$i_t^{us} = \frac{1}{1+\bar{\beta}^{us}\gamma^{us}} \left(i_{t-1}^{us}\right) + \frac{\bar{\beta}^{us}\gamma^{us}}{1+\bar{\beta}^{us}\gamma^{us}} E_t i_{t+1}^{us} + \frac{1}{1+\bar{\beta}^{us}\gamma^{us}} \frac{1}{(\gamma^{us})^2 (S^{us})''} q_t^{us} + \varepsilon_t^{i,us}$$

Tobin q equation

$$q_t^{us} = \frac{1-\delta^{us}}{1-\delta^{us}+r_*^{k,us}} E_t q_{t+1}^{us} + \frac{r_*^{k,us}}{1-\delta^{us}+r_*^{k,us}} E_t r_{t+1}^{k,us} - \left(r_t^{us} - E_t \pi_{t+1}^{us}\right) + \frac{1}{\frac{1-\frac{h^{us}}{\gamma^{us}}}{\left(1+\frac{h^{us}}{\gamma^{us}}\right)\sigma_c^{us}}} \varepsilon_t^{b,us}$$

Capital accumulation equation

$$k_t^{us} = \left(1 - \frac{i_*^{us}}{k_*^{us}}\right) k_{t-1}^{us} + \frac{i_*^{us}}{k_*^{us}} i_t^{us} + \frac{i_*^{us}}{k_*^{us}} \left(\gamma^{us}\right)^2 S^{us\prime\prime} \varepsilon_t^{i,us}$$

Taylor Rule

$$\begin{aligned} r_t^{us} &= \rho r_{t-1}^{us} + (1-\rho)\left[r_\pi^{us}\pi_t^{us} + r_y^{us}\left(y_t^{us} - y_t^{usf}\right)\right] \\ &\quad + r_{\Delta y}^{us}\left(y_t^{us} - y_t^{usf} - y_{t-1}^{us} + y_{t-1}^{usf}\right) + \varepsilon_t^{r,us} \end{aligned}$$

Price setting equation

$$\begin{aligned} r_t^{k,us} &= \frac{1}{\alpha^{us}\frac{\left(1-\bar{\beta}^{us}\gamma^{us}\xi_p^{us}\right)\left(1-\xi_p^{us}\right)}{\xi_p^{us}\left(\left(\phi_p^{us}-1\right)\zeta_p^{us}+1\right)}} \left[\begin{array}{c} \left(1+\bar{\beta}^{us}\gamma^{us}\iota_p^{us}\right)\left(\pi_t^{us} - \varepsilon_t^{\pi,us}\right) - \\ \bar{\beta}^{us}\gamma^{us}E_t\pi_{t+1}^{us} - \iota_p^{us}\pi_{t-1}^{us} \end{array} \right] \\ &\quad - \frac{1}{\alpha^{us}}\left(1-\alpha^{us}\right) w_t^{us} + \frac{1}{\alpha^{us}}\varepsilon_t^{a,us} \end{aligned}$$

Labour supply

$$\begin{aligned} w_t^{us} &= \frac{\bar{\beta}^{us}\gamma^{us}}{1+\bar{\beta}^{us}\gamma^{us}} E_t w_{t+1}^{us} + \frac{1}{1+\bar{\beta}^{us}\gamma^{us}} w_{t-1}^{us} + \frac{\bar{\beta}^{us}\gamma^{us}}{1+\bar{\beta}^{us}\gamma^{us}} E_t \pi_{t+1}^{us} - \frac{1+\bar{\beta}^{us}\gamma^{us}\iota_w^{us}}{1+\bar{\beta}^{us}\gamma^{us}} \pi_t^{us} \\ &\quad + \frac{\iota_w^{us}}{1+\bar{\beta}^{us}\gamma^{us}} \pi_{t-1}^{us} - \frac{1}{1+\bar{\beta}^{us}\gamma^{us}} \left(\frac{\left(1-\bar{\beta}^{us}\gamma^{us}\xi_w^{us}\right)\left(1-\xi_w^{us}\right)}{\xi_w^{us}\left(\left(\lambda_w^{us}-1\right)\zeta_w^{us}+1\right)} \right) \\ &\quad \left(w_t^{us} - \sigma_l^{us} l_t^{us} - \left(\frac{1}{1-\frac{h^{us}}{\gamma^{us}}}\right)\left(c_t^{us} - \frac{h^{us}}{\gamma^{us}} c_{t-1}^{us}\right)\right) + \varepsilon_t^{w,us} \end{aligned}$$

Labour demand

$$l_t^{us} = -w_t^{us} + \left(1 + \frac{1-\psi^{us}}{\psi^{us}}\right) r_t^{k,us} + k_{t-1}^{us}$$

Market clearing condition

$$y_t^{us} = c_y^{us} c_t^{us} + i_y^{us} i_t^{us} + crkky \frac{1-\psi^{us}}{\psi^{us}} r_t^{k,us} + \frac{im_*^{ea}}{y_*^{us}} im_t^{ea} - \frac{im_*^{us}}{y_*^{us}} im_t^{us} + \varepsilon_t^{g,us}$$

Production function

$$r_t^{k,us} = \frac{1}{\phi_p^{us} \alpha^{us} \frac{1-\psi^{us}}{\psi^{us}}} \left(y_t^{us} - \phi_p^{us} \alpha k_{t-1}^{us} - \phi_p^{us} (1-\alpha) l_t^{us} - \phi_p^{us} \varepsilon_t^{a,us} \right)$$

Imports

$$im_t^{us} = c_t^{us} + \sigma_g^{us} Q_t$$

Exchange rate

$$Q_t = r_t^{us} - E_t \pi_{t+1}^{us} - \left(r_t^{ea} - E_t \pi_{t+1}^{ea} \right) + 0.9999 E_t Q_{t+1}$$

