Terms-of-trade shocks in a small open economy

Chia, Wai-Mun

2006

Chia, W. M. (2006). Terms-of-trade shocks in a small open economy. Doctoral thesis,
Nanyang Technological University, Singapore.

<https://hdl.handle.net/10356/36145>

<https://doi.org/10.32657/10356/36145>

Terms-of-Trade Shocks in a Small Open Economy

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A thesis submitted to the Nanyang Technological University in fulfillment of the
requirement for the degree of Doctor of Philosophy

2006

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For my late father, beloved mother and loved ones

Acknowledgments

I would like to thank my supervisor, colleagues, friends and family who were very supportive during the writing of my thesis. In particular, I am greatly indebted to my thesis supervisor, Associate Professor Joseph D. Alba for his inspirational guidance and support. I also thank Associate Professor Huang Weihong, Associate Professor Liu Yunhua, Associate Professor Park Donghyun and Associate Professor Low Chan Kee for their constructive comments and numerous suggestions on the earlier drafts of this thesis. I am also indebted to Associate Professor Ho Mian Lian, for enlightening me on many aspects of my thesis-writing. Thanks go to Professor Philip Lane from Trinity College Dublin, for his encouraging comments on one of my journal papers which was developed from this thesis and Professor Ng Yew Kwang from Monash University for his ever encouraging support to all young researchers. Their guidance and encouragement were critical inputs.

I owe a debt of gratitude to friends and colleagues at the School of Humanities and Social Sciences, Nanyang Technological University. In particular, I would like to express my sincerest appreciation to Zhang Yang, Tan Khay Boon, Sng Hui Ying, Fang Woan Pin, Xiao Qin, Ho Woon Yee, Yew Siew Ling, James Ang Beng Juinn and Asif Iqbal Siddiqui for their friendship, encouragement and support.

Thanks go to Associate Professor Liu Ai Qun and his research fellow Dr Zhang Xuming from the School of Electrical and Electronic Engineering for sharing their valuable research experience and skills in running some software programs.

Finally I would like to express my greatest gratitude to my mother, siblings and loved ones for their encouragement, love and support. Thanks go also to my nieces, Kit Yee and Kah Yee, who always cheer me up. I wish to dedicate this thesis to them and my late father who was most supportive throughout my studies. This thesis would not have been possible without the generous support of all the people I have mentioned above.

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Executive Summary

This study concentrates on the effects of terms-of-trade shocks in a small open economy. Generally, studies concerned with terms-of-trade fluctuations focus on a few important issues, best summed up by four key questions: (a) What are the short run and long run impacts of the alleged terms-of-trade shock on primary producers? (b) What are the features of an economy that determine the relationship between terms-of-trade shocks and the current account fluctuations? (c) What is the role of exchange rate regimes in mitigating the effects of terms-of-trade shocks? (d) What is the effect of terms-of-trade shocks on economic growth under alternative exchange rate regimes?

The thesis provides new perspectives to the second and third questions by utilizing a newly emerging area of research on open economy dynamic general equilibrium models that incorporate imperfect competition and nominal rigidities. First, in contrast to the past literature which assumes perfect competitive markets and perfect price flexibility, the relationship between the terms-of-trade shocks and the current account of a small open economy is investigated in the presence of imperfect competition and nominal price rigidities in the nontraded sector. It is shown that the effects of permanent terms-of-trade shocks on the current account depend on the degree of price stickiness. When prices are sticky, the effects of permanent term-of-trade shocks on the current account are contingent upon the intra- and inter-temporal elasticities of substitution in consumption. When prices are perfectly flexible, permanent terms-of-trade shocks have no dynamic effects on the current account. On the other hand, a temporary terms-of-trade improvement results in a current account surplus since the increase in

consumption of traded goods is smaller than the magnitude of terms-of-trade shock. This result is consistent with the well-known Harberger-Laursen-Metzler (HLM) effect.

Second, the effects of terms-of-trade shocks are investigated using a dynamic stochastic general equilibrium model of a small open economy. The model assumes nominal price rigidity and allows variation in exchange rates from fixed to flexible regimes. The model's numerical solutions are broadly consistent with the empirical regularities documented by Broda (2004). First, the responses of short-run output to shocks are significantly smoother in floats than in pegs. Second, in moving from pegs to floats, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. Finally, in all types of exchange rate regimes, the most volatile variable is the holding of net foreign assets.

Chapter 1

Introduction

Many central questions of international economics focus on the study of terms-of-trade which is commonly defined as the relative price of exports to imports. One of the main reasons is because terms-of-trade disturbances have been regarded as a major source of output and current account fluctuations in a small open economy by many economists (see Mendoza, 1995 and Kose, 2002). This is particularly true for developing countries, whose export earnings are dominated by a narrow range of primary commodities (Kose, 2002). Since the prices of these primary commodities are subject to large price fluctuations in the world market, terms-of-trade fluctuations in developing countries are observed to be more volatile than those of industrialized countries. Given the significance of terms-of-trade fluctuations on domestic macroeconomic variables, understanding the transmission and propagation of terms-of-trade fluctuations is crucial in the design and conduct of macroeconomic policies in both industrialized and developing countries. As a result, research on issues related to terms-of-trade disturbances has always been an area of great controversy.

Some of these questions which are related to the issues of terms-of-trade shocks have a very long history, dating back to Marshall (1930) or probably before. Among these questions are: what are the trends in the terms-of-trade between primary prices to those of manufactures? Do less-developed countries (LDCs) experience a long-run deterioration in their terms-of-trade with developed countries (DCs) causing an ever-

widening gap in their per capita incomes with developed countries? What is the relation between the terms-of-trade and the trade balance? What features of an economy determine whether a negative shift in the terms-of-trade is associated with improvement or deterioration in the trade balance? Does exchange rate regime play a role in mitigating the disturbances brought by terms-of-trade fluctuations? What are the impacts of terms-of-trade fluctuations on a country's long-run economic growth? Although an extensive and controversial literature has been developed around these issues, some of them still remain as an area of great controversy which is full of lively speculation and debate. Most often, researchers reconsider some of these conventional issues by entertaining a variety of assumptions whenever there emerges a new class of models and formal analysis.

In recent years, there has been an outpouring research on open economy dynamic general equilibrium models that incorporate imperfect competition and nominal rigidities. Since the publication of the *Redux* model (Obstfeld and Rogoff, 1995 and 1996), the research on open-economy macroeconomics has produced a synthesis of dynamic intertemporal approaches with sticky-price models of macroeconomic fluctuations. This synthesis has subsequently become widely known as the new open economy macroeconomics, NOEM¹. This new class of models has allowed economists to tackle many classical problems with new tools and at the same time generated new ideas and questions.

¹ For electronic links to many of the papers in this newly emerging literature, see the NOEM internet site professionally maintained by Brian Doyle: http://www.geocities.com/brian_m_doyle/open.html. Lane (2001) and Sarno (2001) offer an interim survey of this literature.

In this thesis, we attempt to answer some of these questions arising from terms-of-trade fluctuations using the new tools developed by Obstfeld and Rogoff (1995 and 1996). We focus on two main issues. First, we examine the relationship between terms-of-trade shocks on the trade balance by incorporating imperfect competition and nominal rigidities into a dynamic general equilibrium model. Second, we evaluate the role of exchange rate regime and nominal price rigidities in mitigating the disturbances from terms-of-trade. When we compare our results to those obtained from the past literature, our results help to gain significant new insights into such pressing issues.

In analyzing the effects of a terms-of-trade shock on the current account balance, we integrate the intertemporal equilibrium framework with nominal price rigidities and imperfect competitive markets to analyze the dynamics of current account arising from terms-of-trade fluctuations. This is in sharp contrast to the other work in the literature which assumes flexible price and perfect competitive markets. We adapt the model of Lane and Milesi-Ferretti (2004) and construct an intertemporal framework with tradable and nontradable sectors. The nontradable sector is assumed to be a monopolistic competitive market where prices in this sector are set one period in advance and they adjust to shocks only by period two². The tradable sector, on the other hand, is viewed as a perfectly competitive market where prices are fully flexible and covered by the law of

² This assumption is arbitrary but convenient. As in Corsetti and Pesenti (1997), a sufficiently large shock would violate firms' participation cost by raising marginal cost above price. Most literature has largely emphasized price stickiness as the locus of nominal rigidities for the reasons discussed by Kimball (1995). Others, such as Hau (2000), Bergin (1995), Obstfeld and Rogoff (2000) consider cases in which prices are flexible but nominal wages are predetermined.

one price. The existence of tradables and nontradables introduces additional features into the analysis and provides a richer framework for analyzing the current account dynamics in the face of terms-of-trade fluctuations. In the first model, we show that the relationship between terms-of-trade shocks and the current account depends significantly on the degree of nominal rigidity, especially when the shocks are permanent. For instance, when prices are sticky, the effects of permanent term-of-trade shocks on current account depend mainly upon the intra- and intertemporal elasticities of substitution in consumption. On the other hand, when prices are perfectly flexible, permanent terms-of-trade shocks have no dynamic effects on the current account. We also show that a temporary terms-of-trade improvement results in a current account surplus since the increase in consumption of traded goods is smaller than the magnitude of terms-of-trade shock. This result is consistent with the well-known HLM effect.

In evaluating the role of exchange rate regime and nominal rigidity in mitigating the effects of terms-of-trade shocks, we examine the link between terms-of-trade shocks and some macroeconomic variables by numerically solving a dynamic general equilibrium model of a small open economy. Our work combines nominal price rigidity under different exchange rate regimes. We follow some features from our previous model and construct an intertemporal equilibrium framework with nominal price rigidities and imperfect competitive markets to analyze the dynamics of some macroeconomic variables arising from terms-of-trade shocks under alternative exchange rate systems. In contrast to our first model, this model differs in two aspects. First, instead of letting prices in the nontradable sector to adjust by period two, we assume Calvo (1983) pricing

where firms set prices on a staggered basis³. Second, we design a model that combines nominal price rigidity under different exchange rate regimes where exchange rate is allowed to vary from fixed to flexible whereas in the first model, we assume only fixed regimes. In the second model, the numerical solutions obtained are compared with some empirical regularities documented in the literature. Our results show that the responses of short-run output to shocks are significantly smoother in flexible than in fixed. Additionally, in moving from pegs to floats, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. Finally, in all types of exchange rate regimes, the most volatile variable is the holding of net foreign assets.

This thesis is organized as follows. Chapter 2 provides literature review on studies and issues related to terms-of-trade shocks in general. We also give literature review in particular relation to terms-of-trade shocks and current account fluctuations, and terms-of-trade shocks under different exchange rate regimes. Chapter 3 highlights the main features observed in the models of new on new open economy macroeconomics. Chapter 4 gives an analysis on the effects of terms-of-trade shocks on the current account by incorporating imperfect competition and nominal rigidity into the model. Chapter 5 examines the role of exchange rate regime and nominal rigidity in mitigating the effects of terms-of-trade shocks. We show the link between terms-of-trade shocks and some

³ Many authors follow Calvo (1983). For instance, Taylor (1983) and Blanchard (1983) showed that staggering is a potential persistence mechanism since the adjustment to shock cannot be achieved instantaneously. Others who followed staggering include Kollman (1997), Chari et al (1998), and Jeanne (1998).

macroeconomic variables by numerically solving a dynamic stochastic general equilibrium model of a small open economy. The model combines nominal price rigidity under different exchange rate regimes. The numerical solutions of the model are compared with the empirical regularities documented in the literature. Chapter 6 offers some conclusions.

Chapter 2

Literature Review on Issues Related to Terms-of-trade Shocks

2.1 Introduction

Studies related to terms-of-trade usually have a long history, some dating back to Marshall (1930) and probably before. Most of this work has concentrated around few controversial issues which are still generating lively debate, and dominated the literature for decades. In this chapter, our attempt is to provide a general literature review on some main issues and studies related to terms-of-trade disturbances⁴. Our focus is then devoted to the literature of two main issues in which we aim to provide some contributions to the literature.

2.2 Studies and Issues Related to Terms-of-trade

2.2.1 *Trends of Terms-of-trade between Primary Commodities and Manufactures*

⁴ While many studies treated terms-of-trade as an exogenous variable, there are studies which assume terms-of-trade and other international prices as endogenous variables. Among them are studies by Senhadji (1998), Backus et al. (1992 and 1994), Kollman (1992 and 1994), Baxter and Cruccini (1993 and 1995), Stockman and Tesar (1995) and Yi (1993). However, in this thesis we attach to the assumption of exogenous terms-of-trade disturbances. This is consistent with McCallum's (1989) view as well as the arguments forwarded by Mendoza (1995).

Terms-of-trade is commonly defined as the ratio of export prices to import prices. One of the most debatable issues related to terms-of-trade is perhaps the one raised by Raoul Prebisch (1950) and Hans Singer (1950) which remains an area of great controversy until today. The first phenomenon claimed by Prebisch is that the unfavorable impact of unrestricted trade on terms-of-trade and current account of developing countries far outweighs any advantages with respect to a more efficient allocation of resources. In the early 1950s, Prebisch alleged that the terms-of-trade of the primary-product-producing Third World had deteriorated and would continue to deteriorate as long as they specialized in primary products. He advanced two explanations for this and explained why the benefits of technical progress tend to flow from the developing to the developed countries. The first explanation concerns the relation between income and productivity. He suggested that factor incomes tend to rise with productivity increases in developed countries, they rise more slowly than productivity in the developing countries owing to population pressure and surplus labor. Thus there is a greater upward pressure on final goods' prices in developed than developing countries. The second explanation is that a ratchet effect operates with primary product prices relative to manufactured goods' prices falling during cyclical downturns by more than they rise relative to the prices of manufacturers on the upturns. Such asymmetrical cycles produces a secular trend decline in terms-of-trade of primary products from the 1870s to the 1930s and it was used to help explain the widening gap between the developed countries and the less developed countries. The argument supported the policy move towards Third World autarky in the 1940s, 1950s and 1960s, a highly interventionist industrialization policy choice which was eventually known as 'import substitution'. Hans Singer (1950) claimed that even if the terms-of-trade of

primary products improved, it would reduce the incentive for industrialization in developing countries while encouraging the incentive to produce more primary products. Many years later, this effect was widely known as an ‘industrialization crowding out’ or a ‘Dutch disease’.

The second phenomenon mentioned by Prebisch is the current account effects of differences in the income elasticity of demand for different types of goods. Generally, the income elasticities of demand for most primary commodities are lower than that for manufactured commodities. In the two-country, two-good case the lower income elasticity of demand for primary commodities will mean that for a given growth of world income, the current account of primary-producing developing countries will automatically deteriorate vis-à-vis the current account of developed countries producing and exporting industrial goods. The modern terms-of-trade debate triggered by Prebisch and Singer spans for few decades. Hadass and Williamson (2001) provides a detail survey. One of the most recent study has been conducted by Zanas (2005).

2.2.2 Terms-of-trade Shocks as a Source of Current Account Fluctuations

The concern of Prebisch is two distinct but not unrelated phenomena. The relationship between terms-of-trade and current account has been an area of great controversy especially after the work of Harberger (1950) and Laursen and Metzler (1950). This sub-section provides literature review on terms-of-trade shocks and current account fluctuations.

The relationship between terms-of-trade and current account has always been a perennial research topic in international macroeconomics ever since the seminal work of Harberger (1950) and Laursen and Metzler (1950)⁵. In this work, the authors argued that in a Keynesian framework with marginal propensity to consume less than unitary, a favorable terms-of-trade shock induces an increase in savings and net exports of the economy because a rise in the purchasing power of exports improves real income. Similarly, savings and net exports are lower when terms-of-trade worsens because the reduction in the purchasing power of exports decreases real income. This theoretical development in the literature has subsequently been known as the Harberger-Laursen-Metzler (HLM) effect.