Consumption decomposition

$$c_t^{us} = \omega^{us} c_t^{usd} + (1-\omega^{us}) im_t^{us}$$

Shock processes

$$\begin{aligned}
\varepsilon_t^{b,us} &= \rho_b^{us} \varepsilon_{t-1}^{b,us} + \eta_t^{b,us} \\
\varepsilon_t^{i,us} &= \rho_i^{us} \varepsilon_{t-1}^{i,us} + \eta_t^{i,us} \\
\varepsilon_t^{a,us} &= \rho_a^{us} \varepsilon_{t-1}^{a,us} + \eta_t^{a,us} \\
\varepsilon_t^{r,us} &= \rho_r^{us} \varepsilon_{t-1}^{r,us} + \eta_t^{r,us} \\
\varepsilon_t^{w,us} &= \rho_w^{us} \varepsilon_{t-1}^{w,us} + \eta_t^{w,us} - \mu_w^{us} \eta_{t-1}^{w,us} \\
\varepsilon_t^{\pi,us} &= \rho_\pi^{us} \varepsilon_{t-1}^{\pi,us} + \eta_t^{\pi,us} - \mu_\pi^{us} \eta_{t-1}^{\pi,us} \\
\varepsilon_t^{g,us} &= \rho_g^{us} \varepsilon_{t-1}^{g,us} + \eta_t^{g,us} + \rho_{ga} \eta_t^{a,us} \\
\varepsilon_t^{wNC,us} &= \rho_{wNC} \varepsilon_{t-1}^{wNC,us} + \eta_t^{wNC,us} - \mu_{wNC}^{us} \eta_{t-1}^{wNC,us}
\end{aligned}$$

Exogenous innovations

$$\eta_t^{b,us} \sim IID\text{-}Normal$$
$$\eta_t^{i,us} \sim IID\text{-}Normal$$
$$\eta_t^{a,us} \sim IID\text{-}Normal$$
$$\eta_t^{r,us} \sim IID\text{-}Normal$$
$$\eta_{t-1}^{w,us} \sim IID\text{-}Normal$$
$$\eta_{t-1}^{\pi,us} \sim IID\text{-}Normal$$
$$\eta_t^{g,us} \sim IID\text{-}Normal$$
$$\eta_{t-1}^{wNC,us} \sim IID\text{-}Normal$$

B.2.2 Euro Area (Overseas)

Flexible economy

$$c_t^{eaf} = \frac{1}{c_y^{ea}}\left(y_t^{eaf} - \delta^{ea} k_y^{ea} i_t^{eaf} - \varepsilon_t^{g,ea} - \frac{im_*^{us}}{y_*^{ea}} im_t^{usf} + \frac{im_*^{ea}}{y_*^{ea}} im_t^{eaf}\right)$$

$$i_t^{eaf} = \frac{1}{1+\beta^{ea}} i_{t-1}^{eaf} + \frac{\beta^{ea}}{1+\beta^{ea}} E_t i_{t+1}^{eaf} + \frac{\frac{1}{\bar{S}^{ea\prime\prime}}}{1+\beta^{ea}} q_t^{eaf} + \varepsilon_t^{i,ea}$$

$$q_t^{eaf} = -r_t^{eaf} + \frac{1-\delta^{ea}}{1-\delta^{ea}+\bar{r}^{k,ea}} E_t q_{t+1}^{eaf} + \frac{\bar{r}^{k,ea}}{1-\delta^{ea}+\bar{r}^{k,ea}} E_t r_{t+1}^{k,eaf}$$

$$k_t^{eaf} = \left(1-\delta^{ea}\right) k_{t-1}^{eaf} + \delta^{ea} i_{t-1}^{eaf}$$

$$w_t^{eaf} = \sigma_l^{ea} l_t^{eaf} + \frac{\sigma_c^{ea}}{1-h^{ea}}\left(c_t^{eaf} - h^{ea} c_{t-1}^{eaf}\right) + \varepsilon_t^{w,ea}$$

$$l_t^{eaf} = -w_t^{eaf} + \left(1+\psi\right) r_t^{k,eaf} + k_{t-1}^{eaf}$$

$$y_t^{eaf} = \phi^{ea}\alpha^{ea}\psi^{ea} r_t^{k,eaf} + \phi^{ea}\alpha^{ea} k_{t-1}^{eaf} + \phi^{ea}\left(1-\alpha^{ea}\right) l_t^{eaf} + \phi^{ea}\varepsilon_t^{a,ea}$$

$$r_t^{k,eaf} = \frac{1}{\alpha^{ea}}\varepsilon_t^{a,ea} - \frac{1-\alpha^{ea}}{\alpha^{ea}}w_t^{eaf}$$

$$r_t^{eaf} = \frac{(1+h^{ea})\,\sigma_c^{ea}}{1-h^{ea}}\left(\frac{h^{ea}}{1+h^{ea}}c_{t-1}^{eaf} + \frac{1}{1+h^{ea}}E_t c_{t+1}^{eaf} - c_t^{eaf}\right) + \varepsilon_t^{b,ea}$$

$$im_t^{eaf} = c_t^{eaf} - \sigma_g^{ea}Q_t^f$$

$$c_t^{eaf} = \omega^{ea}c_t^{eadf} + (1-\omega^{ea})\,im_t^{eaf}$$

Sticky economy

Market-clearing equation

$$c_t^{ea} = \frac{1}{c_y^{ea}}\left(y_t^{ea} - \delta^{ea}k_y^{ea}i_t^{ea} - \varepsilon_t^{g,ea} - \frac{im_*^{us}}{y_*^{ea}}im_t^{us} + \frac{im_*^{ea}}{y_*^{ea}}im_t^{ea}\right)$$

Investment Euler equation

$$i_t^{ea} = \frac{1}{1+\beta^{ea}}i_{t-1}^{ea} + \frac{\beta^{ea}}{1+\beta^{ea}}E_t i_{t+1}^{ea} + \frac{\frac{1}{\bar{S}^{ea\prime\prime}}}{1+\beta^{ea}}q_t^{ea} + \varepsilon_t^{i,ea}$$

Tobin's q equation

$$q_t^{ea} = -\left(r_t^{ea} - E_t\pi_{t+1}^{ea}\right) + \frac{1-\delta^{ea}}{1-\delta^{ea}+\bar{r}^{k,ea}}E_t q_{t+1}^{ea} + \frac{\bar{r}^{k,ea}}{1-\delta^{ea}+\bar{r}^{k,ea}}E_t r_{t+1}^{k,ea}$$