The theoretical proposition of HLM has then been subjected to considerable scrutiny since the 1980s which has further induced a strong motivation for the international macroeconomic researchers to extend this proposition in many different directions. Using an intertemporal utility maximizing approach, Obstfeld (1983) and Svensson and Razin (1983) showed that with perfect capital mobility, price flexibility and competitive world capital market, the relationship between terms-of-trade and current account depends on the degrees of persistence in the terms-of-trade shocks. In general, they found that HLM effect results only with transitory or temporary terms-of-trade shocks. When there is a temporary deterioration in terms-of-trade, borrowing from abroad by rational agents to smooth consumption will worsen the current account. In sharp contrast to the HLM effect, a permanent terms-of-trade deterioration leaves current

⁵ The question concerning the relation between the terms-of-trade and the current account has a long history, dating back to Marshall (1930) and probably before.

account unaffected. This is because rational agents will revise their expected current and future income downward when the shock is permanent without changing savings. However, these theoretical predictions were found to be inconsistent with the empirical regularities documented by Mendoza (1995). In the 1970s and 1980s, many countries faced large fluctuations in their terms-of-trade, stemming principally from the oil-price shocks of the 1970s and the marked swings in non-oil commodity prices in the 1980s. These events attracted Mendoza to conduct an empirical examination of the relationship between terms-of-trade shocks and business cycles from the perspective of an intertemporal general equilibrium framework. In Mendoza, current account and terms-of-trade are positively correlated which are consistent with the Obstfeld-Svensson-Razin framework, but the fact that these positive correlations are observed to be independent of the persistence of terms-of-trade shocks raises challenges to the intertemporal model. This finding has subsequently revived growing interest among international economics researchers in exploring the issues of terms-of-trade disturbances and the current account. More recent studies related to this issue include the work of Senhadji (1998), Kose (2002), Cashin and McDermott (2002), and Otto (2003).

In an attempt to examine the inconsistency between theoretical predictions provided by Obstfeld-Svensson-Razin and empirical regularities documented by Mendoza, we develop an intertemporal optimizing model with imperfect competition and nominal price rigidities in Chapter 4. As a result, our model is different compared to the past literature which examined the relationship between terms-of-trade and current account by focusing on flexible-price economies and assuming away the awkward reality of nominal price rigidities. Since empirical regularities indicate that terms-of-trade

shocks play a crucial role in determining real variables, such as current account, this yields legitimacy to incorporate nominal price rigidities in the model to provide a candidate explanation for the real effects of terms-of-trade shocks⁶.

2.2.3 Terms-of-trade Shocks under Different Exchange Rate Regimes

As terms-of-trade disturbances are one of the contributing factors to the fluctuations in the current account, researchers may question the effectiveness of exchange rate regime in mitigating the effect of terms-of-trade disturbances on an economy. Literature review on this issue is provided in this sub-section.

The merit which is often attributed to flexible exchange rate regimes over fixed exchange rate regimes is their ability to insulate the economy more effectively against real shocks. This hypothesis was first proposed by Friedman (1953) in the early 1950s. Since then the choice of the exchange rate regime has been an area of great controversy and debate. In theory, the presence of price stickiness explains why the exchange rate regime may matter. When an economy is hit by real shocks, the economy that can change relative prices more quickly will have smaller and smoother adjustment in output. This is particularly true in a world with price stickiness where the speed at which relative prices

⁶ In Mendoza (1995), the co-movements between these variables are observable once uncertainty, capital accumulation, and structural differences in tastes and technology are considered, without abandoning the assumptions of perfect capital mobility, price flexibility and competitive capital markets. As a result, he concluded that the observed low correlations between trade balance and terms-of-trade (and independence of these correlations to terms-of-trade autocorrelations) are not indicators of credit constraints or lack of capital mobility.

can adjust depends crucially on the exchange rate regime. Under flexible exchange rate regimes, relative prices can adjust instantly through changes in nominal exchange rate; while under fixed exchange rate regimes, relative prices can adjust only at the speed that is permitted by the price stickiness, which is usually much slower. Therefore, flexible exchange rate regimes allow smoother adjustment in output and quicker adjustment in relative prices than fixed exchange rate regimes.

The theoretical proposition by Friedman has subsequently prompted international economists to examine the effects on economic variables of different types of exchange rate regimes. While some focused on building theoretical models (Poole, 1970; Dornbusch, 1980), others focused on documenting empirical regularities (Baxter and Stockman, 1989; Taylor, 1993; Devereux, 2000; Collard and Dellas, 2002; Bleaney and Fielding, 2002; Broda, 2001 and 2004).

From the theoretical perspective, many economists still believe that the relative merits of the exchange rate regimes crucially depend on the type and the nature of shocks hitting the economy⁷. When the shocks are nominal in nature, fixed exchange rate regimes automatically prevent them from affecting real output. For example, when money demand increases, under fixed exchange rate regimes, money supply increases as the monetary authority buys foreign currency to prevent the appreciation of the local currency. This leaves real output unchanged. In contrast, under flexible exchange rate

⁷ Poole (1970) predicted that the standard deviations of output across exchange rate regimes crucially depend on the nature of the shocks. When the shocks are nominal (real) in nature, then the standard deviations in fixed (flexible) is relatively smaller.

regimes, money supply is left unchanged and the local currency is allowed to appreciate so real output falls and money demand returns to its initial level.

When the shocks are real in nature, flexible exchange rate regimes are more effective as they allow a smoother adjustment to real shocks. For example, when there is a negative terms-of-trade shock in an economy where prices are sticky, the nominal exchange rate depreciates under flexible exchange rate regimes. The depreciation of nominal exchange rate, in turn, increases the price of tradable goods which partially offsets the effect of the negative terms-of-trade shock. However, under fixed exchange rate regimes, money supply decreases as monetary authority contracts money supply to prevent a nominal depreciation of local currency. This response is inherently contractionary and induces an additional fall in real output. Therefore, fixed exchange rate regimes have to rely on the adjustment in domestic prices to pull the economy out of a recession.

From the empirical perspective, the empirical evidence is far from conclusive on the effects of shocks on real output, real exchange rate and nominal exchange rate. Baxter and Stockman (1989) show empirical insensitivity of output volatility to the type of exchange rate regime. They also find that a broad range of real macroeconomic variables are independent of the underlying exchange rate regimes. Devereux (2000) analyzes the effects of supply, fiscal and money shocks using a model with nominal goods priced in the sellers' currency and with prices which are sticky over one period. He finds that the exchange rate does not respond to either supply or fiscal shocks so macroeconomic volatility is the same across fixed and flexible systems. In contrast, Collard and Dellas (2002) suggest larger differences in volatility across regimes. They find that output

volatility is significantly higher under fixed exchange rate regimes relative to flexible exchange rate regimes. Using data from 80 developing countries, Bleaney and Fielding (2002) also show that countries with fixed exchange rate regime have significantly greater output variance than a typical floating-rate country.

While the theoretical literature emphasizes the importance of the nature of the shocks in determining the relative merits of the different types of exchange rate regimes, the empirical literature on exchange rate regimes does not clearly distinguish between nominal and real shocks. Hence, it would be meaningful for an empirical study to clearly identify real shocks from nominal shocks. This is particularly true if one can study the effects of terms-of-trade shocks on macroeconomic variables under alternative exchange rate systems. The reasons for choosing terms-of-trade shocks are twofold. Firstly, terms-of-trade disturbances are regarded as a major source of output fluctuations in a small open economy (Mendoza, 1995; Kose, 2002). Secondly, since most developing countries' export earnings are dominated by a narrow range of primary commodities (Kose, 2002) and the prices of these primary commodities are subjected to large price fluctuations in the world market, terms-of-trade fluctuations in developing countries are observed to be more volatile.

Because of the prominent role played by exchange rate regimes in developing countries, Broda (2004) examines the effect of a single real shock given by terms-of-trade changes of a country under different exchange rate regimes. Using data from seventy five developing countries from 1973 to 1996, he identifies the responses of real GDP, real exchange rate and consumer prices to exogenous terms-of-trade changes across different regimes. His findings generally support Friedman's proposition. First, the short run real

GDP response to terms-of-trade shocks is significantly smaller in countries with flexible exchange rate regimes than those with fixed exchange rate regimes. Second, the depreciation of real exchange rate is immediate after a negative terms-of-trade shock under flexible exchange rate while the depreciation is slower under fixed exchange rate. Third, countries with flexible exchange rate regimes can absorb real shocks better than those with fixed exchange rate regimes.

Given the significance of terms-of-trade fluctuations on domestic macroeconomic variables, understanding the transmission and propagation of terms-of-trade fluctuations is crucial in the design and conduct of macroeconomic policies in both industrialized and developing countries. Therefore, in Chapter 5, we use an intertemporal equilibrium framework with nominal price rigidities and imperfect competitive markets to analyze the dynamics of some macroeconomic variables arising from term-of-trade fluctuations under alternative exchange rate systems. The numerical solutions obtained from the model are compared with the empirical regularities documented by Broda (2004).

2.2.4 Terms-of-trade Shocks, Exchange Rate Regimes and Economic Growth

While many researchers have identified the role of exchange rate in mitigating the effect of real shocks, for instance, terms-of-trade shocks on the domestic aggregate output, there is surprisingly scant study that attempts to show the link between terms-of-trade shocks, exchange rate regimes and economic growth. This sub-section shows literature review of the latest study by Edwards and Levy Yeyati (2005). They examine the long run impact of terms-of-trade shocks on economies with different exchange rate regimes.

One of the most recent and interesting areas of research related to terms-of-trade shocks is the study by Edwards and Levy Yeyati. Edwards and Levy Yeyati examine the impact of terms-of-trade shocks on economies with different exchange rate regimes. While many studies have looked at the relationship between terms-of-trade and economic growth, they explain, few have studied how the choice of exchange rate system mediates that relationship. From a sample of annual observations for 183 countries over the 1974-2000 period, they find that economies with flexible exchange rates grow more rapidly than those with fixed regimes. The difference in the rate of growth of GDP per capita is substantial, on the order of 0.66 and 0.85 percentage points more per year for countries with flexible regimes.

Focusing on external shocks, Edwards and Levy Yeyati also find that terms-of-trade are exacerbated – in terms of the impact on economic growth – in countries with more rigid exchange rate systems. They explain that under flexible exchange rates the effects of terms-of-trade shocks on growth are approximately one half that under pegged regimes.

Edwards and Levy Yeyati also find evidence of an asymmetry in terms-of-trade shocks i.e output growth is more sensitive to negative than to positive shocks, and the sensitivity increases the more inflexible the exchange rate regime. The advantage of flexible regimes resides in their ability to adjust more smoothly to negative shocks via depreciations in the real exchange rate. In pegged systems, a depreciation on the real exchange rate requires a decline in nominal prices; if these are too rigid, negative terms-of-trade shocks will produce unemployment and a slower rate of economic growth.

Since the economic contraction associated with a terms-of-trade shock nearly doubles under a pegged system, the choice of exchange rate regime has important implications in terms of output volatility. Moreover, pegged systems are also associated with deeper and longer contractions in economic performance.

2.3 Conclusions

We have clearly organized the studies and issues related to terms-of-trade into four main categories. First, we have discussed the literature of Prebisch-Singer hypothesis. Two distinct but not unrelated phenomena have been identified. The first phenomenon mentioned by Prebisch is the falling terms-of-trade trend for primary-producing developing countries. The second phenomenon is the current account effects of differences in the income elasticity of demand for different types of goods. Since the income elasticity of demand for most primary commodities is lower than that for manufactured commodities, the current account position of primary-producing developing countries is expected to deteriorate over time. Second, we have also provided the literature that studies the relationship between terms-of-trade shocks and the current account. Generally, these studies concluded that the effect of terms-of-trade shocks on the current account depends on the duration and the persistence of the shocks. Others also mentioned the significance of inter- and intra-temporal elasticity of substitution between tradables and nontradables. After the first two questions, it is not surprisingly to observe literature that focuses on the role of exchange rate regime in mitigating terms-of-trade shocks. Friedman (1953) created interest in this area of research. Subsequently, an outpouring of research has been observed to discuss the effectiveness of exchange rate

regime in mitigating both nominal and real shocks. Finally, in a very recent study by Edwards and Levy Yeyati (2005), when they examine the long run impact of terms-of-trade shock on economies under different exchange rate regimes, they find that exchange rate regime is one of the contributing factors to the long run economic growth of an economy.

All these studies have a common feature – they assumed perfect price flexibility. This assumption is arbitrary but convenient. However, as price adjustment does not come into the scenario, it allows no room for explicit analysis of pricing decision. As a result, when we assume away the awkward reality of price stickiness, we lose sight to some significant international transmission mechanism at the same time. Indeed, many classic issues at the center of international macroeconomics would be of relatively little consequence in a flexible-price world. Therefore, in our work, we show that the features of imperfect competition and nominal price stickiness provide new perspectives to some of these controversial issues. We also show that the international transmission of terms-of-trade shocks prove to be quite sensitive to the precise specification of price stickiness.

Chapter 3

The Model: A New Open Economy Macroeconomic Perspective

3.1 Introduction

Macroeconomists have endlessly debated whether actual economies can usefully be characterized by flexible-price models. Much of the debate is over aesthetics: it is difficult to find a single compelling theoretical story that convincingly explains why nominal price adjustment appears sluggish in practice. Indeed, largely because of theoretical difficulties, it has been a fashion for some time to ignore price rigidities altogether. However, studies and some empirical regularities documented show that the idea of nominal price rigidities is irrelevant seem difficult to sustain. For instance, countries with floating currencies and open capital markets show that exchange rates are an order of magnitude more volatile than CPIs. An immediate corollary of this result is that the short-run volatility of real exchange rates is very similar to that of nominal exchange rates. This striking empirical regularity is totally at odds except when most significant shocks buffeting the economy are real. It is highly implausible, however, that most of the variability in real exchange rates is attributable to real shocks. This evidence motivated Obstfeld and Rogoff (1995) to take a look at a classic sticky-price extension of the flexible-price model.

In this chapter, we provide a brief literature review on the NOEM which incorporates imperfect competition and nominal rigidities into dynamic general equilibrium models. In contrast to the past literature which examines issues related to terms-of-trade shocks by focusing on flexible-price economies, our work particularly emphasizes on the role of imperfect competition and nominal price rigidities in providing a candidate explanation for some of the controversial issues related to terms-of-trade shocks.

3.2 New Open Economy Macroeconomics, NOEM

Since the publication of the *Redux* model (Obstfeld and Rogoff, 1995 and 1996), there has been a growing body of research on open economy dynamic general equilibrium models that incorporate imperfect competition and nominal rigidities. This recent research on open-economy macroeconomics has produced a synthesis of dynamic intertemporal approaches with sticky-price models of macroeconomic fluctuations. This synthesis has subsequently become widely known as the new open economy macroeconomics, NOEM. Obstfeld and Rogoff (1995) is commonly recognized as the contributor that launched and effectively initiated this new wave of research. An important precursor was the paper by Svensson and Wijnbergen (1989).

This recent literature with its basic ingredient of (1) imperfect competition, (2) microeconomic optimization, and (3) nominal rigidities offers several attractions over the conventional Mundell-Fleming model. The assumption of imperfect competition – in either product or factor markets, which is the key component in the new models, provides new insights. First, in contrast to perfect competition under which economic agents are

price takers, imperfect competition allows for the explicit analysis of pricing decision. Second, equilibrium prices set above marginal cost rationalize demand-determined output in the short run. Third, monopoly power implies the possibilities of equilibrium production to fall below the social optimum, which is a distortion that can be corrected by policy intervention. On the other hand, the presence of microeconomic optimization, for instance, explicit utility and profit maximization problems, provides welcome clarity that allows a rigorous welfare analysis of policies and regimes, thereby laying the groundwork for credible policy evaluation. Lastly, the feature of nominal rigidities, in either prices or wages, alters the transmission mechanism for shocks and also provides more potent role for monetary policy. In this way, by addressing issues of concern to policymakers, one goal of this new strand of research is to provide an analytical framework that is relevant for policy analysis and offers a superior alternative to the conventional Mundell-Fleming model.

In general, an open economy dynamic general equilibrium models must contain a number of basic elements. First, household preference must be specified. The elasticity of substitution between home-produced and foreign-produced goods must be specified. This makes the open economy models more complicated compared to the closed economy models. Similar treatment must also be given to the production function since imported intermediate goods are a potentially important linkage across economies. Second, The international dimension of how do financial assets are traded must be determined, detailing whether home and foreign households share risks via state-contingent assets or just engage in bond trade or face even more restricted opportunities for international financial transactions. Third, the form of nominal rigidities must also be determined. The

researchers are tasked to determine the sluggishness in good prices versus wages, the duration of rigidities and the currency denomination of these sticky goods or factor prices. Finally, the researchers are required to incorporate the nature of monetary and fiscal policies into the model.

While allowing economists to tackle classical problems with new tools, this new strand of research has also generated new ideas and questions (Obstfeld, 2002). Many assumptions in the *Redux* model have been modified in the subsequent work. In the literature, many economists have attempted to build a new class of models based on this research program to capture empirical regularities more accurately. Some of these models appear to call for a radical rethinking of conventional views regarding the potential inefficiencies in adjusting to fundamental shocks, the role of exchange rates in international adjustment, the international transmission and welfare effects of monetary shocks, and many others. The new open-economy macroeconomics provides an ideal setting to explore these questions.

Since Lane (2001) has provided a thorough literature review on the new open economy macroeconomics, in the following sections, we only look particularly into literature related to nominal rigidities arising from the final goods sector.

3.3 Nominal Price Rigidities

In literature, nominal rigidity is always been introduced as an exogenous feature of the environment. In the *Redux* model, firms simultaneously set prices one period in advance but adjust to flexible-price levels after a period, absent new shocks. This assumption is arbitrary but convenient, since all adjustments are completed after just one

period. There are basically two categories of explanations for prices to be set a period in advance, those that rely on costs of price adjustment and those that portray inflexible price equilibria as a focal equilibrium in a world of multiple equilibrium. Geanakoplos and Polemarchakis (1986) show that in principle one can rationalize sluggish price adjustment without appealing to non-Walrasian frictions. In their model, there are multiple equilibria, one of which exhibits sticky prices (See also Benhabib and Farmer, 1994). Multiple-equilibria explanations have the appeal of not having to posit a cost-of-adjustment technology for prices. On the other hand, they ultimately beg the question of why the sticky-price equilibrium would be consistently chosen across different eras and different countries if there are other, more efficient, equilibria.

Probably the best extant rationalization for setting prices one period in advance is the menu cost approach of Akerlof and Yellen (1985) and Mankiw (1985). In this model, producers set prices to maximize real revenue net of the cost of forgone leisure. Because prices are set optimally by utility-maximizing monopolists, the envelope theorem implies that small changes in an individual's price will have only a second-order impact on his welfare. If there are finite menu costs to changing prices, even if these costs are fairly small, producers will not necessarily find it profitable to change prices in the face of sufficiently small demand shocks. Clearly, if price stickiness is motivated by an underlying fixed menu cost, firms will be motivated to immediately adjust prices in the event of large enough shock. In Chapter 4, we adopt this type of one-step-ahead pricing to evaluate the relationship between terms-of-trade shocks and the current account. Since in linearizing the model we are already restricting our attention to small shocks, the menu costs justification is quite appropriate.

Even though the simultaneous one-step-ahead pricing has the beauty of ease of exposition, it has the counterfactual implication that the price level experiences large, discrete jumps. After the introduction of the *Redux* model, richer models of price rigidities have been advanced. Staggered price setting is an alternative way to introduce price stickiness that permits smooth price level adjustment. This staggering means that each firm must take into account the previous and future pricing decisions of other firms in optimally setting its price. Many authors follow Calvo (1983). The Calvo pricing assumption is that the opportunity to adjust its price arrives stochastically to each firm. Independence across a large number of firms means that a fixed fraction adjusts its price each period so that the price level is a smooth variable and changes only gradually over time: if the Poisson arrival rate of a price-change opportunity is θ , a fraction θ of firms changes its price each period and $1/\theta$ is the average interval between price changes for a given firm. In Chapter 5, we employ this type of staggered price setting as an alternative way to introduce price stickiness into our model.

3.4 Conclusions

After the introduction of the *Redux* model, international macroeconomists have been convinced with the idea of introducing nominal rigidities into their models. There is a sense that researchers are converging on a common modeling framework that integrates imperfect competition and nominal rigidities into dynamic general equilibrium models.

Chapter 4

Terms-of-trade Shocks and the Current Account[†]

4.1 Introduction

In an attempt to examine the inconsistency between theoretical predictions provided by Obstfeld-Svensson-Razin and empirical regularities documented by Mendoza, in this chapter, we develop a dynamic general equilibrium model which incorporate imperfect competition and nominal price rigidities. As a result, our model is different compared to the past literature which examined the relationship between terms-of-trade and current account by focusing on flexible-price economies and assuming away the awkward reality of nominal price rigidities. In our model, the nontraded sector is assumed to be a monopolistic competitive market⁸ where prices in this monopolistic nontraded sector are set one period in advance and they adjust to shocks only by period two. In other words, prices in the nontraded sector are sticky in the short run. The traded sector, on the other hand, is viewed as a perfectly competitive market where prices are

[†] A paper entitled “Terms-of-trade shocks and the current account” was developed from this chapter. The paper was presented at the *IEFS-UK Chapter conference in “Finance in the International Economy”* at City University, London, 27-28 November 2003. This paper was also accepted by the *Journal of Economic Integration* and nominated for the Daeyang Economics Prize in which the prize is awarded to author who has written the best paper of the year.

⁸ We follow the assumption in Lane and Milesi-Ferretti (2004) that the domestic aggregate demand conditions matter more for the nontraded sector than the traded sector.

fully flexible and covered by the law of one price. The asymmetric treatment between these two sectors allows us to show the link between these two sectors when there is a terms-of-trade disturbance. We show clearly the propagation mechanism of terms-of-trade shocks on the dynamics of the current account where terms-of-trade shocks first perturb consumption in the traded sector in both the short run and the long run which eventually leads to a change in consumption in the nontraded sector and net foreign asset position of the country.

The structure of this chapter is organized as follows. Section 4.2 lays out the theoretical model. The effects of a permanent and a temporary terms-of-trade shock are analyzed in Sections 4.3 and 4.4 respectively. Conclusions are offered in Section 4.4.

4.2. The Model

In this section an intertemporal model of a small open economy is derived to analyze the way in which different terms-of-trade deterioration – temporary and permanent – affects the current account. This model is adapted from Lane and Milesi-Ferretti (2004). In order to address the intratemporal aspects of the problem, three main assumptions are made. First, importable is consumed but not produced, and exportable is produced but not consumed. In other words, the import and the nontradables are consumed domestically but the export and the nontradable are produced domestically. Second, investment is held constant where the capital stock is an endowment which is not affected by the terms-of-trade shocks. Third, the economy is small in the sense that it can

influence neither the world interest rate nor the terms-of-trade of the economy⁹. We also assume that the output of the traded goods sector is an endowment of y_T which is sold in the world markets at the export price of P_T^x , where P_T^x is measured in units of the imported consumption good, which is used as the numeraire. Since consumption of the export goods is assumed to be zero, P_T^x , by definition is the terms-of-trade and is exogenous to the country.

Consider an economy populated by a continuum of yeoman-farmers along the unit interval $[0,1]$. The representative agent aims to maximize the intertemporal utility function which is given by

$$(1) \quad V_j = \sum_{t=0}^{\infty} \beta^t \left[\frac{\sigma}{\sigma-1} C_t^{\frac{\sigma-1}{\sigma}} - \frac{k}{2} y_{Nt}^2(j) \right]$$

where $\beta \in (0,1)$, $\sigma, k > 0$. β is a preference parameter which is called the subjective discount or time preference factor, σ is the intertemporal elasticity of substitution, and k is the marginal disutility of work. The consumption index C aggregates the consumption of traded and nontraded goods,

$$(2) \quad C_t = \left[\gamma^{\frac{1}{\theta}} C_{Tt}^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{Nt}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

⁹ Many (Senhadji, 1998 and Backus et al., 1994) have modeled terms-of-trade as an endogenous variables. However, by studying Granger-Sims statistical causality, Mendoza found that except for the United States and a few major fuel exporters, the null hypothesis of exogeneity of terms-of-trade for small open economies cannot be rejected.

where $\theta > 1$ which is the intratemporal elasticity of substitution between the traded and nontraded goods. $y_{Nt}(j)$ is the production of j -th variety of the nontraded goods. The second terms in the objective function in (1) captures the disutility of work effort.

The dynamic budget constraint is

$$(3) \quad B_{t+1} = (1+r)B_t + p_{Nt}(j)y_{Nt}(j) + P_T^x y_T - P_t C_t$$

where agent invests in an international real bond, B_t , denominated in units of the import good that pay off a real return r , which is exogenously determined. Each agent also receives an exogenous endowment of traded good y_{Tt} each period. The consumption price index is given by

$$(4) \quad P_t = \left[\gamma + (1-\gamma)P_{Nt}^{1-\theta} \right]^{\frac{1}{1-\theta}}$$

Agent j is the monopoly producer of variety j of the nontraded goods and faces the demand function

$$(5) \quad y_{Nt}^d(j) = \left[\frac{p_{Nt}(j)}{P_{Nt}} \right]^{-\mu} C_{Nt}^A \quad \mu > 1$$

where C_{Nt}^A is the aggregate consumption of nontraded goods and the index functions for nontraded consumption and price can be written as

$$(6) \quad C_{Nt} = \left[\int_0^1 c_N(z)^{\frac{\mu-1}{\mu}} dz \right]^{\frac{\mu}{\mu-1}}$$

$$(7) \quad P_{Nt} = \left[\int_0^1 p_N(z)^{1-\mu} dz \right]^{\frac{1}{1-\mu}}$$

4.2.1 First Order Conditions

Assuming that there is no desire to borrow and lend at the steady state, therefore $\beta(1+r)=1$. Maximize the objective function with respect to B_{t+1} , C_{Nt} , y_{Nt} subject to the dynamic budget constraint and assuming no-Ponzi-Game condition yields the following first order conditions:

$$(8) \quad \frac{C_{t+1}}{C_t} = \left[\frac{P_t}{P_{t+1}} \right]^\sigma \Leftrightarrow \frac{C_{Tt+1}}{C_{Tt}} = \left[\frac{P_t}{P_{t+1}} \right]^{\sigma-\theta}$$

$$(9) \quad \frac{C_{Nt}}{C_{Tt}} = \frac{1-\gamma}{\gamma} (P_{Nt})^{-\theta}$$

$$(10) \quad y_{Nt}^{\frac{\mu+1}{\mu}} = \frac{\mu-1}{\mu k} \left[\frac{P_{Nt}}{P_t} \right] (C_{Nt}^A)^{\frac{1}{\mu}} C_t^{-\frac{1}{\sigma}}$$

Equation (8) is the intertemporal Euler equation. This equation which governs the dynamics of consumption can be rewritten as the consumption-based real interest rate¹⁰. If the aggregate price level relative to the price of traded goods is currently higher than its future value, there will be a change in the consumption of traded and nontraded goods due to the inter- and intratemporal substitution effects. First, since the current aggregate price level relative to traded goods is higher (the consumption-based real interest rate is higher), agents may choose to postpone or delay their consumption. This increase raises the optimal growth rate of real consumption with the intertemporal elasticity of substitution, σ where $C_t < C_{t+1}$ or $C_{Tt} < C_{Tt+1}$. Second, it also encourages substitution

¹⁰ Refer to Obstfeld and Rogoff (1996, Chapter 4). When the current price is higher relative to the future price, the consumption-based real interest rate is also higher as $(1+r_{t-1}^c) = (1+r)P_t/P_{t-1}$.

from nontraded to traded goods as traded goods become relatively cheaper and rises as a fraction of consumption with intratemporal elasticity of substitution, θ . These intertemporal and intratemporal substitution on consumption of traded goods work exactly in opposite directions. It is also interesting to note that if price is constant or $\sigma = \theta$, current consumption equals to future consumption. In other words, the gross growth rate of real consumption path is flat.

Equation (9) shows the relationship between the consumption of traded and nontraded goods. The elasticity between the two goods is parameterized by θ . Finally, equation (10) shows that the production of nontraded goods is inversely related to the consumption index, C .

4.2.2 Steady State Equilibrium

All variables are assumed to be constant at the steady state. Assuming that the level of initial net foreign assets is zero i.e. $\bar{B}_0 = 0$ ¹¹. We normalize the endowment of the traded goods so that the relative price of nontraded goods in terms of traded goods P_N is unity in the steady state, $\bar{P}_{N0} = 1$ and we also assume that the terms-of-trade, $\bar{P}_{T0}^x = 1$ at the initial steady state. In this symmetric equilibrium, $\bar{C}_N^A = \bar{C}_N = \bar{y}_N = (1 - \gamma)\bar{C}$ and the steady state consumption and production of traded and nontraded goods are

$$(11) \quad \bar{y}_T = \bar{C}_T = \frac{\gamma}{1 - \gamma} \bar{C}_N$$

¹¹ The 0 subscripts on barred variables denote the initial preshock symmetric steady state. For instance, $\bar{X}_0$ is the initial steady state value of variable X .

$$(12) \quad \bar{y}_N = \bar{C}_N = \left[\frac{\mu - 1}{\mu k} \right]^{\frac{\sigma}{\sigma+1}} (1 - \gamma)^{\frac{1}{\sigma+1}}$$

Equation (12) shows that the production and consumption of nontraded goods are directly related to the level of competition in the nontraded goods sector i.e. the larger is μ , the larger is the steady state production and consumption of nontraded goods. From this expression, it is also true that the production and consumption of nontraded goods will be larger, the less taxing is work effort (the smaller is k) and the larger is the weight placed on the consumption of nontraded goods in the utility function (the larger is $1 - \gamma$).

4.2.3 The Log-linearized Version of FOCs and Other Conditions

In this section, we develop the linearized version of all the model's equilibrium conditions. We begin with the three first order conditions:

$$(13) \quad \tilde{C}_{Tt+1} - \tilde{C}_{Tt} = (\sigma - \theta)(\tilde{P}_t - \tilde{P}_{t+1})$$

$$(14) \quad \tilde{C}_{Nt} - \tilde{C}_{Tt} = -\theta \tilde{P}_{Nt}$$

$$(15) \quad \tilde{y}_{Nt} = -\frac{1}{\sigma} \tilde{C}_t + (\tilde{P}_{Nt} - \tilde{P}_t)$$

and log-linearized versions of the consumption price index and consumption index are

$$(16) \quad \tilde{P}_t = (1 - \gamma) \tilde{P}_{Nt}$$

$$(17) \quad \tilde{C}_t = \gamma \tilde{C}_{Tt} + (1 - \gamma) \tilde{C}_{Nt}$$

The impact of steady state variation in net foreign asset (B), tradable output (y_T) and the terms-of-trade (P_T^x) can be derived by taking the linear approximation of (3) around the steady state which yields

$$(18) \quad \frac{dB_{t+1}}{C_{T0}} = (1+r) \frac{dB_t}{C_{T0}} + \tilde{y}_t + \tilde{P}_t^x - \tilde{C}_t$$

A change in the net foreign assets in period $t+1$ equals to the sum of net foreign assets together with its interest return in period t , a change in the endowment of traded output, and a change in the terms-of-trade minus a change in the consumption of traded goods.

4.3 An Unanticipated Permanent Terms-of-Trade Shocks

We now investigate the effects of an unanticipated permanent terms-of-trade shock that occurs at time 1. Prices in the competitive traded goods sector are fully flexible prices while prices in the nontraded goods sector are set one period in advance and adjust to flexible price levels only after a period in the absence of new shocks. In the event of an unanticipated permanent terms-of-trade shock, rational agent can only adjust its price one period later. With sticky nominal prices, the economy reaches the steady state equilibrium only in the long run i.e. given the structure of the nominal rigidity, the new steady state is attained after one period. To distinguish between the short run and the long run effects of the terms-of-trade shock we let $\tilde{X} \equiv (X_1 - \bar{X}_0) / \bar{X}_0$ to denote the short run percentage deviation in X from $\bar{X}_0$, the initial steady state value of X , and $\hat{X} \equiv (\bar{X} - \bar{X}_0) / \bar{X}_0$ to denote the long run steady state percentage deviation.