Capital accumulation equation

$$k_t^{ea} = (1-\delta^{ea})\,k_{t-1}^{ea} + \delta^{ea}i_{t-1}^{ea}$$

Taylor rule equation

$$\begin{aligned} r_t^{ea} &= \rho^{ea} r_{t-1}^{ea} + (1-\rho^{ea}) \left[r_\pi^{ea} \pi_{t-1}^{ea} + r_y^{ea} \left(y_t^{ea} - y_{t-1}^{eaf} \right) \right] \\ & +r_{\Delta\pi}^{ea} \left(\pi_t^{ea} - \pi_{t-1}^{ea} \right) + r_{\Delta y}^{ea} \left(y_t^{ea} - y_t^{eaf} - y_{t-1}^{ea} + y_{t-1}^{eaf} \right) + \varepsilon_t^{\pi,ea} \end{aligned}$$

Labour supply

$$\begin{aligned} w_t^{ea} &= \frac{\beta^{ea}}{1+\beta^{ea}} E_t w_{t+1}^{ea} + \frac{1}{1+\beta^{ea}} w_{t-1}^{ea} + \frac{\beta^{ea}}{1+\beta^{ea}} E_t \pi_{t+1}^{ea} \\ & -\frac{1+\beta^{ea}\gamma_w^{ea}}{1+\beta^{ea}} \pi_t^{ea} + \frac{\gamma_w^{ea}}{1+\beta^{ea}} \pi_{t-1} - \frac{1}{1+\beta} \frac{\left(1-\beta^{ea}\xi_w^{ea}\right)\left(1-\xi_w^{ea}\right)}{\left(1+\frac{(1+\lambda_w^{ea})\sigma_L}{\lambda_w^{ea}}\right)\xi_w^{ea}} \\ & \left(w_t^{ea} - \sigma_l^{ea} l_t^{ea} - \frac{\sigma_c^{ea}}{1-h^{ea}} \left(c_t^{ea} - h^{ea} c_{t-1}^{ea} \right) \right) + \varepsilon_t^{w,ea} \end{aligned}$$

Labour demand

$$l_t^{ea} = -w_t^{ea} + (1+\psi) r_t^{k,ea} + k_{t-1}^{ea}$$

Production function

$$y_t^{ea} = \phi^{ea} \alpha^{ea} \psi^{ea} r_t^{k,ea} + \phi^{ea} \alpha^{ea} k_{t-1}^{ea} + \phi^{ea} (1-\alpha^{ea}) l_t^{ea} + \phi^{ea} \varepsilon_t^{a,ea}$$

Price-setting equation

$$\begin{aligned} r_t^{k,ea} &= \frac{1}{\left(\frac{1}{1+\beta^{ea}\gamma_p^{ea}}\right)\left(\frac{\left(1-\beta^{ea}\xi_p^{ea}\right)\left(1-\xi_p^{ea}\right)}{\xi_p^{ea}}\right)\alpha^{ea}} \left(\begin{array}{c} \pi_t^{ea} - \frac{\beta^{ea}}{1+\beta^{ea}\gamma_p^{ea}} E_t \pi_{t+1}^{ea} - \\ \frac{\gamma_p^{ea}}{1+\beta^{ea}\gamma_p^{ea}} \frac{\left(1-\beta^{ea}\xi_p^{ea}\right)\left(1-\xi_p^{ea}\right)}{\xi_p^{ea}} \pi_{t-1}^{ea} - \varepsilon_t^{p,ea} \end{array} \right) \\ & -\frac{1-\alpha^{ea}}{\alpha^{ea}} w_t^{ea} + \frac{1}{\alpha^{ea}} \varepsilon_t^{a,ea} \end{aligned}$$

Consumption Euler equation

$$r_t^{ea} = E_t \pi_{t+1}^{ea} + \frac{1}{\frac{1-h^{ea}}{(1+h^{ea})\sigma_c^{ea}}} \left(\frac{h^{ea}}{1+h^{ea}} c_{t-1}^{ea} + \frac{1}{1+h^{ea}} E_t c_{t+1}^{ea} - c_t^{ea} + \varepsilon_t^{b,ea} \right)$$

Imports

$$im_t^{ea} = c_t^{ea} - \sigma_g^{ea} Q_t$$

Consumption decomposition

$$c_t^{ea} = \omega^{ea} c_t^{ead} + (1 - \omega^{ea})\, im_t^{ea}$$

Net exports

$$nx_t = im_t^{ea} - im_t^{us}$$

Shock processes

$$\begin{aligned}
\varepsilon_t^{g,ea} &= \rho_g^{ea} \varepsilon_{t-1}^{g,ea} + \eta_t^{g,ea} \\
\varepsilon_t^{i,ea} &= \rho_i^{ea} \varepsilon_{t-1}^{i,ea} + \eta_t^{i,ea} \\
\varepsilon_t^{\pi,ea} &= \rho_\pi^{ea} \varepsilon_{t-1}^{\pi,ea} + \eta_t^{\pi,ea} \\
\varepsilon_t^{w,ea} &= \rho_w^{ea} \varepsilon_{t-1}^{w,ea} + \eta_t^{w,ea} \\
\varepsilon_t^{a,ea} &= \rho_a^{ea} \varepsilon_{t-1}^{a,ea} + \eta_t^{a,ea} \\
\varepsilon_t^{b,ea} &= \rho_b^{ea} \varepsilon_{t-1}^{b,ea} + \eta_t^{b,ea} \\
\varepsilon_t^{p,ea} &= \rho_p^{ea} \varepsilon_{t-1}^{p,ea} + \eta_t^{p,ea} \\
\varepsilon_t^{wNC,ea} &= \rho_{wNC}^{ea} \varepsilon_{t-1}^{wNC,ea} + \eta_t^{wNC,ea}
\end{aligned}$$

Exogenous innovations

$$\begin{aligned}
\eta_t^{g,ea} &\sim IID\text{-}Normal \\
\eta_t^{i,ea} &\sim IID\text{-}Normal \\
\eta_t^{\pi,ea} &\sim IID\text{-}Normal \\
\eta_t^{w,ea} &\sim IID\text{-}Normal \\
\eta_t^{a,ea} &\sim IID\text{-}Normal \\
\eta_t^{b,ea} &\sim IID\text{-}Normal \\
\eta_t^{p,ea} &\sim IID\text{-}Normal \\
\eta_t^{wNC,ea} &\sim IID\text{-}Normal
\end{aligned}$$

Flexible Economy Variable		Flexible Economy Variable	
$r_t^{k,usf}$	US rental rate of capital	c_t^{eaf}	EA real consumption
w_t^{usf}	US real wage	y_t^{eaf}	EA real output
z_t^{usf}	the degree of capital utilisation in the US	i_t^{eaf}	EA real investment
l_t^{usf}	US labour (hours)	im_t^{eaf}	EA imports from the US
k_t^{usf}	US capital stock	q_t^{eaf}	the value of capital in the EA
$k_t^{s,usf}$	current capital service used in production	r_t^{eaf}	EA nominal interest rate
i_t^{usf}	US real investment	k_t^{eaf}	EA capital stock
q_t^{usf}	the value of capital in the US	w_t^{eaf}	EA real wage
r_t^{usf}	US nominal interest rate	l_t^{eaf}	EA labour (hours)
c_t^{usf}	US real consumption	$r_t^{k,eaf}$	EA rental rate of capital
y_t^{usf}	US real output	c_t^{eadf}	EA real domestic consumption
im_t^{usf}	US imports from the EA		
Q_t^f	real USD/EUR exchange rate		
c_t^{usdf}	US real domestic consumption		

Table B.1: Variables in the Flexible Economy

Sticky Economy Variable		Sticky Economy Variable	
c_t^{us}	US real consumption	c_t^{ea}	EA real consumption
l_t^{us}	US labour	l_t^{ea}	EA labour
r_t^{us}	US nominal interest rate	r_t^{ea}	EA nominal interest rate
π_t^{us}	US inflation	π_t^{ea}	EA inflation
i_t^{us}	US real investment	i_t^{ea}	EA real investment
q_t^{us}	the value of capital in the US	q_t^{ea}	the value of capital in the EA
k_t^{us}	US capital stock	k_t^{ea}	EA capital stock
y_t^{us}	US real output	y_t^{ea}	EA real output
w_t^{us}	US real wage	w_t^{ea}	EA real wage
$r_t^{k,us}$	US rental rate of capital	$r_t^{k,ea}$	EA rental rate of capital
im_t^{us}	US imports from the EA	im_t^{ea}	EA imports from the US

Table B.2: Variables in the Sticky Economy

US shocks		EA shocks	
$\varepsilon_t^{b,us}$	US preference shock	$\varepsilon_t^{g,ea}$	EA government spending shock
$\varepsilon_t^{i,us}$	US investment technology shock	$\varepsilon_t^{i,ea}$	EA investment technology shock
$\varepsilon_t^{a,us}$	US productivity shock	$\varepsilon_t^{\pi,ea}$	EA monetary shock
$\varepsilon_t^{r,us}$	US monetary shock	$\varepsilon_t^{w,ea}$	EA wage mark-up shock
$\varepsilon_t^{w,us}$	US wage mark-up shock	$\varepsilon_t^{a,ea}$	EA productivity shock
$\varepsilon_t^{\pi,us}$	US price mark-up shock	$\varepsilon_t^{b,ea}$	EA preference shock
$\varepsilon_t^{g,us}$	US government spending shock	$\varepsilon_t^{p,ea}$	EA price mark-up shock
$\varepsilon_t^{wNC,us}$	US labour supply shock	$\varepsilon_t^{wNC,ea}$	EA labour supply shock

Table B.3: Structural Shocks

	Calibration	**Descriptions**
α^{us}	0.19	share of capital in production
β^{us}	0.9984	discount factor $\bar{\beta}^{us} = \beta^{us} \left(\gamma^{us}\right)^{-\sigma_c^{us}} = 0.9925$
h^{us}	0.71	external habit formation
$\frac{im_*^{ea}}{y_*^{us}}$	0.016066	US equilibrium export to output ratio
$\frac{im_*^{us}}{y_*^{us}}$	0.020635	US equilibrium import to output ratio
σ_g^{us}	0.8	elasticity of import to real exchange rate
ω^{us}	0.7	porpotion of domestic product in total domestic consumption
$\bar{S}^{us\prime\prime}$	5.74	steady state elasticity of capital adjustment cost
δ^{us}	0.025	capital depreciation rate
ς_w^{us}	10	curvature parameters of Kimball aggregator in labour market
ς_p^{us}	10	curvature parameters of Kimball aggregator in good market
γ^{us}	1.0043	parameter of US common quarterly trend
λ_w^{us}	1.5	steady state mark-up in labour market
ϕ_p^{us}	1.5	one plus the share of fixed costs in production
ψ^{us}	0.54	elasticity of capital utilisation cost
σ_c^{us}	1.38	coefficient of relative risk aversion of households
σ_l^{us}	1.83	inverse of elasticity of labour supply with respect to real wages
ξ_w^{us}	0.7	degree of nominal wage stickiness
ξ_p^{us}	0.66	degree of nominal price stickiness
ι_w^{us}	0.58	degree of indexation to past indexation in wage setting
ι_p^{us}	0.24	degree of indexation to past indexation in price setting
Φ_w^{us}	0.1	weights of NK in wage setting equation
Φ_p^{us}	0.2	weights of NK in price setting equation
Φ_m^{us}	0	weights of NK in monetary policy rule
ρ^{us}	0.81	degree of interest rate smoothing in monetary policy rule
r_π^{us}	2.04	coefficient of inflation deviation in monetary policy rule
r_y^{us}	0.08	coefficient of output gap in monetary policy rule
$r_{\Delta y}^{us}$	0.22	coefficient for short-run output gap in monetary policy rule
$r_*^{k,us}$	0.0326	$r_*^{k,us} = \frac{1}{\beta^{us}} \left(\gamma^{us}\right)^{\sigma_c^{us}} - \left(1 - \delta^{us}\right)$
$\frac{i_*^{us}}{k_*^{us}}$	0.0292	$\frac{i_*^{us}}{k_*^{us}} = 1 - \frac{1-\delta^{us}}{\gamma^{us}}$
i_y^{us}	0.1710	$i_y^{us} = \frac{i_*^{us}}{k_*^{us}} \gamma^{us} * \phi_p^{us} \left(\frac{1-\alpha^{us}}{\alpha^{us}} \frac{r_*^{k,us} \left[\phi_p^{us} \left(\frac{i_*^{us}}{k_*^{us}} \right)^{\alpha^{us}} \right]^{\frac{1}{1-\alpha^{us}}}}{\left(\alpha^{us}\right)^{\alpha^{us}} \left(1-\left(\alpha^{us}\right)^{\alpha^{us}}\right)} \right)^{\alpha^{us}-1}$
c_y^{us}	0.6535	$c_y^{us} = 1 - 0.18 - i_y^{us} - \frac{im_*^{ea}}{y_*^{us}} + \frac{im_*^{us}}{y_*^{us}}$
$crkky$	0.19	$crkky = r_*^{k,us} \phi_p^{us} \left(\frac{1-\alpha^{us}}{\alpha^{us}} \frac{r_*^{k,us} \left[\phi_p^{us} \left(\frac{i_*^{us}}{k_*^{us}} \right)^{\alpha^{us}} \right]^{\frac{1}{1-\alpha^{us}}}}{\left(\alpha^{us}\right)^{\alpha^{us}} \left(1-\left(\alpha^{us}\right)^{\alpha^{us}}\right)} \right)^{\alpha^{us}-1}$
$\frac{w_*^h L}{c_*}$	0.8263	$\frac{w_*^h L}{c_*} = \frac{1}{\lambda_w^{us}} \frac{1-\alpha^{us}}{\alpha^{us}} \frac{r_*^{k,us} \phi_p^{us} \left(\frac{1-\alpha^{us}}{\alpha^{us}} \frac{r_*^{k,us} \left[\phi_p^{us} \left(\frac{i_*^{us}}{k_*^{us}} \right)^{\alpha^{us}} \right]^{\frac{1}{1-\alpha^{us}}}}{\left(\alpha^{us}\right)^{\alpha^{us}} \left(1-\left(\alpha^{us}\right)^{\alpha^{us}}\right)} \right)^{\alpha^{us}-1}}{c_y^{us}}$