We first consider an unanticipated permanent favorable terms-of-trade shock, $\hat{P}_T^x = \tilde{P}_T^x > 0$. Since the nontraded goods sector is assumed to be a monopolistic market and prices in this sector are set one period in advance, they adjust to the shock only by

period two. In the short run, prices in the nontraded goods sector are fixed and nontraded output is demand determined. Therefore, we have

$$(19) \quad \tilde{P}_N = 0$$

$$(20) \quad \tilde{C}_N = \tilde{y}_N$$

which implies from (14) the relationship between $\tilde{C}_N$ and $\tilde{C}_T$

$$(21) \quad \tilde{C}_N = \tilde{C}_T$$

With P_N fixed, the short run and the long run change in the consumption-based price index are

$$(22) \quad \tilde{P} = 0$$

$$(23) \quad \hat{P} = (1 - \gamma)\hat{P}_N$$

the relationship between $\hat{C}_T$ and $\tilde{C}_T$ are linked by

$$(24) \quad \hat{C}_T - \tilde{C}_T = -(\sigma - \theta)(1 - \gamma)\hat{P}_N$$

From (18), given a constant endowment of the traded goods, the steady state consumption of traded goods can only be increased by the income earned from the accumulation of net foreign assets and the change in the terms-of-trade

$$(25) \quad \hat{C}_T = r\hat{b} + \hat{P}_T^x$$

where $\hat{b} = \frac{dB}{\bar{C}_{T0}}$. In turn the accumulation of foreign assets dB is generated by the short

run current account surplus

$$(26) \quad \hat{b} = \hat{P}_T^x - \tilde{C}_T$$

The supply condition (15) and the optimize relationship between $\tilde{C}$ and $\tilde{C}_N$ give

$$(27) \quad \hat{y}_N = \hat{C}_N = \frac{\sigma - \theta}{1 + \sigma} (\hat{P}_N - \hat{P})$$

Lastly, from the consumption optimization condition between the traded and the nontraded goods (14)

$$(28) \quad \hat{C}_N - \hat{C}_T = -\theta \hat{P}_N$$

Equations (19)-(28) allow us to solve for both the short run and the steady state effects of an unanticipated favorable terms-of-trade shock.

The solution has the following form

$$(29) \quad \hat{y}_N = \hat{C}_N = \frac{(\sigma - \theta)(1 + r)}{a_0} \hat{P}_T^x$$

$$(30) \quad \hat{C}_T = \frac{(1 + r)[\theta(1 - \gamma) + \sigma(\theta + \gamma)]}{a_0} \hat{P}_T^x$$

$$(31) \quad \hat{P}_N = \frac{(1 + r)(1 + \sigma)}{a_0} \hat{P}_T^x$$

$$(32) \quad \hat{P} = \frac{(1 + r)(1 + \sigma)(1 - \gamma)}{a_0} \hat{P}_T^x$$

$$(33) \quad \hat{C} = \frac{\gamma\sigma(1 + r)(1 + \theta)}{a_0} \hat{P}_T^x$$

$$(34) \quad \hat{b} = -\frac{(1 - \gamma)(\sigma - \theta)(1 + \sigma)}{a_0} \hat{P}_T^x$$

$$(35) \quad \tilde{C}_T = \tilde{C}_N = \tilde{y}_N = \frac{\sigma(1 + r)[\sigma(1 - \gamma) + (1 + \theta\gamma)]}{a_0} \hat{P}_T^x$$

$$(36) \quad \hat{C}_T - \tilde{C}_T = -\frac{(\sigma - \theta)(1 + r)(1 - \gamma)(1 + \sigma)}{a_0} \hat{P}_T^x$$

where $a_0 = r\sigma^2(1 - \gamma) + \theta(1 - \gamma) + r\sigma(1 + \theta\gamma) + \sigma(\theta + \gamma) > 0$.

There are three cases to consider: (i) $\sigma = \theta$, (ii) $\sigma > \theta$ and (iii) $\sigma < \theta$. With an unanticipated permanent improvement in the terms-of-trade, the economy is perturbed in both the short run and the long run. The results show that the effects of an unanticipated permanent improvement in the terms-of-trade on the current account will depend upon the inter- and intra- elasticities of substitution¹². All the three cases can be clearly summarized in Table 4.1:

Table 4.1 Effects of an unanticipated permanent terms-of-trade shock

Variables	$\sigma = \theta$	$\sigma > \theta$	$\sigma < \theta$
$\hat{y}_N = \hat{C}_N$	0	+	-
$\hat{C}_T$	+	+	+
$\hat{C}$	+	+	+
$\hat{P}_N$	+	+	+
$\hat{P}$	+	+	+
$\hat{b}$	0	-	+
$\hat{C}_T - \tilde{C}_T$	0	-	+
$\tilde{C}_N = \tilde{C}_T = \tilde{y}_N$	+	+	+

In case (i) when $\sigma = \theta$, a permanent terms-of-trade improvement will only lead to an increase in the consumption of traded goods in both the short run and the long run by equal proportion without any real effects on the holding of the net foreign asset. The current account is balanced as in the initial steady state. Since the elasticities of intertemporal and intratemporal substitution are equal, there is no spillover effect from

¹² In Appendix A, we show that without nominal rigidities and imperfect competition, a permanent terms-of-trade deterioration does not have any effect on the current account of a small open economy. As a result, fluctuation in the current account due to a permanent terms-of-trade shock is purely a result of nominal rigidities and imperfect competition in this setup.

the traded goods sector to the nontraded goods sector in the long run. Hence the output and the consumption of the nontraded goods in period two remain unchanged.

However, in case (ii) when $\sigma > \theta$, the elasticity of intratemporal substitution is low (relative to the elasticity of intertemporal substitution) which implies that traded goods and nontraded goods are poor substitutes or good complements. A permanent terms-of-trade improvement induces a rise in the consumption of traded goods $\hat{C}_T > 0$, which further stimulates an extra demand in the nontraded goods sector, $\hat{C}_N > 0$. In the short run, the price of nontraded goods is sticky, $\tilde{P}_N = 0$. This makes the price of the traded goods (importables) relatively cheaper than the price of the nontraded goods in the short run. Then, the desire to consume more of the nontraded goods in the short run before the price increases raises the price of the nontraded goods in the long run, $\hat{P}_N > 0$. As the price of nontraded goods is rising in the long run, the price gap between the tradables and the nontradables are even larger in the long run. First, the consumption of the tradables increases in the short run because of the terms-of-trade improvement. Second, the higher short run consumption of the nontradables (before the price of the nontradables goods increases) induces a further increase in the short run consumption of the tradables for the case of stronger intratemporal complementarity. Therefore, we expect the increase in the consumption of tradables in the short run to be larger than the increase in the long run, $\hat{C}_T < \tilde{C}_T$. It should be noted that when this effect is significantly large, it dominates the initial effect of an improvement in terms-of-trade which makes the current account into surplus. The permanent terms-of-trade shock causes a larger increase in the consumption of the traded goods in the short run and hence a decumulation in the

holding of net foreign assets, $\hat{b} < 0$. It is because of this asymmetric adjustment in the consumption of traded goods in the short run and the long run that brings to a decrease in the holding of net foreign assets, in other words, the current account goes into deficit and $\hat{C}_T < \hat{P}_T^x < \tilde{C}_T$.

On the other hand, in case (iii) when $\sigma < \theta$, the elasticity of intratemporal substitution is relatively large compared to the elasticity of intertemporal substitution, traded goods and nontraded goods are close substitutes. A permanent terms-of-trade improvement raises the consumption of traded goods, $\hat{C}_T > 0$ which further contracts the demand for nontraded goods, $\hat{C}_N < 0$. In this case, similar argument follows. The consumption of the traded goods increases in the short run because of the terms-of-trade improvement. However, the higher short-run consumption of the nontraded goods before the price of the nontraded goods rises decreases the consumption of the traded goods in the short run for the case of stronger intratemporal substitutability. As the price gap between the tradables and the nontradables is observed to be larger in the long run, the long run increase in the consumption of traded goods is larger than the short run, $\hat{C}_T > \tilde{C}_T$. Since the increase in the consumption of traded goods in the short run is relatively small, this will enhance an accumulation in the holding of net foreign assets which enables for a larger increase in the consumption of traded goods in the long run. As a result of this asymmetric adjustment, the current account goes into surplus and $\hat{C}_T > \hat{P}_T^x > \tilde{C}_T$.

From this simple but rigorous analysis, the effect of favorable permanent terms-of-trade shocks on the current account depends critically on the adjustments of

consumption in traded goods in both the short run and the long run. These adjustments, in turn, depend significantly on the relationship between the traded and nontraded goods. If the two goods are substitutes, in the presence of nominal price rigidities in the nontraded goods sector, a permanent improvement in terms-of-trade generates an increase in the holding of net foreign assets and hence current account surplus. On the other hand, if the two goods are good complements, a permanent improvement in terms-of-trade leads to a current account deficit.

4.4 An Unanticipated Temporary Terms-of-Trade Shocks

With an unanticipated temporary Terms-of-trade shock, $\tilde{P}_T^x < 0$ and $\hat{P}_T^x = 0$. All equations from (19)-(28) remain unchanged except equations (25) and (26) which will change to

$$(25a) \quad \hat{C}_T = r\hat{b}$$

$$(26a) \quad \hat{b} = \tilde{P}_T^x - \tilde{C}_T$$

Solve (19)-(24), (25a), (26a) and (27)-(28) simultaneously to analyze the short run and the long run effects of an unanticipated temporary improvement in terms-of-trade disturbance yields the following form of solution:

$$(37) \quad \hat{y}_N = \hat{C}_N = \frac{r\gamma(\sigma - \theta)}{a_0} \tilde{P}_T^x$$

$$(38) \quad \hat{C}_T = \frac{r[\theta(1 - \gamma) + \sigma(\theta + \gamma)]}{a_0} \tilde{P}_T^x$$

$$(39) \quad \hat{P}_N = \frac{r(1 + \sigma)}{a_0} \tilde{P}_T^x$$

(40) $\hat{P} = \frac{r(1+\sigma)(1-\gamma)}{a_0} \tilde{P}_T^x$

(41) $\hat{C} = \frac{\gamma\sigma(1+\theta)}{a_0} \tilde{P}_T^x$

(42) $\hat{b} = \frac{\theta(1-\gamma)+\sigma(\theta+\gamma)}{a_0} \tilde{P}_T^x$

(43) $\tilde{C}_T = \tilde{C}_N = \tilde{y}_N = \frac{\sigma r[\sigma(1-\gamma)+(1+\theta\gamma)]}{a_0} \tilde{P}_T^x$

(44) $\hat{C}_T - \tilde{C}_T = -\frac{r(\sigma-\theta)(1-\gamma)(1+\sigma)}{a_0} \tilde{P}_T^x$

The effects of a temporary favorable shock on a small open economy are summarized as follows:

Table 4.2 Effects of an unanticipated temporary terms-of-trade shock

Variables	$\sigma = \theta$	$\sigma > \theta$	$\sigma < \theta$
$\hat{y}_N = \hat{C}_N$	0	+	-
$\hat{C}_T$	+	+	+
$\hat{C}$	+	+	+
$\hat{P}_N$	+	+	+
$\hat{P}$	+	+	+
$\hat{b}$	+	+	+
$\hat{C}_T - \tilde{C}_T$	0	-	+
$\tilde{C}_N = \tilde{C}_T = \tilde{y}_N$	+	+	+

Notice that even though the shock is temporary, the traded goods are relatively cheaper than the nontraded goods in both the short run and the long run. This is mainly due to the increase in the prices of the nontraded goods in the long run even after a temporary terms-of-trade shock. In this case, the model generates an increase in the consumption of traded goods in both periods and a rise in the holding of net foreign

assets, $\hat{b} > 0$ in response to a positive temporary terms-of-trade shock regardless of the size of the elasticities of intertemporal, σ and intratemporal, θ substitution. When the Terms-of-trade improves, it induces the consumption of traded goods to increase but by less than the proportionate change in terms-of-trade, i.e. $\tilde{C}_T < \tilde{P}_T^x$. This is perhaps due to the consumption-smoothing behaviour of the rational agents. As a result, a positive temporary terms-of-trade shock always brings the current account into surplus and this accumulation of net foreign assets allows for a higher consumption of traded goods in the long run, $\hat{C}_T > 0$. However, the effects of positive terms-of-trade shocks on the output and consumption of nontraded goods depend critically on the relative size of the two elasticities. There are three cases to consider: (i) $\sigma = \theta$, (ii) $\sigma > \theta$ and (iii) $\sigma < \theta$.

In case (i), the utility function is in the form of log-separable. A temporary terms-of-trade improvement immediately induces the consumption of traded goods in the short run. Traded goods are relatively cheaper in both the short run and the long run. Hence, there is also an increase in the consumption of traded goods in the long run. However, the intertemporal and intratemporal substitution effects cancel out, so that there is no spillover on the consumption of nontraded goods in the long run. Effects of a favorable temporary terms-of-trade shock are the same for the consumption of traded goods in both the short run and the long run.

In case (ii), a rise in the consumption of traded goods in the long run, $\hat{C}_T > 0$ stimulates an expansion in the production and consumption in the nontraded goods sector, $\hat{C}_N > 0$. This is mainly a result of relatively low elasticity of substitution between traded goods and nontraded goods (relative to the intertemporal elasticity of substitution). It is

also interesting to note that in this case, due to the rise in the prices of nontraded goods in the long run and low elasticity of intratemporal substitution, the impacts of a temporary improvement in the terms-of-trade on the consumption of traded goods is larger in the short run, $\hat{C}_T < \tilde{C}_T$.

In case (iii), as a result of relatively larger elasticity of intratemporal substitution, the spillover between traded and nontraded consumption is negative. A surge in the consumption of traded goods, $\hat{C}_T > 0$ contracts the production and consumption in the nontraded goods sector, $\hat{C}_N < 0$. Moreover, the traded and nontraded goods are substitutes in this case, the adverse impacts on the consumption of traded goods is smaller in the short run, $\hat{C}_T > \tilde{C}_T$.

4.5 Conclusions

This model which captures the spirit of the recent intertemporal sticky price literature has clearly demonstrated the effects of an adverse terms-of-trade on current account – both temporary and permanent. The model predicts a few outcomes. First, the current account always goes into surplus (deficit) with a temporary terms-of-trade improvement (deterioration) and the result holds with or without nominal rigidities. Second, in the presence of nominal rigidities and imperfect competition, a permanent terms-of-trade improvement may cause the current account to move in either direction, surplus or deficit, depends critically on the relative elasticities of intertemporal and

intratemporal substitution¹³. Third, the impacts of a terms-of-trade on consumption and output of nontraded goods in the long run ($\hat{C}_N$ and $\hat{y}_N$), price of nontraded goods in the long run ($\hat{P}_N$), overall price in the long run ($\hat{P}$), consumption of traded goods ($\tilde{C}_T$) and consumption and output of nontraded goods in the short run ($\tilde{C}_N$ and $\tilde{y}_N$) are magnified when the shock is permanent. Finally, when prices are perfectly flexible, the intertemporal Euler equation shows that the optimal consumption growth path is flat. As a result, the holding of net foreign assets remains unchanged even when the terms-of-trade shock is permanent.

This study shows results that are consistent with others (Sach, 1981; Obstfeld, 1982; Svensson and Razin, 1983) who argue that HLM effect only holds true for temporary Terms-of-trade shocks. In this model, a temporary positive terms-of-trade shock induces a relatively higher prices in the nontraded goods sector in both the short run and the long run. In the short run, with sticky prices in the nontraded goods, a positive terms-of-trade shock will result in relatively higher prices of nontraded goods as price of traded goods is lower but the price of nontraded goods remains unchanged. In the long run, a temporary terms-of-trade shock will cause a rise in the prices of nontraded goods but the price of traded goods returns back to its initial level. Hence, after the temporary terms-of-trade shock ceases, the prices in the nontraded goods sector remain relatively higher. As a result, stickiness in the nontraded goods sector will generate an increase in the consumption of traded goods in both periods. However, since the

¹³ This paper is purely theoretical. The relative size of inter- and intra-temporal elasticities of substitution which determines the relationship between tradable and nontradable remains an empirical question.

consumption of traded goods rises by less than the terms-of-trade, the holding of net foreign assets is always higher.