Table B.4: Parameter calibration for the US economy

	Value	Descriptions
α^{ea}	0.3	share of capital in production
β^{ea}	0.99	discount factor
h^{ea}	0.552	external habit formation
$\frac{im_*^{ea}}{y_*^{ea}}$	0.001413	EA equilibrium import to output ratio
$\frac{im_*^{us}}{y_*^{ea}}$	0.00122	EA equilibrium export to output ratio
σ_g^{ea}	0.8	elasticity of import to real exchange rate
ω^{ea}	0.7	propotion of domestic products in total domestic consumption
$\bar{S}^{ea\prime\prime}$	7	steady state elasticity of capital adjustment cost
δ^{ea}	0.025	capital depreciation rate
ϕ^{ea}	1.487	one plus the share of fixed costs in production
ψ^{ea}	0.175	elasticity of capital utilisation cost
σ_c^{ea}	1.608	coefficient of relative risk aversion of households
σ_l^{ea}	1.188	the inverse of elasticity of labour supply with respect to real wages
λ_w^{ea}	0.596	coefficient of Dixit-Stiglitz aggregator
ξ_w^{ea}	0.758	degree of nominal wage stickiness
ξ_p^{ea}	0.909	degree of nominal price stickiness
γ_w^{ea}	0.663	degree of indexation to past indexation in wage setting
γ_p^{ea}	0.425	degree of indexation to past indexation in price setting
ϕ_w^{ea}	0.08	weights of NK in wage setting equation
ϕ_p^{ea}	0.06	weights of NK in price setting equation
ϕ_m^{ea}	0.04	weights of NK in monetary policy rule
ρ^{ea}	0.931	degree of interest rate smoothing in monetary policy rule
r_π^{ea}	1.661	coefficient of inflation deviation in monetary policy rule
r_y^{ea}	0.143	coefficient of output gap in monetary policy rule
$r_{\Delta y}^{ea}$	0.173	coefficient for short-run output gap in monetary policy rule
$r_{\Delta\pi}^{ea}$	0.221	coefficient for short-run inflation deviation in monetary policy rule
k_y^{ea}	2.2	capital output ratio
c_y^{ea}	0.7652	$c_y^{ea} = 1 - \delta^{ea} k_y^{ea} - 0.18 - 0.00122 + 0.001413$

Table B.5: Parameter calibration for the EA economy

B.3 Data Resources and Formulae

Code	Description
GDPC96	Real Gross Domestic Product
GDPDEF	Gross Domestic Product: Implicit Price Deflator
PCEC	Personal Consumption Expenditures
FPI	Fixed Private Investment
CE16OV	Civilian Employment
FEDFUNDS	Effective Federal Funds Rate
LNS10000000	Population Level-Civilian noninstitutional population
PRS85006023	Major sector productivity and cost index-Average weekly hours
PRS85006103	Major sector productivity and cost index-Hourly Compensation

Table B.6: US raw data series

Time series	Formular of constructing
Output	$100 * \ln \frac{\text{real GDP}}{\text{population index}}$
Consumption	$100 * \ln \frac{\text{personal consumption expenditure/GDP deflator}}{\text{population index}}$
Investment	$100 * \ln \frac{\text{fixed private investment/GDP deflator}}{\text{population index}}$
Inflation	$100 * [\ln (GDP\ deflator_t) - \ln (GDP\ deflator_{t-1})]$
Hours	$100 * \ln \frac{\text{average weekly hours*employment index/100}}{\text{population index}}$
Real wage	$100 * \ln \frac{\text{hourly compensation}}{\text{GDP deflator}}$
Interest rate	$\frac{\text{Effective federal fund rate}}{4}$

Table B.7: List of the formulae for US macroeconomic time series

Code	Description	Units
PCR	Rea private consumption	Millions of ECU/Euro
ITR	Real gross investment	Millions of ECU/Euro
YER	Real GDP	Millions of ECU/Euro
LNN	Total employment	Thousands of persons
WRN	Average compensation per head	
YED	GDP deflator	Index 1995 = 1.0
STN	Short-term nominal interest rate-three months	

Table B.8: EA raw data series

Time series	Formular of constructing
Output	$100 * \ln \frac{\text{real GDP}}{\text{population index}}$
Consumption	$100 * \ln \frac{\text{real private consumption}}{\text{population index}}$
Investment	$100 * \ln \frac{\text{real gross investment}}{\text{population index}}$
Hours	$100 * \ln \frac{\text{total employment}}{\text{population index}}$
Inflation	$100 * [\ln(GDP\ deflator_t) - \ln(GDP\ deflator_{t-1})]$
Real wages	$100 * \ln \frac{\text{Wage per head}}{\text{GDP deflator}}$
Interest rate	$\frac{\text{Short-term nominal interest rate}}{4}$

Table B.9: List of the formulae for EA macroeconomic time series

B.4 Non-Stationarity Properties of Key Marcroeconomic Time Series

Seventeen key macroeconomic time series are tested for their non-stationarity by ADF tests and PP tests (without trend and intercept). The following three tables report the result of non-stationarity (ADF and PP) tests for 17 key macroeconomic time series. The time series range from 1947Q1 to 2010Q3 for the US (255 observations in total); range from 1970Q1 to 2009Q4 for the EA (160 observations in total); range from 1970Q1 to 2008Q3 for US imports from and exports to the EA (155 observations in total); range from 1958Q1 to 2011Q2 (214 observations in total). Since the length of time series differs, tests are carried out individually in accordance with each time series' own length.

The probability (in bracket) is shown below the test statistics. * indicates significant stationarity at 10% level, ** indicates significant stationarity at 5% level, and *** indicates significant stationarity at 1% level. For those time series that are non-stationary at level, tests for the first order difference are also conducted and reported. US inflation, real wage, imports, and exports are stationary at level, the tests for the first order difference are, therefore, unnecessary.

B.5 VAR(1) Expectation

There are 11 forward-looking variables required to derive structural shocks and their associated exogenous innovations. They are US consumption, investment,

	y_t^{us}		c_t^{us}		i_t^{us}	
	Levels	1^{st} Diff.	Levels	1^{st} Diff.	Levels	1^{st} Diff.
ADF Statistic	4.458	−6.726	4.947	−6.174	0.975	−8.716
	(1.00)	(0.00)***	(1.00)	(0.00)***	(0.913)	(0.00)***
PP Statistic	5.219	−9.692	7.398	−13.76	1.242	−8.743
	(1.00)	(0.00)***	(1.00)	(0.00)***	(0.945)	(0.00)***
	l_t^{us}		π_t^{us}		w_t^{us}	
	Levels	1^{st} Diff.	Levels	1^{st} Diff.	Levels	1^{st} Diff.
ADF Statistic	−0.573	−9.026	−2.218	—	−11.21	—
	(0.47)	(0.00)***	(0.03)*	—	(0.00)***	—
PP Statistic	−0.74	−9.1	−3.03	—	−9.414	—
	(0.4)	(0.00)***	(0.00)***	—	(0.00)***	—
	r_t^{us}					
	Levels	1^{st} Diff.				
ADF Statistic	−1.112	−7.171				
	(0.24)	(0.00)***				
PP Statistic	−1.3708	−12.33				
	(0.16)	(0.00)***				

Table B.10: Non-stationarity tests for US time series

	im_t^{us}		ex_t^{us}		Q_t	
	Levels	1^{st} Diff.	Levels	1^{st} Diff.	Levels	1^{st} Diff.
ADF Statistic	−2.41237	—	−2.03484	—	−1.09352	−11.3158
	(0.016)**	—	(0.041)*	—	(0.248)	(0.000)***
PP Statistic	−1.97406	—	−2.24603	—	−1.25016	−11.3716
	(0.047)*	—	(0.024)**	—	(0.194)	(0.000)***

Table B.11: Non-stationarity tests for trade variables and the real exchange rate

	y_t^{ea}		c_t^{ea}		i_t^{ea}	
	Levels	1^{st} Diff.	Levels	1^{st} Diff.	Levels	1^{st} Diff.
ADF Statistic	4.902	−4.086	3.263	−2.261	1.668	−5.702
	(1.00)	(0.00)***	(1.00)	(0.02)**	(0.98)	(0.00)***
PP Statistic	6.618	−5.8	6.967	−7.184	2.199	−9.81
	(1.00)	(0.00)***	(1.00)	(0.00)***	(0.99)	(0.00)***
	l_t^{ea}		π_t^{ea}		w_t^{ea}	
	Levels	1^{st} Diff.	Levels	1^{st} Diff.	Levels	1^{st} Diff.
ADF Statistic	1.381	−3.273	−1.292	−11.73	2.11	−3.974
	(0.96)	(0.00)***	(0.181)	(0.00)***	(0.99)	(0.00)***
PP Statistic	2.533	−3.346	−1.477	−25.87	3.158	−6.1
	(1.00)	(0.00)***	(0.13)	(0.00)***	(1.00)	(0.00)***
	r_t^{ea}					
	Levels	1^{st} Diff.				
ADF Statistic	−1.138	−7.55				
	(0.23)	(0.00)***				
PP Statistic	−1.055	−7.55				
	(0.26)	(0.00)***				

Table B.12: Non-stationarity tests for EA time series inflation, rental rate of capital, real wage and labour; EA consumption, investment, inflation, rental rate of capital and real wages.

The values of these forward-looking variables are obtained from a $VAR(1)$ regression on these 11 time series. The comparison of obtained forward-looking time series and original time series is presented in Figure B-1 and B-2.

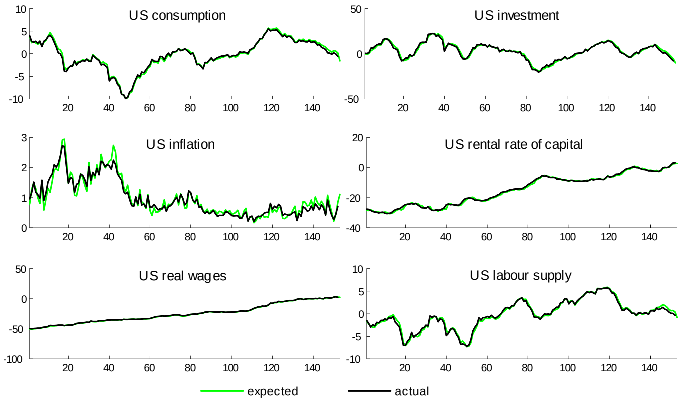


Figure B-1: US forward-looking variables predicted by VAR(1)