In contrast to the Obstfeld-Svensson-Razin model which finds that permanent terms-of-trade shocks leave the current account unchanged, this model shows that permanent terms-of-trade may have a positive effect or negative effect on the current account in the presence of nominal rigidities and imperfect competition. The impact of a permanent terms-of-trade shock on the current account depends critically on the degree of substitutability between the traded and nontraded goods. When prices are perfectly flexible, permanent terms-of-trade shocks do not affect the holding of net foreign assets. In conclusion, permanent changes in terms-of-trade do not affect the current account when prices are perfectly flexible, whereas temporary changes do, temporary improvement causing surpluses and temporary decline producing deficit.

Chapter 5

Terms-of-trade Shocks and the Exchange Rate Regimes[†]

5.1 Introduction

Given the significance of terms-of-trade fluctuations on domestic macroeconomic variables, understanding the transmission and propagation of terms-of-trade fluctuations is crucial in the design and conduct of macroeconomic policies in both industrialized and developing countries. In this chapter, we use an intertemporal equilibrium framework with nominal price rigidities and imperfect competitive markets to analyze the dynamics of some macroeconomic variables arising from term-of-trade fluctuations under alternative exchange rate systems¹⁴. We adapt the model of Lane and Milesi-Ferretti¹⁵ (2004) and construct an intertemporal framework with tradable and nontradable sectors. The existence of traded and nontraded goods provides a richer framework for analyzing

[†] A paper developed from this chapter was presented at *The 2005 Australian Conference for Economists* at University of Melbourne, Australia, 26-28 September 2005. This paper has been accepted by *the Economic Record* for publication.

¹⁴ Monacelli (2004) uses a dynamic general equilibrium model of a small open economy combining nominal price rigidity with a systematic behavior of monetary policy. He considers shocks due to productivity, domestic preferences, world interest rate and world demand but not terms-of-trade shocks.

¹⁵ This model was originally used to show that countries with net external liabilities have larger real exchange rate depreciation, in which the main channel of transmission works through the relative price of nontraded goods rather than through the relative price of traded goods across countries.

the dynamics of important macroeconomic variables resulting from terms-of-trade shocks. Furthermore, by incorporating nontraded goods, the model is extended to involve both intertemporal and intratemporal substitution effects.

In our model, the nontraded sector is assumed to be a monopolistic competitive market¹⁶ where prices are sticky. The traded sector, on the other hand, is assumed to be a perfectly competitive market where prices are fully flexible and the law of one price holds. The asymmetric treatment of the two sectors allows us to show the link between the sectors when there is a terms-of-trade disturbance. We clearly show the propagation mechanism of terms-of-trade shocks on the dynamics of some macroeconomic variables.

We use numerical solution methods to demonstrate the impulse responses of macroeconomic aggregates induced by a negative terms-of-trade shock. We examine the link between terms-of-trade shock and some macroeconomic aggregates by numerically solving a dynamic stochastic general equilibrium model of a small open economy. The numerical solutions of the model are compared with the empirical regularities documented by Broda (2001 and 2004). Our results are broadly consistent with the following empirical regularities. First, the responses of short-run output to shocks are significantly smoother in floats than in pegs; second, in moving from pegs to floats, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate; and third, in all types of exchange rate regimes, the most volatile variable is the holding of net foreign assets.

¹⁶ We follow the assumption in Lane and Milesi-Ferretti (2004) that the domestic aggregate demand conditions matter more for the nontraded sector than the traded sector.

The chapter is organized as follows. Section 5.2 lays out a dynamic general equilibrium model of a small economy that combines nominal price rigidity with a terms-of-trade shock; the model parameterization is provided in Section 5.3; the fluctuations of the output, the real exchange rate and the price level as a result of terms-of-trade shocks are analyzed in Section 5.4; and the conclusions are in Section 5.5.

5.2 The Model

We derive an intertemporal model of a small open economy to analyze the way in which terms-of-trade shock affects some real variables in an economy with different exchange rate regimes. To address the intratemporal aspects of the problem, we make three main assumptions. First, the importable is consumed but not produced, and the exportable is produced but not consumed. In other words, the importable and the nontradable are consumed domestically but the exportable and the nontradable are produced domestically. Second, investment is held constant and the capital stock is an endowment which is not affected by the terms-of-trade shocks. Third, the economy is small in the sense that it cannot influence the terms-of-trade of the economy¹⁷. We also assume that the output of the traded goods sector is an endowment of the tradable good y_T , which is sold in the world markets at the export price of P_T^x , where P_T^x is measured in units of the imported consumption good and the imported consumption good is used as

¹⁷ Many (Senhadji, 1998 and Backus et al., 1994) have modeled terms-of-trade as an endogenous variable. However, by studying Granger-Sims statistical causality, Mendoza (1995) finds that except for the United States and a few major fuel exporters, the null hypothesis of exogeneity of terms-of-trade for small open economies cannot be rejected.

the numeraire. Since consumption of the export goods is assumed to be zero, P_T^x , by definition is the terms-of-trade and is exogenous to the country.

5.2.1 The Households

Consider an economy populated by a continuum of yeoman-farmers along the unit interval $[0,1]$. The representative agent aims to maximize the intertemporal utility function which is given by:

$$(1) \quad V^j = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{\sigma}{\sigma-1} C_t^{\frac{\sigma-1}{\sigma}} - \frac{h}{2} y_{Nt}^2(j) \right]$$

where $\beta \in (0,1)$, $\sigma, h > 0$. β is a preference parameter which is known as the subjective discount or time preference factor, σ is the intertemporal elasticity of substitution, and h is the marginal disutility of work. E_t is the expectation operator. $y_{Nt}(j)$ is the production of j -th variety of the nontraded goods. The subscripts N and t represent nontradable goods and time, respectively. The second term in the objective function captures the disutility of work effort. The consumption index C_t , aggregates the consumption of traded goods (C_{Tt}) and nontraded goods (C_{Nt}):

$$(2) \quad C_t = \left[\gamma^{\frac{1}{\theta}} C_{Tt}^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{Nt}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

where $\theta > 1$ which is the intratemporal elasticity of substitution between the traded and nontraded goods, and $\gamma \in [0, 1]$ is the share of consumption of traded good in total consumption. The consumption-based price index is given by:

$$(3) \quad P_t = \left[\gamma P_{Tt}^{1-\theta} + (1-\gamma) P_{Nt}^{1-\theta} \right]^{\frac{1}{1-\theta}}$$

where P_{Tt} is the price of the traded good expressed in units of domestic currency. P_{Nt} is the price of the nontraded good.

Agent j is the monopoly producer of variety j of the nontraded good. The optimal allocation of any given expenditure within each category of goods yields the demand functions for any variety j :

$$(4) \quad y_{Nt}^d(j) = \left[\frac{P_{Nt}(j)}{P_{Nt}} \right]^{-\mu} C_{Nt}^A \quad \mu > 1$$

for all $j \in [0, 1]$, where μ is the price elasticity of demand faced by each monopolist and C_N^A is the summation of the consumption of nontraded good j .

The j -th individual's consumption of nontraded goods can be written as:

$$(5) \quad C_{Nt}^j = \left[\int_0^1 c_N(m)^{\frac{\mu-1}{\mu}} dm \right]^{\frac{\mu}{\mu-1}}$$

where m denotes nontraded goods which $m \in [0, 1]$.

The price of nontraded goods is:

$$(6) \quad P_{Nt} = \left[\int_0^1 p_N(m)^{1-\mu} dm \right]^{\frac{1}{1-\mu}}$$

Each domestic agent holds only one type of asset, namely an internationally traded bond, B . The agent produces a single nontraded good, $y_{Nt}(j)$, in a monopolistic competitive way and he receives a constant endowment of y_T units of traded good. The flow of budget constraint faced by agent j is given by:

$$(7) \quad P_{Tt} B_{t+1} = (1 + r_t) P_{Tt} B_t + P_{Nt}(j) y_{Nt}(j) + P_T^x y_T - P_t C_t,$$

where B_t is the number of real bonds which is denominated in tradables and r_t is the return of the international bond. Maximization of (1) subject to (4) and (7) generates the following relationships:

$$(8) \quad E_t \left(\frac{C_{Tt+1}}{C_{Tt}} \right) = \beta^{-\sigma} E_t (1 + r_{t+1})^{-\sigma} \left(\frac{P_t / P_{Tt}}{P_{t+1} / P_{Tt+1}} \right)^{\sigma - \theta},$$

$$(9) \quad \frac{C_{Nt}}{C_{Tt}} = \frac{1 - \gamma}{\gamma} \left(\frac{P_{Nt}}{P_{Tt}} \right)^{-\theta}, \text{ and}$$

$$(10) \quad y_{Nt}^{\frac{\mu+1}{\mu}} = \left(\frac{\mu - 1}{\mu h} \right) \left(\frac{P_{Nt}}{P_t} \right) \left(C_{Nt}^A \right)^{\frac{1}{\mu}} C_t^{-\frac{1}{\sigma}},$$

Equation (8) is the Euler equation governing the dynamic evolution of consumption. Given the interest rate, if the aggregate price level relative to the price of traded goods is currently low relative to its future value, the present consumption is encouraged over the future consumption. However, it also encourages substitution from traded to nontraded goods. The former effect dominates if intertemporal elasticity of substitution is greater than the intratemporal elasticity of substitution ($\sigma > \theta$), and vice versa.

Equation (9) relates consumption of nontraded and traded goods. When the relative price is unity, the relative consumption of nontraded good is larger the smaller the share of consumption of traded goods in total consumption (γ). Finally, equation (10) shows the equilibrium supply of nontraded goods. The higher is the consumption index (C), the lower is the production level. Additionally, the larger is the relative price of nontraded good to the aggregate price level, the larger is the production level.

5.2.2 Domestic Firms

The production sector is characterized by household that acts as a monopoly in the production of a single nontraded good. The household j (household and domestic firm are used interchangeably) operates a constant return to scale linear technology, $y_{Nt} = AL_{Nt}$ in which labour is the only factor of production and A is the total factor productivity shifter. Assume that the firm is a price taker in the labour market and a monopoly in the good market. In the labour market, the firm chooses optimal labour by taking the output level as given. Then, the cost minimization condition for the choice of optimal labour implies that labour is paid according to its marginal productivity. Therefore, mc_t which is the firm's real marginal cost is defined as real wage in terms of nontraded goods over the total factor productivity shifter. This real marginal cost is also defined as the nominal marginal cost over price of nontradables ($mc_t = MC_t / P_{Nt}$). In the good market, the firm maximizes profits by choosing the price of the good j that it produces subject to the demand for this good. As in Calvo (1983), the firm sets price on a staggered basis where it is allowed to reset the output price according to a time-dependent rule where ϕ is the probability that the firm keeps its price fixed in a given period and

$1 - \phi$ is the probability that the firm changes its price. The probability draws are assumed to be independent and identically distributed (iid) over time. This implies that, when allowed to reset its price, domestic firm j will choose $p_{Nt+k}^{new}(j)$ to maximize:

$$(11) \quad E_t \left\{ \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} [p_{Nt+k}^{new}(j) - MC_{t+k}] y_{Nt+k}(j) \right\},$$

subject to the demand schedule:

$$(12) \quad y_{Nt+k}(j) \leq \left[\frac{p_{Nt+k}^{new}(j)}{P_{Nt+k}} \right]^{-\mu} C_{Nt+k}^A,$$

where $\Lambda_{t,t+k}$ is the time-varying portion of the firm's discount factor and MC_t is the nominal marginal cost. The necessary first-order condition of this problem gives:

$$(13) \quad p_{Nt}^{new}(j) = \left(\frac{\mu}{\mu-1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} MC_{t+k} y_{Nt+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} y_{Nt+k}(j) \right\}}.$$

This dynamic markup equation states that the current price is set based on the firm's forecast in future demand and marginal cost. Note that if a firm was able to freely adjust its price each period, it will choose a constant mark-up over marginal cost, i.e. $\phi = 0$ implies:

$$(14) \quad p_{Nt}^{new}(j) = \left(\frac{\mu}{\mu-1} \right) MC_t.$$

Given the pricing rule, in a symmetric equilibrium where the law of large numbers holds, the nontradable aggregate price index evolves according to:

$$(15) \quad P_{Nt} = \left[\beta \phi P_{Nt-1}^{1-\mu} + (1 - \beta \phi) (P_{Nt}^{new})^{1-\mu} \right]^{1/(1-\mu)}.$$

5.2.3 International Capital Market

As in Soto (2003), we assume imperfect international capital markets where the interest rate depends on the stock of net foreign debt of the economy. In particular, the interest rate is given by:

$$(16) \quad (1 + r_t) = (1 + r_t^*) \left(\frac{B_t}{\tilde{B}} \right)^\psi,$$

where $(1 + r_t^*)$ is the risk-free international interest rate and $\psi \geq 0$ is a parameter that measures the premium the domestic economy must pay. This expression implies that a country with a large stock of debt over a stock of minimum debt ($\tilde{B}$), starts paying a premium over the interest rate that prevails in the international capital market. However, for a stock of debt below this threshold, the country receives a discount.

5.2.4 Prices and Real Exchange Rate

The nominal exchange rate e_t is the price of one unit of foreign currency expressed in units of domestic currency. The real exchange rate is defined as:

$$(17) \quad q_t = \frac{e_t P_t^*}{P_t}.$$

The foreign price level is assumed to be given and the foreign price denominated in price of tradable is normalized to be one. When the law of one price holds for traded goods, it implies that $q_t = P_{Ti} / P_t$.

5.2.5 Monetary Policy and Exchange Rate Regimes

The formulation of monetary policy by the domestic authority follows a generalized rule, in which deviations of inflation, nontraded output and nominal exchange rate from their long-run target have a feedback on short-run movements of the nominal interest rate. As in many others (Taylor, 1993; Clarida, Gali, and Gertler, 1999; Rotemberg and Woodford, 1998 and Monacelli, 2004), the following equation describes the target for the nominal interest rate:

$$(18) \quad (1 + \tilde{i}_t) = \left(\frac{P_t}{P_{t-1}} \right)^{\omega_\pi} y_{Nt}^{\omega_y} e^{\frac{\omega_\epsilon}{1-\omega_\epsilon}}.$$

where $\tilde{i}_t$ is the target for nominal interest rate, ω_ϵ , ω_π and ω_y are weight assigned to the movements of nominal exchange rate, inflation and nontradable output, respectively. From equation (18) the monetary authority reacts to the contemporaneous level of inflation, nontraded output and nominal exchange rate. The determination of the actual short-run interest rate that accounts for the desire of the monetary authority to smooth changes in the interest rate is:

$$(19) \quad (1 + i_t) = (1 + \tilde{i}_t)^{1-\lambda} (1 + i_{t-1})^\lambda.$$

5.2.6 Steady State Equilibrium

We first consider the situation in which all prices are fully flexible. All variables are assumed to be constant at the steady state. Any variable with a bar on top denotes the variable at its steady state. We normalize the endowment of the traded good so that the relative price of nontraded goods in terms of traded goods is unity in the steady state, $(\bar{P}_{N0}/\bar{P}_{T0})=1$. In this symmetric equilibrium, $\bar{y}_{N0} = \bar{C}_{N0} = (1-\gamma)\bar{C}_0$ and $\bar{C}_{N0} = (1-\gamma)\bar{C}_{T0}/\gamma$. The aggregate price level, the price of traded good and consumption of traded goods are constant at the steady state. At the initial steady state, we also assume that the terms-of-trade is one, $\bar{P}_{T0}^* = 1$. Then, from equation (8), the steady state value for the real domestic interest rate is:

$$(20) \quad \bar{r}_0 = \beta^{-1} - 1.$$

Given the stock of minimum foreign debt $\tilde{B}$, at steady state the following relationship is observed:

$$(21) \quad \bar{B}_0 = \left(\frac{1+r}{1+r^*} \right)^{\frac{1}{\psi}} \tilde{B}$$

If we assume $r = r^*$, then $B = \tilde{B}$. From equation (7), the consumption of traded goods in steady state satisfies:

$$(22) \quad \bar{C}_{T0} = r\bar{B}_0 + \bar{y}_{T0}.$$

The steady state consumption and production of nontraded goods is given by:

$$(23) \quad \bar{y}_{N0} = \bar{C}_{N0} = \left(\frac{\mu - 1}{\mu h} \right)^{\frac{\sigma}{1+\sigma}} (1 - \gamma)^{\frac{1}{1+\sigma}}.$$

The term $(\mu - 1)/\mu$ is the inverse of the markup for the fully flexible prices case. From this expression, output of the nontraded goods will be larger, the more competitive is the nontraded goods sector (the larger is μ), the less taxing is work effort (the smaller is h) and the larger is the weight placed on the consumption of nontraded goods in the utility function (the larger is $(1 - \mu)$).

5.2.7 The Log-linearized Version of FOC and Other Conditions

The model is solved by taking a log-linear approximation around the steady state. We let a variable with hat to denote the log-deviation of a variable from the steady state and a variable with bar to denote a variable at steady state. Then, the model can be described by a system of linear equations as discussed in the following subsections.

Aggregate supply and inflation

Let $\hat{x}_{Nt}$ be the output gap in the nontraded sector which is measured as the deviation between the stochastic component of current output and the potential output. The following equation shows the inflation of nontraded goods:

$$(24) \quad \hat{\pi}_{Nt} = \lambda \hat{x}_{Nt} + E_t \hat{\pi}_{Nt+1},$$

where $\lambda = \frac{(1 - \phi)(1 - \beta\phi)}{\phi}$ and E_t is the expectation operator. This equation suggests that inflation is positively related to output gap.

Aggregate demand

By taking a log-linear approximation of (8) and (17), the following equation can be obtained:

$$(25) \quad E_t(\hat{C}_{Tt} - \hat{C}_{Tt+1}) = E_t[-\sigma\hat{r}_t + (\theta - \sigma)(\hat{q}_{t+1} - \hat{q}_t)].$$

This equation shows that the consumption of traded goods adjusts according to the evolution of real interest rate and real exchange rates. From the log-linear approximation of (3), (9) and (17), an expression that relates the output gap in the nontraded sector with the deviation of real exchange rate from its steady state and the deviation of consumption of traded goods from its steady state is derived as:

$$(26) \quad \hat{x}_{Nt} = \frac{\theta}{1 - \gamma} \hat{q}_t + \hat{C}_{Tt} - \hat{z}_{Nt},$$

where the last term denotes the potential output which is assumed to follow a stationary stochastic process.

Real interest rate and current account

The log-deviation of the real interest rate faced by domestic agents corresponds to:

$$(27) \quad \hat{r}_t = \hat{r}_t^* + \psi\hat{B}_t.$$

Using equation (7), the linear expression of the stock of foreign assets is:

$$(28) \quad \hat{B}_{t+1} = (1 + \bar{r}_0)(\hat{r}_t + \hat{B}_t) - \frac{\bar{C}_{T0}}{\bar{B}_0} \hat{C}_t + \frac{\bar{y}_{T0}}{\bar{B}_0} (\hat{p}_{Tt}^x - \hat{p}_{Tt}).$$

Uncovered interest parity condition with nominal and real interest rates

The uncovered interest parity defines a linear expression for the exchange rate which can be expressed as:

$$(29) \quad \hat{i}_t = \hat{i}_t^* + E_t(\hat{e}_{t+1} - \hat{e}_t)$$

where i_t and i_t^* are domestic and foreign nominal interest rate respectively and

$\hat{i}_t = \log(1 + i_t / 1 + \bar{i})$ The relationship between the nominal and real interest rates is defined by:

$$(30) \quad \hat{r}_t = \hat{i}_t + E_t(\hat{P}_t - \hat{P}_{t+1})$$

Monetary policy rule

Equation (31) is obtained by taking a log-linear approximation of (18) and (19)

$$(31) \quad \hat{i}_t = \tilde{\omega}_\pi \hat{\pi}_t + \tilde{\omega}_y \hat{y}_{Nt} + \tilde{\omega}_e \hat{e}_t + \chi \hat{i}_{t-1}$$

where $\tilde{\omega}_\pi \equiv (1 - \chi)\omega_\pi$, $\tilde{\omega}_y \equiv (1 - \chi)\omega_y$, and $\tilde{\omega}_e \equiv (1 - \chi)(\omega_e / 1 - \omega_e)$. Following Monacelli (2004), this specification allows us to approximate the systematic behavior of monetary policy under the floating and the fixed exchange rate regimes. In particular, $\omega_e = 0$ describes the behavior of the monetary authority practicing the floating exchange rate regime; whereas $\omega_e \in (0, 1]$ approximates the behavior of the monetary authority practicing policies ranging from managed to the fixed exchange rate regimes.

Exogenous stochastic process

The stochastic processes for the world (foreign) interest rate, terms-of-trade and potential output can be summarized as

$$(32) \quad (1 + i_t^*) = (1 + i_{t-1}^*)^{\rho^i} \exp(\varepsilon_t^{i^*})$$

$$(33) \quad P_{Tt}^x = P_{Tt-1}^x \exp(\varepsilon_t^{P_T^x})$$

$$(34) \quad z_t = z_{t-1} \exp(\varepsilon_t^z)$$

with $E_t \varepsilon_{t+1}^u = 0$, $E_t \varepsilon_{t+1}^u \varepsilon_{t+1}^{u'} = \Sigma$ where $u = i^*, P_T^x, z$ where ε_t^u are iid.

5.3 Model Parameterization

The model is solved numerically¹⁸ and the parameter choices for the model are summarized in Table 1. By following the business cycle literature, the discount rate β is set at 0.99 and the marginal disutility of work effort h is set at 3. The price elasticity between nontraded goods or the steady-state markup μ is set at 1.2. As it is now common in the literature using Calvo pricing, the probability of price non-adjustment ϕ is set at 0.75. In other words, this implies that the average frequency of price adjustment is four quarters. The elasticity of intertemporal substitution σ is set at 1/4, whereas the elasticity of intratemporal substitution θ is set at 1/6. This assumes that the intertemporal elasticity dominates intratemporal elasticity of substitution. Following Soto (2003), these

¹⁸ For the numerical solution of the model, we modify Uhlig's MATLAB program. The program is implemented using the methods of undetermined coefficients. For details of the program and the methodology, please refer to Uhlig (1997).

values are not set based on any estimation but are arbitrary¹⁹. Degree of openness is allowed to vary from completely closed to completely open. This implies that $\gamma \in (0,1)$.

As to the monetary policy rule parameters, we follow the benchmark values in Monacelli (2004), where ω_π is set to 1.5, ω_y is set to 0 and $\omega_e \in (0,1)$. To calibrate the sources of stochastic volatility, we assume US interest rate is the driving force describing the world (nominal and real) interest rate and the world price is constant. As a result, by following from Monacelli (2004), ρ^{i^*} is 0.8 and $\sigma_{\epsilon^{i^*}}$ is .01379. Following Mendoza's (1995) study on developing countries, the mean serial correlation of the terms-of-trade ρ^{P_T} equals to 0.414 and the standard deviation $\sigma_{\epsilon^{P_T}}$ equals to 0.1177. Since the potential output is nonobservable, the serial correlation of the potential output ρ^z and the standard deviation σ_z is arbitrarily fixed at 0.5 and 1 respectively. As the study only concentrates on the effect of terms-of-trade shock, the results from other shocks are not reported.

¹⁹ Since the goal is not to address the quantitative results about the response of the trade balance and the current account, arbitrarily select the elasticities of intertemporal and intratemporal substitution will not have significant influence on the results of the analysis. As in Lane and Milesi-Ferretti (2004) and Chia and Alba (2005), when the elasticity of intratemporal substitution is relatively large compared to the elasticity of intertemporal substitution, traded and nontraded goods are close substitutes.

Table 1 Calibration of model

Parameter	Definition and Description	Value
θ	Intratemporal elasticity of substitution	1/4
σ	Intertemporal elasticity of substitution	1/6
ϕ	Probability of price non-adjustment	0.75
γ	Degree of openness	0.5
λ	$(1-\phi)(1-\beta\phi)/\phi$	0.0858
β	Discount rate	0.99
μ	Elasticity of substitution between nontradables	1.2
h	Intertemporal elasticity of labour supply	3
ψ	Elasticity of net foreign asset to interest differentials	0.015
χ	Interest smoothing parameter	0.5
ρ^{i^*}	Autocorrelation of foreign nominal interest rate	0.8
$\sigma_{\varepsilon^{i^*}}$	Standard deviation of foreign nominal interest rate	1.379
ρ^{p_T}	Autocorrelation of terms-of-trade	0.414
$\sigma_{\varepsilon^{p_T}}$	Standard deviation of terms-of-trade	11.77
ρ^z	Autocorrelation of potential output	0.5
σ_z	Standard deviation of potential output	1
ω_e	Responsiveness of monetary policy to exchange rate	0.25 and 0.99
ω_π	Responsiveness of monetary policy to inflation	1.5
ω_y	Responsiveness of monetary policy to output	0

5.4. The Volatility of the Output, the Real Exchange Rate and the Price Level

We conduct an experiment to investigate whether the baseline model illustrated above can replicate the quantitative evidence reported in Broda (2004). To characterize a fixed (flexible) exchange rate regime, we let ω_e approach one (zero). The benchmark calibration described above permits us to choose $\omega_e = 0.99$ for fixed exchange rate regime and $\omega_e = 0.25$ for a more flexible exchange rate regime. We then investigate whether the model described is able to generate similar volatility in output, real exchange rate and price level as documented by Broda.

Figures 1a and 1b illustrate the effect of a negative shock to the terms-of-trade. Suppose there is a reduction in export demand that leads to a deteriorating terms-of-trade. This results in a nominal depreciation of domestic currency. Since traded and nontraded goods are assumed to be close substitutes, the depreciation of domestic currency induces a switch in consumption from the consumption of tradable to the consumption of nontradables. This substitution effect causes an increase in the price of nontradables. The degree of change in price of nontradables during the period of shock depends on two factors. First, with the same degree of nominal price rigidity, under fixed exchange rate regime, as nominal exchange rate is not allowed to respond much, price of nontradables jumps by more compared to the one under flexible exchange rate regime. Second, under both exchange rate regimes, when the degree of nominal rigidity is low and prices are allowed to adjust freely, the jump in the price of nontradables is therefore larger. Additionally, from the figures, overshooting in nominal and real exchange rates is observed as the substitution effect takes place before the income effect. The size of nominal depreciation during the period of shock is larger under flexible than fixed. Over time, when income effect starts to dominate (as a result of lower purchasing power), nominal exchange rate appreciates, so does real exchange rate. It is also noted from the figures that the speed of adjustment in real exchange rate is a lot faster under flexible exchange rate regime.

5.4.1 Sensitivity Analysis: Different Degree of Rigidities in Nominal Exchange Rate

In this section, to investigate whether the model illustrated is able to replicate the empirical evidence reported by Broda (2004) and following the method of Monacelli (2004), the exercise then consists of checking whether the model is able to generate

similar volatility for a few key variables such as price of nontradables, price, nominal and real exchange rates, bonds, output and consumption. Therefore to study the volatility of these variables, we define volatility as the standard deviations of these variables. Without shock in terms-of-trade, all variables take on the values of their respective steady states. Table 2 and Figure 2 summarize the standard deviations of key macroeconomic variables with different degrees of rigidities in nominal exchange rate when the model is driven by the terms-of-trade shock.

Table 2 Statistics for the calibrated economy with different degrees of rigidities in nominal exchange rate

Variable	Standard Deviation HP-Filtered			
	$\omega_e = 0.25$	$\omega_e = 0.50$	$\omega_e = 0.75$	$\omega_e = 0.99$
Price of nontradables, P_N	0.311	0.446	0.503	0.531
Price, P	1.020	0.804	0.701	0.647
Nominal exchange rate, P_T	1.055	0.420	0.167	0.007
Real exchange rate, q	0.627	0.384	0.300	0.266
Bonds, B	11.474	12.638	13.275	13.619
Nontradable output, y_N	2.824	3.713	4.046	4.225
Consumption, C	0.642	0.778	0.820	0.602

Notes: Standard deviations are obtained from Hodrick-Prescott filtered data. ω_e shows the responsiveness of monetary policy to exchange rate. The higher the value of ω_e , the more responsive is the monetary policy to exchange rate implying the more rigid the exchange rate regime.

Several interesting results emerge. First, under a flexible exchange rate regime, the real nontradable output has a smaller fluctuation when countries are hit by terms-of-trade shock whereas the price level, the nominal and the real exchange rates have larger fluctuations. On the other hand, under a fixed exchange rate regime, the real nontradable output tends to fluctuate more whereas the price level, the nominal and the real exchange rates have smaller fluctuations. These observations are consistent with Broda (2004) and Mussa (1986). Second, in moving from fixed to flexible, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate.

This observation implies that nominal and real exchange rates are strongly correlated. Countries, moving from fixed to floating exchange rate regime, will experience a dramatic rise in the volatility of the real exchange rate. The correlation between nominal and real exchange rates is consistent with the Mussa's (1986) facts. Monacelli (2004) also shows that this result is robust to other types of shocks such productivity, preference, world interest rate and world demand shocks. Third, small open economies that peg their exchange rates achieve lower fluctuation in price than those whose exchange rates float. Fourth, the volatility of the holding of net foreign assets is always the largest in all types of exchange rate regimes but this fluctuation tends to be smaller under a more flexible exchange rate regime.

Figure 2 Variability of some macroeconomic variables

5.4.2 Sensitivity Analysis: Different Degrees of Price Rigidities

We address the role of price rigidities under two exchange rate regimes: the flexible vs. the fixed exchange rate. We set the probability of price non-adjustment ϕ , at 0.25, 0.50 and 0.75. When $\phi = 0.25$, $\phi = 0.50$ and $\phi = 0.75$, prices completely adjust after approximately 1.3 quarters, 2 quarters and 4 quarters respectively. The simulation results are summarized in Table 3. Despite the type of regime adopted by a small open economy, the volatility of the nontradable output increases when the probability of non-price adjustment increases from 0.25 (flexible prices) to 0.75 (rigid prices). This is particularly true under the fixed exchange rate regime. This result supports the conventional wisdom that real output, after experiencing a specific type of real shock, should have smoother responses if the price adjustments to shocks are quicker.

Table 3 Statistics for the calibrated economy with different degrees of price rigidities

Variables	Percent of Standard Deviation (HP-Filtered)					
	$\phi = 0.25$		$\phi = 0.50$		$\phi = 0.75$	
	Fixed	Float	Fixed	Float	Fixed	Float
Price of nontradables, P_N	3.007	2.269	1.592	1.080	0.531	0.311
Price, P	0.638	1.131	0.639	1.071	0.647	1.020
Nominal exchange rate, P_T	0.008	1.174	0.008	1.108	0.007	1.055
Real exchange rate, q	1.506	1.542	0.798	0.973	0.264	0.627
Bonds, B	13.679	11.466	13.649	11.469	13.619	11.474
Nontradable output, y_N	3.445	2.757	3.801	2.684	4.225	2.824
Consumption, C	0.908	0.684	0.866	0.659	0.840	0.642

Note: ϕ shows the probability of non-price adjustment. When ϕ is 0.5, prices completely adjust after 2 quarter and when ϕ is 0.75, prices completely adjust after 4 quarters. In other words, the larger the value of ϕ , the higher the degree of rigidity in prices.