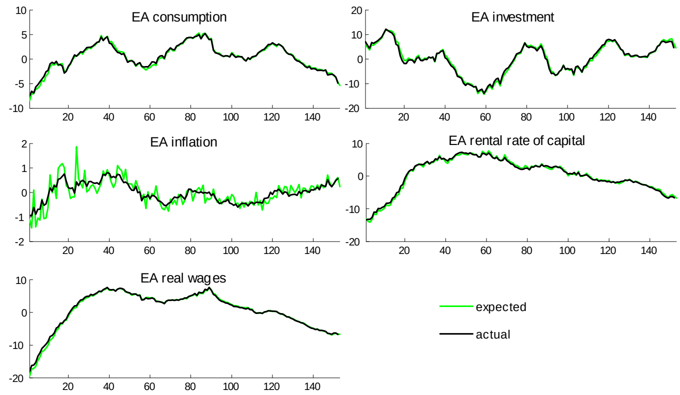


Figure B-2: EA forward-looking variables predicted by VAR(1)

B.6 Statistical Distribution for Testing Statistics

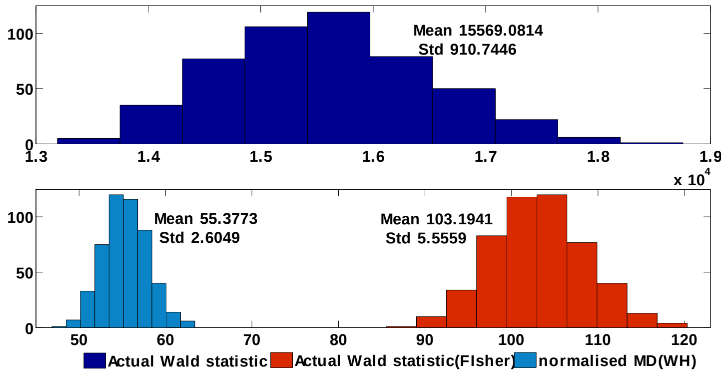


Figure B-3: Statistical distribution for the non-coordination model (NonC) (testing)

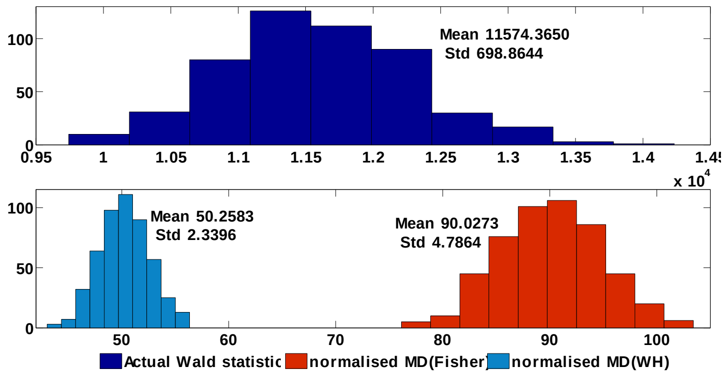


Figure B-4: Statistical distribution for the coordination model (C-3.6) (testing)

Appendix C

Chapter 5 Appendix

C.1 Statistical Distribution for Test Statistics

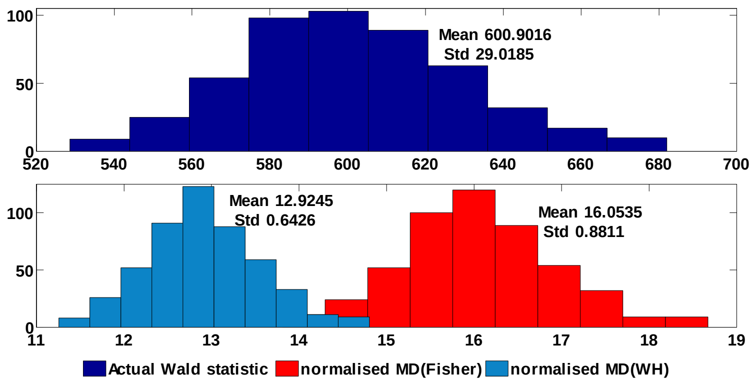


Figure C-1: Statistical distribution for the partial-coordination model(estimation)

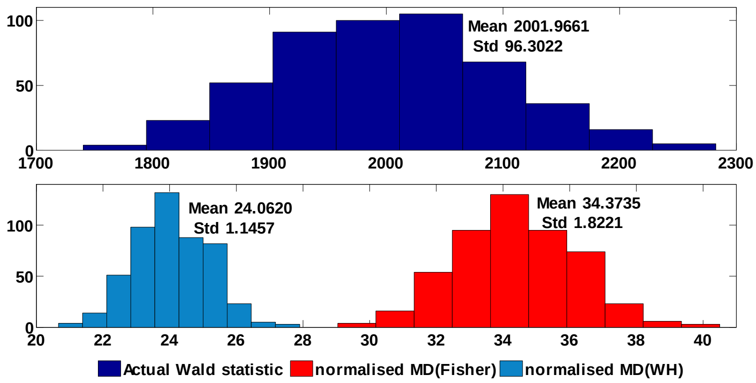


Figure C-2: Statistical distribution for the non-coordination model (estimation)