5.4.3 Sensitivity Analysis: Different Degrees of Openness

In this section we test the sensitivity of the predictions of the model to alternative values of a critical parameter – degree of openness. The results are shown in Table 4. A few interesting results stand out. First, when the degree of openness reaches its highest possible value, the real exchange rate is almost twice more volatile under flexible than it is under fixed. Second, both exchange rates - nominal and real - are always more volatile under flexible. Third, nontradable output is always more volatile under fixed than floating exchange rates.

Table 4 Statistics for the calibrated economy with different degrees of openness

Variables	Percent of Standard Deviation (HP-Filtered)					
	$\gamma = 0.25$		$\gamma = 0.50$		$\gamma = 0.75$	
	Fixed	Float	Fixed	Float	Fixed	Float
Price of nontradables, P_N	0.516	0.404	0.531	0.311	0.505	0.307
Price, P	0.302	1.246	0.647	1.020	0.472	1.114
Nominal exchange rate, P_T	0.009	0.760	0.007	1.055	0.007	0.987
Real exchange rate, q	0.388	0.818	0.266	0.627	0.127	0.298
Bonds, B	6.892	8.271	13.619	11.474	8.096	6.416
Nontradable output, y_N	3.833	3.880	4.225	2.824	4.029	3.001
Consumption, C	0.718	0.865	0.840	0.642	0.781	0.684

Note: γ measures the degree of openness where the larger the value of γ , the more open is an economy.

5.5 Conclusions

We examine the link between terms-of-trade shocks and some macroeconomic variables by numerically solving a dynamic stochastic general equilibrium model of a small open economy. The model combines nominal price rigidity under different exchange rate regimes. The numerical solutions are compared with the actual empirical

regularities. In the model, households consume tradable and nontradable goods. The traded sector is viewed as a perfectly competitive market where prices are fully flexible and covered by the law of one price. The nontraded sector, on the other hand, is assumed to be a monopolistic competitive market where prices in this sector are sticky. The economy is small in the sense that it cannot influence the terms-of-trade of the economy.

Generally, the simulations show that the model duplicates many of the stylized facts documented by Broda (2004). First, under a more flexible exchange rate regime, the real nontraded output has smaller fluctuations but the price and real exchange rate have larger fluctuations when countries are hit by terms-of-trade shocks. This result is in favor of Friedman's prediction that short run output responses to shocks are significantly smoother in floats than in pegs. Second, in moving from fixed to flexible, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. This implies that countries, moving from fixed to floating exchange rate regime, will experience a dramatic rise in the volatility of the real exchange rate. Third, the volatility of the holding of net foreign assets is always the largest in all types of exchange rate regimes but this fluctuation tends to be smaller under a more flexible exchange rate regime.

Sensitivity analysis shows that despite the type of regime adopted by a small open economy, the volatility of the nontradable output increases when the probability of non-price adjustment increases. Additionally, despite the degree of openness, volatility of the nontradable output is always higher under fixed than floating exchange rates.

The appealing results obtained from the model suggest other topics for further investigation. The artificial economy and the numerical methods employed here can be used to explore quantitatively the effects of other economic policies implemented in small open economies.

Figure 1a Effects of a negative terms-of-trade shock under fixed exchange rate regime

Figure 1b Effects of a negative terms-of-trade shock under flexible exchange rate regime

Chapter 6

Conclusions and Future Work

Studies and issues related to terms-of-trade shocks have always been an area of great controversy. In this thesis, we have clearly classified these issues into four many categories. These issues are distinct but not unrelated. The first issued is widely known as the Prebisch and Singer hypothesis. Two phenomena were raised. The first phenomenon is that there is an observed unfavorable impact of unrestricted trade on terms-of-trade and current account of developing countries. This unfavorable impact far outweighs any advantages with respect to a more efficient allocation of resources. The second phenomenon mentioned by Prebisch is the current account effects of differences in the income elasticity of demand for different types of goods. Generally, the income elasticity of demand for most primary commodities is lower than that for manufactured commodities. In the two-country, two-good case the lower income elasticity of demand for primary commodities will mean that for a given growth of world income, the current account of primary-producing developing countries will automatically deteriorate vis-à-vis the current account of developed countries producing and exporting industrial goods. The second issue concerns the relationship between terms-of-trade shocks and the current account of an economy. Generally, researchers are keen to investigate on the features of an economy that determine this relationship. The third issue focuses on the role of exchange rate regime in mitigating the effects of terms-of-trade shocks. Most often, merit is attributed to flexible exchange rate regimes for its ability to insulate the economy more effectively against terms-of-trade shocks. The fourth issue concentrates on the long term impact of terms-of-trade shocks on economies with different exchange rate regimes. The

most recent work by Edwards and Levy Yeyati (2005) has studied how the choice of exchange rate mediates the relationship between terms-of-trade and economic growth.

In the thesis, an attempt is made to provide new perspectives to the second and third issues. In contrast to the past studies which often assume flexible-price economies, a newly emerging research on open economy dynamic general equilibrium models that incorporate imperfect competition and nominal rigidity is utilized. By following this new strand of research, the models developed provide some new perspectives which are not obvious in the past literature.

In analyzing the effects of terms-of-trade shocks on the current account balance, we integrate the intertemporal equilibrium framework with nominal price rigidities and imperfect competitive markets to analyze the dynamics of current account arising from terms-of-trade fluctuations. The work contributes to an expanding body of research in international macroeconomics that illustrates how does the terms-of-trade shocks affects the current account and other macroeconomic variables in a small open economy. For instance, in analyzing the effects of terms-of-trade shocks on the current account balance, our study shows results that are consistent with others (Sach, 1981; Obstfeld, 1983; Svensson and Razin, 1983) who argued that an adverse temporary terms-of-trade shocks will worsen the current account balance. In our study, the current account always goes into deficit with a temporary deterioration in terms-of-trade and this result holds regardless of the degree of nominal rigidity. Additionally, we also find a few new outcomes. First, in the presence of nominal rigidities and imperfect competition, a permanent terms-of-trade improvement may cause the current account to move into either direction, surplus or deficit, depends critically on the relative elasticities of intertemporal and intratemporal substitution. Second, the impacts of a terms-of-trade on consumption

and output of nontraded goods in the long run, price of nontraded goods in the long run, overall price in the long run, consumption of traded goods, and consumption and output of nontraded goods in the short run are magnified when the shock is permanent. Finally, when prices are perfectly flexible, the intertemporal Euler equation shows that the optimal consumption growth path is flat. As a result, the holding of net foreign assets remains unchanged even when the terms-of-trade shock is permanent.

In examining the link between the terms-of-trade shocks and other macroeconomic variables under alternative exchange rate regimes we show that our model duplicates and captures many of the stylized facts documented in the literature. First, under a more flexible exchange rate regime, the real nontraded output has smaller fluctuations but the price and real exchange rate have larger fluctuations when countries are hit by terms-of-trade shocks. This result is in favor of Friedman's prediction that short run output responses to shocks are significantly smoother in floats than in pegs. Second, in moving from fixed to flexible, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. This implies that countries, moving from fixed to floating exchange rate regime, will experience dramatic rise in the variability of the real exchange rate. Third, the volatility of the holding of net foreign assets is always the largest in all types of exchange rate regimes but this fluctuation tends to be smaller under a more flexible exchange rate regime. Sensitivity analysis shows that despite the type of regime adopted by a small open economy, the volatility of the nontradable output increases when the probability of non-price adjustment increases.

Based on the results obtained from the thesis, we identify other interesting fields of research for future development. First, while the theory clearly demonstrates the

relationship between the terms-of-trade shock and the current account balance, some evidence on whether there is any empirical support for the existence of a HLM effect is desirable in general, and in particular, we may empirically investigate the response of the current account balance to a terms-of-trade shock on countries with different degree of nominal rigidities. Second, while our model succeeds in duplicating some stylized facts on some macroeconomic variables when an economy is hit by terms-of-trade shock, we assume perfect pass-through. Future work which entertains a variety of assumptions regarding the behavior of international prices will pay additional dividends. Third, the intertemporal models developed in this thesis argue that the results obtained are attributed to ‘nominal rigidities’ and ‘imperfect competition’. However, these two points, though related, are conceptually distinct. It is possible to have imperfect competition without price rigidities and similarly, it is possible to have price rigidities with perfect competition. Richer results may be obtained by alternative modeling methods of imperfect competition (with or without price rigidities). Lastly, our results show that there is non-monotonic effect of openness on some variables. For instance, the volatility of nontradable output and price level appears to be highest under both exchange rate regimes at the intermediate level of trade openness. The non-monotonicity in the relationship among the variables can be further investigated.

Appendix A

Flexible Prices and Perfect Competitive Market

(i) Permanent terms-of-trade shock with perfect price flexibility and perfectly competitive markets

In the absence of nominal rigidities and assume that the markets are perfectly competitive, the model shows that an unanticipated permanent terms-of-trade shock does not have any effect on the current account. This prediction is consistent with the Obstfeld-Svensson-Razin model. When prices are perfectly flexible, Equation (13) $\tilde{C}_{T+1} - \tilde{C}_T = (\sigma - \theta)(\tilde{P}_T - \tilde{P}_{T+1})$ shows that $\tilde{C}_{T+1} = \tilde{C}_T$, since $\tilde{P}_N \neq 0$ and $\tilde{P}_T = \tilde{P}_{T+1} = (1 - \gamma)\tilde{P}_N \neq 0$. By solving this model accordingly, we obtain the following results:

$$(29a) \quad \tilde{C}_N = \hat{C}_N = \tilde{y}_N = \hat{y}_N = \frac{\gamma(\sigma - \theta)}{b_0} \hat{P}_T^x$$

$$(30a) \quad \tilde{C}_T = \hat{C}_T = \hat{P}_T^x$$

and the accumulation of net foreign assets is

$$(34a) \quad \hat{b} = 0$$

where $b_0 = \theta(1 - \gamma) + \sigma(\theta + \gamma) > 0$. It is also noted that when $\sigma > \theta$, the elasticity of intratemporal substitution is low relative to the elasticity of intertemporal substitution which implies that traded and nontraded goods are poor substitutes, a permanent terms-of-trade deterioration has a contractionary effect on the nontraded goods sector and vice versa.

(ii) Temporary terms-of-trade shock with perfect price flexibility and perfectly competitive markets

In this setup, when prices are perfectly flexible and nontraded goods sector is perfectly competitive, a temporary terms-of-trade shock will always deteriorate the current account. Our model shows that

$$(38a) \quad \tilde{C}_T = \hat{C}_T = \frac{r}{1+r} \tilde{P}_T^x$$

and the accumulation of net foreign assets is

$$(42a) \quad \hat{b} = \frac{1}{1+r} \tilde{P}_T^x$$

When there is a temporary adverse terms-of-trade shock, the consumption smoothing behaviour of the individuals induces them to decrease the consumption of traded goods in the short run by less than the amount of the shock. As a result, there is a decumulation of net foreign assets. It should also be noted that in the absence of nominal rigidities, the change in the consumption of traded goods in the short run equals to the change in the consumption of traded goods in the long run.

Appendix B

Mathematical Derivation

Assumptions:

- (a) Importable is consumed but not produced, and the exportable is produced but not consumed.
- (b) Investment is held constant and the capital stock is an endowment which is not affected by the terms-of-trade shocks.
- (c) The economy is small in the sense that it cannot influence the terms-of-trade of the economy.
- (d) We also assume that the output of the traded goods sector is an endowment of the tradable good y_T , which is sold in the world markets at the export price of P_T^x , where P_T^x is measured in units of the imported consumption good and the imported consumption good is used as the numeraire.
- (e) Since consumption of the export goods is assumed to be zero, P_T^x , by definition is the terms-of-trade and is exogenous to the country.

Households

An economy is populated by a continuum of yeoman-farmers along the unit interval $[0,1]$.

The representative agent aims to maximize the intertemporal utility function which is given by:

$$(1) \quad V^j = \sum_{t=0}^{\infty} \beta^t \left[\frac{\sigma}{\sigma-1} C_t^{\frac{\sigma-1}{\sigma}} - \frac{h}{2} y_{Nt}^2(j) \right],$$

The consumption price index is

$$(2) \quad C_t = \left[\gamma^{\frac{1}{\theta}} C_{It}^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{Nt}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}},$$

The consumption-based price index is

$$(3) \quad P_t = \left[\gamma P_{Tt}^{1-\theta} + (1-\gamma) P_{Nt}^{1-\theta} \right]^{\frac{1}{1-\theta}}$$

For (2) and (3), we minimize

$$(3a) \quad X_t = P_{Tt} C_{Tt} + P_{Nt} C_{Nt}$$

w.r.t C_{Tt} and C_{Nt} subject to

$$(3b) \quad \left[\gamma^{\frac{1}{\theta}} C_{Tt}^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{Nt}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} = 1$$

From the Lagrangian,

$$(3c) \quad L = P_{Tt} C_{Tt} + P_{Nt} C_{Nt} - \lambda_t \left[\left(\gamma^{\frac{1}{\theta}} C_{Tt}^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{Nt}^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}} - 1 \right]$$

we get

$$(3c) \quad C_{Tt} = \gamma \left(\frac{P_{Tt}}{\lambda_t} \right)^{-\theta}$$

$$(3d) \quad C_{Nt} = (1-\gamma) \left(\frac{P_{Nt}}{\lambda_t} \right)^{-\theta}$$

and the constraint of (3b). Substitute (3c), (3d) into (3b) gives (2) as $P_t = \lambda_t$.

Agent j is the monopoly producer of variety j of the nontraded good and faces the demand function:

$$(4) \quad y_{Nt}^d(j) = \left[\frac{P_{Nt}(j)}{P_{Nt}} \right]^{-\mu} C_{Nt}^A \quad \mu > 1$$

The nontraded consumption and price can be written as:

$$(5) \quad C_{Nt} = \left[\int_0^1 c_N(m)^{\frac{\mu-1}{\mu}} dm \right]^{\frac{\mu}{\mu-1}}$$

$$(6) \quad P_{Nt} = \left[\int_0^1 p_N(z)^{1-\mu} dz \right]^{\frac{1}{1-\mu}}$$

The flow of budget constraint faced by agent j is

$$(7) \quad P_{Tt} B_{t+1} = (1+r_t) P_{Tt} B_t + p_{Nt}(j) y_{Nt}(j) + P_T^x y_T - P_t C_t,$$

Maximize of (1) subject to (4) and (7). The Lagrangian is

$$L = E_t \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{\sigma}{\sigma-1} C_t^{\frac{\sigma-1}{\sigma}} - \frac{h}{2} y_{Nt}^2(j) \right] - \lambda_t \left[B_{t+1} - (1+r_t) B_t - \frac{P_{Nt} y_{Nt}^{\frac{\mu-1}{\mu}} (C_{Nt}^A)^{\frac{1}{\mu}}}{P_{Tt}} - \frac{P_{Tt}^x y_T}{P_{Tt}} + \frac{P_t C_t}{P_{Tt}} \right] \right\}$$

The first order conditions are

$$(8) \quad E_t \left(\frac{C_{Tt+1}}{C_{Tt}} \right) = \beta^{-\sigma} E_t (1+r_{t+1})^{-\sigma} \left(\frac{P_t/P_{Tt}}{P_{t+1}/P_{Tt+1}} \right)^{\sigma-\theta},$$

$$(9) \quad \frac{C_{Nt}}{C_{Tt}} = \frac{1-\gamma}{\gamma} \left(\frac{P_{Nt}}{P_{Tt}} \right)^{-\theta}, \text{ and}$$

$$(10) \quad y_{Nt}^{\frac{\mu+1}{\mu}} = \left(\frac{\mu-1}{\mu k} \right) \left(\frac{P_{Nt}}{P_t} \right) (C_{Nt}^A)^{\frac{1}{\mu}} C_t^{-\frac{1}{\sigma}},$$

Domestic Firms

When allowed to reset its price, domestic firm j will choose $p_{Nt+k}^{new}(j)$ to maximize:

$$(11) \quad E_t \left\{ \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} [p_{Nt+k}^{new}(j) - MC_{t+k}] y_{Nt+k}(j) \right\},$$

subject to the demand schedule:

$$(12) \quad y_{Nt+k}(j) \leq \left[\frac{p_{Nt+k}^{new}(j)}{P_{Nt+k}} \right]^{-\mu} C_{Nt+k}^A,$$

Note that $\frac{\partial y_{Nt+k}(j)}{\partial p_{Nt}(j)} = -\mu \left(\frac{p_{Nt}(j)}{P_{Nt}} \right)^{-\mu} \frac{1}{p_{Nt}(j)} C_{Nt+k}^A = -\mu \frac{y_{Nt+k}(j)}{p_{Nt}(j)}$

This gives rise to the dynamic mark-up equation:

$$(13) \quad p_{Nt}^{new}(j) = \left(\frac{\mu}{\mu-1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} MC_{t+k} y_{Nt+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} y_{Nt+k}(j) \right\}}.$$

Without rigidity, firm will choose a constant mark-up over marginal cost, i.e. $\phi = 0$ implies:

$$(14) \quad p_{Nt}^{new}(j) = \left(\frac{\mu}{\mu-1} \right) MC_t.$$

Given the pricing rule, in a symmetric equilibrium where the law of large numbers holds, the nontradable aggregate price index evolves according to:

$$(15) \quad P_{Nt} = \left[\beta\phi P_{Nt-1}^{1-\mu} + (1-\beta\phi) (P_{Nt}^{new})^{1-\mu} \right]^{1/(1-\mu)}.$$

International Capital Market

Assume imperfect international capital markets where the interest rate depends on the stock of net foreign debt of the economy. In particular, the interest rate is given by:

$$(16) \quad (1+r_t) = (1+r_t^*) \left(\frac{B_t}{\bar{B}} \right)^\psi,$$

Prices and Real Exchange Rate

The real exchange rate is defined as:

$$(17) \quad q_t = \frac{e_t P_t^*}{P_t}.$$

If (i) the foreign price level is assumed to be given, and (ii) the foreign currency denominated price of tradable is normalized to be one. When the law of one price holds for traded goods, it implies that $q_t = P_{Tt}/P_t$.