C.2 Indirect Inference Estimates for the Non-Coordination Model

	Initial	**Estimated from** non-**coordination model**	**% changes**
α^{us}	0.19	0.153690704	−19.11
$(S^{us})''$	5.74	6.064671563	5.656
ϕ_p^{us}	1.5	0.928633478	−38.091
ψ	0.54	0.482219909	−10.7
σ_c^{us}	1.38	1.144585878	−17.059
σ_l^{us}	1.83	1.706728618	−6.736
ξ_w^{us}	0.7	0.644921392	−7.868
ξ_p^{us}	0.66	0.468292485	−29.047
ι_w^{us}	0.58	0.44260073	−23.69
ι_p^{us}	0.24	0.186734192	−22.194
Φ_w^{us}	0.1	0.082842333	−17.158
Φ_p^{us}	0.2	0.195272343	−2.364
ρ^{us}	0.81	0.416474311	−48.58
r_π^{us}	2.04	2.533062127	24.17
r_y^{us}	0.08	0.078880513	−1.399
$r_{\Delta y}^{us}$	0.22	0.189038151	−14.074
α^{ea}	0.3	0.197579577	−34.14
$\bar{S}^{ea\prime\prime}$	7.0	7.112347631	1.605
ϕ^{ea}	1.487	1.488036207	0.07
ψ^{ea}	0.175	0.120034413	−31.409
σ_c^{ea}	1.608	0.938064766	−41.663
σ_l^{ea}	1.188	0.986469299	−16.964
ξ_w^{ea}	0.758	0.475188497	−37.31
ξ_p^{ea}	0.909	0.669281064	−26.372
γ_w^{ea}	0.663	0.519165697	−21.694
γ_p^{ea}	0.425	0.446380231	5.031
ϕ_w^{ea}	0.08	0.060149246	−24.813
ϕ_p^{ea}	0.06	0.054955017	−8.408
ρ^{ea}	0.931	0.619131217	−33.498
r_π^{ea}	1.661	1.213030729	−26.97
r_y^{ea}	0.143	0.139293178	−2.592
$r_{\Delta y}^{ea}$	0.173	0.214415911	23.94
$r_{\Delta \pi}^{ea}$	0.221	0.255054643	15.409

Table C.1: Estimated parameters from the non-coordination model

C.3 IRFs simulated from the model in Ball (1999b)

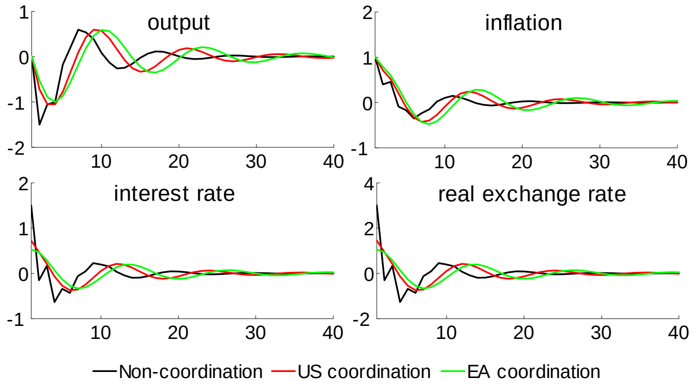


Figure C-3: IRFs to an inflation shock by the model in Ball (1999b)

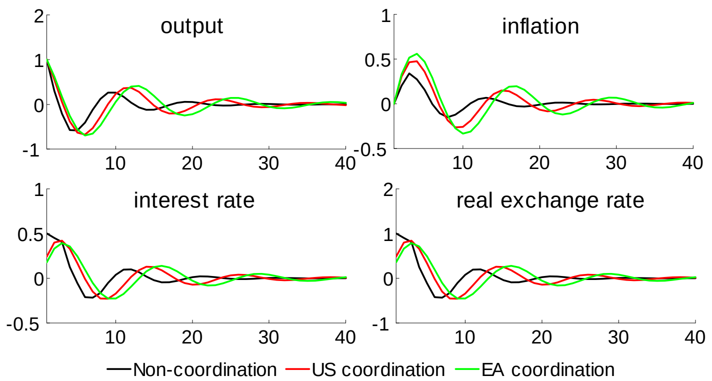


Figure C-4: IRFs to a productivity shock by the model in Ball (1999b)

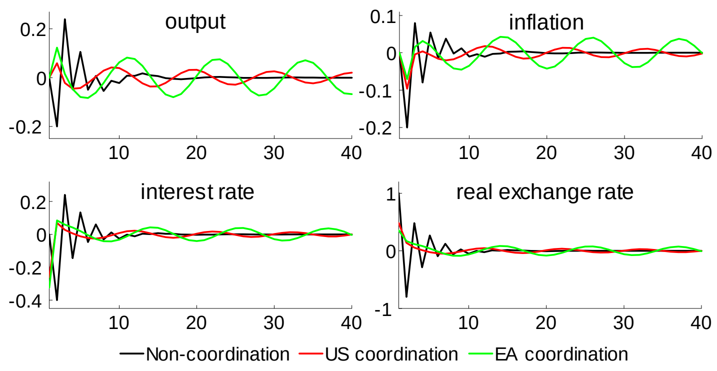


Figure C-5: IRFs to an exchange rate shock - by the model in Ball (1999b) with responses to real exchange rate changes

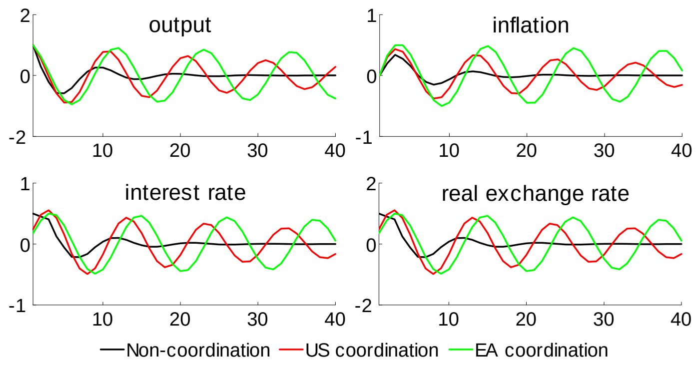


Figure C-6: IRFs to a productivity shock - by the model in Ball (1999b) with responses to real exchange rate changes

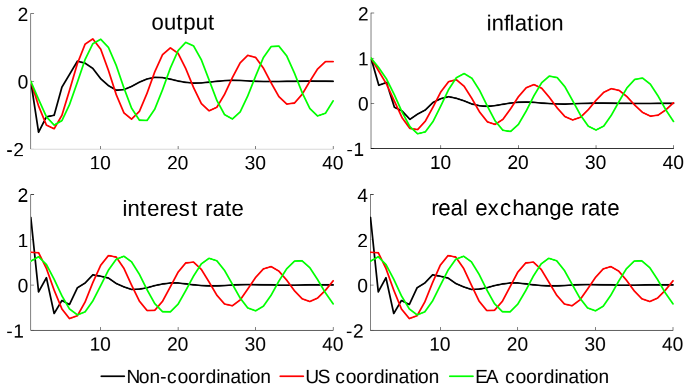


Figure C-7: IRFs to an inflation shock - by the model in Ball (1999b) with responses to real exchange rate changes