Monetary Policy and Exchange Rate Regimes

The following equation describes the target for the nominal interest rate:

$$(18) \quad (1 + \bar{i}_t) = \left(\frac{P_t}{P_{t-1}} \right)^{\omega_\pi} y_{Nt}^{\omega_y} e^{\frac{\omega_\epsilon}{1-\omega_\epsilon}}.$$

The determination of the actual short-run interest rate that accounts for the desire of the monetary authority to smooth changes in the interest rate is:

$$(19) \quad (1 + i_t) = (1 + \bar{i}_t)^{1-\chi} (1 + i_{t-1})^\chi.$$

Steady State Equilibrium

All prices are fully flexible.

All variables are assumed to be constant at the steady state.

Normalize the endowment of the traded good so that the relative price of nontraded goods

in terms of traded goods is unity in the steady state, $(\bar{P}_{N0}/\bar{P}_{T0}) = 1$.

At the initial steady state, the terms-of-trade is one, $\bar{P}_{T0}^x = 1$.

Then, from (8),

$$(20) \quad \bar{r}_0 = \beta^{-1} - 1.$$

Given the stock of minimum foreign debt $\tilde{B}$,

$$(21) \quad \bar{B}_0 = \left(\frac{1+r}{1+r^*} \right)^{\frac{1}{\psi}} \tilde{B}$$

If we assume $r = r^*$, then $B = \tilde{B}$. From equation (7),

$$(22) \quad \bar{C}_{T0} = r\bar{B}_0 + \bar{y}_{T0}.$$

From (9),

$$(23a) \quad \bar{y}_{N0} = \bar{C}_{N0} = (1-\gamma)\bar{C}_0 \text{ and } \bar{C}_{N0} = (1-\gamma)\bar{C}_{T0}/\gamma.$$

From (10),

$$(23b) \quad \bar{y}_{N0}^{\frac{\mu+1}{\mu}} = \left(\frac{\mu-1}{\mu h} \right) \bar{C}_0^{-\frac{1}{\sigma}} \bar{C}_{N0}^{\frac{1}{\mu}}$$

Substitute (23a) into (23b), the steady state consumption and production of nontraded goods is

$$(23) \quad \bar{y}_{N0} = \bar{C}_{N0} = \left(\frac{\mu - 1}{\mu k} \right)^{\frac{\sigma}{1+\sigma}} (1 - \gamma)^{\frac{1}{1+\sigma}}.$$

The Log-Linearized Version of FOC and Other Conditions

The model is solved by taking a log-linear approximation around the steady state. We let a variable with hat, $\hat{X}$ to denote the log-deviation of a variable from the steady state and a variable with bar, $\bar{X}$ to denote a variable at steady state.

Aggregate supply and inflation

$\hat{x}_{Nt}$ is the output gap in the nontraded sector which is measured as the deviation between the stochastic component of current output and the potential output. The inflation of nontraded goods is

$$(24) \quad \hat{\pi}_{Nt} = \lambda \hat{x}_{Nt} + E_t \hat{\pi}_{Nt+1},$$

$$\text{where } \lambda = \frac{(1 - \phi)(1 - \beta\phi)}{\phi}.$$

Aggregate demand

By taking a log-linear approximation of (8) and (17), the following equation can be obtained:

$$(25) \quad E_t (\hat{C}_{Tt} - \hat{C}_{Tt+1}) = E_t [-\sigma \hat{r}_t + (\theta - \sigma)(\hat{q}_{t+1} - \hat{q}_t)].$$

Note that, from (17)

$$(25a) \quad \hat{q}_t = \hat{P}_{Tt} - \hat{P}_t$$

From (9),

$$(25b) \quad \hat{C}_{Tt} - \hat{C}_{Nt} = -\theta \hat{P}_{Tt} + \theta \hat{P}_{Nt}$$

From (3),

$$(25c) \quad \hat{P}_t = \gamma \hat{P}_{Tt} + (1 - \gamma) \hat{P}_{Nt}$$

From (25a), (25b) and (25c), we have

$$(25d) \quad \hat{C}_{Nt} = \frac{\theta}{1 - \gamma} \hat{q}_t + \hat{C}_{Tt}$$

$$(25e) \quad \hat{y}_{Nt} - \hat{z}_{Nt} = \frac{\theta}{1 - \gamma} \hat{q}_t + \hat{C}_{Tt} - \hat{z}_{Nt}$$

If $\hat{x}_{Nt} = \hat{y}_{Nt} - \hat{z}_{Nt}$, then an expression that relates the output gap in the nontraded sector with the real exchange rate and the consumption of traded goods is derived as

$$(26) \quad \hat{x}_{Nt} = \frac{\theta}{1 - \gamma} \hat{q}_t + \hat{C}_{Tt} - \hat{z}_{Nt},$$

where the last term denotes the potential output which is assumed to follow a stationary stochastic process.

Real interest rate and current account

The log-deviation of (16) gives

$$(27) \quad \hat{r}_t = \hat{r}_t^* + \psi \hat{B}_t.$$

Using equation (7), the linear expression of the stock of foreign assets is:

$$(28) \quad \hat{B}_{t+1} = (1 + \bar{r}_0) (\hat{r}_t + \hat{B}_t) - \frac{\bar{C}_{T0}}{\bar{B}_0} \hat{C}_t + \frac{\bar{y}_{T0}}{\bar{B}_0} (\hat{P}_{Tt}^x - \hat{P}_{Tt})$$

Since $\bar{y}_{N0} = \bar{C}_{N0}$, $\bar{P}_{T0} = 1$, $\bar{P}_{N0} = 1$, $\bar{P}_{T0}^x = 1$, $\bar{C}_{T0} = \gamma \bar{C}_0$ and $\bar{C}_0 = \frac{1}{\gamma} \bar{C}_{T0}$.

Uncovered interest parity condition with nominal and real interest rates

The uncovered interest parity defines a linear expression for the exchange rate which can be expressed as:

$$(29) \quad \hat{i}_t = \hat{i}_t^* + E_t(\hat{e}_{t+1} - \hat{e}_t)$$

where $\hat{i}_t = \log(1 + i_t / 1 + \bar{i})$.

Similarly, the relationship between the nominal interest rate and real exchange rate can be shown as

$$(30) \quad \hat{r}_t = \hat{i}_t + E_t(\hat{P}_t - \hat{P}_{t+1})$$

Monetary policy rule

Following Monacelli (2004), the target for nominal interest rate is

$$(31a) \quad (1 + \bar{i}_t) = \left(\frac{P_t}{P_{t-1}} \right)^{\omega_\pi} Y_{Nt}^{\omega_y} e_t^{\frac{\omega_e}{1-\omega_e}}$$

By taking a log-linear approximation of (19) and (31a)

$$(31) \quad \hat{i}_t = \tilde{\omega}_\pi \hat{\pi}_t + \tilde{\omega}_y \hat{y}_{Nt} + \tilde{\omega}_e \hat{e}_t + \chi \hat{i}_{t-1}$$

where $\tilde{\omega}_\pi \equiv (1 - \chi)\omega_\pi$, $\tilde{\omega}_y \equiv (1 - \chi)\omega_y$, and $\tilde{\omega}_e \equiv (1 - \chi)(\omega_e / 1 - \omega_e)$. Following Monacelli (2004), this specification allows us to approximate the systematic behavior of monetary policy under the floating and the fixed exchange rate regimes. In particular, $\omega_e = 0$ describes the behavior of the monetary authority practicing the floating exchange rate regime; whereas $\omega_e \in (0, 1]$ approximates the behavior of the monetary authority practicing policies ranging from managed to the fixed exchange rate regimes.

Exogenous stochastic process

The stochastic processes for the world (foreign) interest rate, terms-of-trade and potential output can be summarized as

$$(32) \quad (1 + i_t^*) = (1 + i_{t-1}^*)^{\rho^{i^*}} \exp(\varepsilon_t^{i^*})$$

$$(33) \quad P_t^* = P_{t-1}^* \rho^{p^*} \exp(\varepsilon_t^{p^*})$$

$$(34) \quad z_t = z_{t-1} \rho^z \exp(\varepsilon_t^z)$$

with $E_t \varepsilon_{t+1}^u = 0$, $E_t \varepsilon_{t+1}^u \varepsilon_{t+1}^{u'} = \Sigma$ where $u = i^*$, P_T^x , z where ε_t^u are iid with zero means.

Appendix C

MATLAB Codes

```
% First, parameters are set and the steady state is calculated. Next, the matrices are
% declared. In the last line, the model is also solved and analyzed by calling DO_IT.M
% Copyright: H. Uhlig. Feel free to copy, modify and use at your own risk.
% However, you are not allowed to sell this software or otherwise impinge
% on its free distribution.
% Adapted by W. M. Chia.
```

```
disp('          Terms-of-trade Shocks under Fixed Exchange Rate Regime');
disp('          W.M. Chia & Joseph. D. Alba');
```

```
disp('Hit any key when ready...');
pause;
```

```
% Setting parameters:
```

```
theta    = 1/4;    % Intratemporal elasticity of substitution
sigma    = 1/6;    % Intertemporal elasticity of substitution
gamma    = 0.50;   % Degree of openness
phi      = 0.75;   % Probability that firms do not change prices
beta     = 0.99;   % Discount rate
psi      = 0.414;  % Autocorrelation of ToT shock
P_bar    = 1;      % Steady state price
PN_bar   = 1;      % Steady state nontradable price
C_bar    = 1;      % Steady state consumption
mu       = 1.2;    % Elasticity of substitution between nontradables
kappa    = 3;      % Intertemporal elasticity of labour supply
sigma_eps = 11.77; % Standard deviation of ToT shock. Units: Percent.
sigma_nu  = 0.75;  % Standard deviation of foreign interest rate
eta      = 0.015;  % Elasticity of net asset position to interest rate differential
psi_nu   = 0.8;    % Autocorrelation of foreign nominal interest rate
omega    = -2.66;  % Ratio of stock of foreign liabilities to total output
chi      = 0.5;    % Interest rate smoothing parameter
we       = 0.25;   % Flexible exchange rate regime
wpi      = 1.5;    % Response of interest rate to inflation
wy       = 0.1;    % Response of interest rate to output
psi_z    = 0.5;    % Autocorrelation of potential output shock
sigma_z   = 1;     % Standard deviation of potential output shock
```

```
% Calculating the steady state:
```

```
rate     = (1-beta)/beta;
CT_bar   = gamma*C_bar;
CN_bar   = (1-gamma)*CT_bar/gamma;
CN_bar   = (1-gamma)*C_bar;
YN_bar   = ((mu-1)/(mu*kappa))^(sigma/(1+sigma))*(1-gamma)^(1/(1+sigma));
B_bar    = omega*(1+omega*gamma)*YN_bar/(1-gamma);
YT_bar   = gamma*YN_bar/(1-gamma)-rate*B_bar;
CT_bar   = rate*B_bar+YT_bar;
```

```

we_bar = (1-chi)*we/(1-we);
wpi_bar = (1-chi)*wpi;
wy_bar = (1-chi)*wy;
lambda = (1-phi)*(1-beta*phi)/phi;

```

```
% Declaring the matrices.
```

```

VARNAMES = ['price of nontradables',
            'nominal interest',
            'price',
            'bond',
            'price of tradables',
            'tradables',
            'nontradables',
            'nontradable output',
            'inflation',
            'real interest',
            'output gap',
            'consumption',
            'real exchange rate',
            'tot',
            'foreign nominal interest',
            'potential output'];

```

```
% Translating into coefficient matrices.
```

```
% The equations are, conveniently ordered:
```

```

% 1) 0 = E_t{-sigma*r(t)+(theta-sigma)[Q(t+1)-Q(t)]+[CT(t+1)-CT(t)]}
% 2) 0 = E_t{lambda*XN(t)+PN(t+1)-2PN(t)+PN(t-1)}
% 3) 0 = E_t{i(t)-r(t)-[P(t+1)-P(t)]}
% 4) 0 = E_t{i(t)-if(t)-[e(t+1)-e(t)]}
% 5) 0 = E_t{(1+rate)[B(t)+r(t)]-CT_bar/B_bar*C(t)+YT_bar/B_bar*[TOT(t)-PT(t)]-B(t+1)}
% 6) 0 = wpi_bar*[P(t)-P(t-1)]+wy_bar*YN(t)+we_bar*PT(t)+chi*i(t-1)-i(t)
% 7) 0 = theta*Q(t)/(1-gamma)+CT(t)-ZN(t)-XN(t)
% 8) 0 = -CT(t)+theta*P(t)+C(t)-theta*PT(t)
% 9) 0 = PN(t)-P(t)-C(t)/sigma-YN(t)
% 10) 0 = gamma*CT(t)+(1-gamma)*CN(t)-C(t)
% 11) 0 = (1-gamma)*PN(t)-(1-gamma)*P(t)-gamma*Q(t)
% 12) 0 = if(t)-r(t)+nu*B(t)
% 13) 0 = P(t)-P(t-1)-pi(t)

```

```
% 14) TOT(t+1) = psi*TOT(t)+TOTepsilon(t+1)
```

```
% 15) if(t+1) = tau*if(t)+ifepsilon(t+1)
```

```
% 16) z(t+1) = psi_z*z(t)+zepsilon(t+1)
```

```
% CHECK: 16 equations, 16 variables
```

```

% for PN(t), i(t), P(t), B(t), PT(t) :
AA = [ 0, -1, wpi_bar, 0, we_bar
      0, 0, 0, 0, 0
      0, 0, theta, 0, -theta
      1, 0, -1, 0, 0

```

```

0,      0,      0,      0,      0
(1-gamma), 0,      0,      0,      -1+gamma
0,      0,      0,      eta,      0
0,      0,      1,      0,      0 ];

% for PN(t-1), i(t-1), P(t-1), B(t-1), PT(t-1) :
BB = [ 0,      chi,      -wpi_bar,      0,      0
0,      0,      0,      0,      0
0,      0,      0,      0,      0
0,      0,      0,      0,      0
0,      0,      0,      0,      0
0,      0,      0,      0,      0
0,      0,      0,      0,      0
0,      0,      -1,      0,      0 ];

%Order: CT(t) CN(t) YN(t) pi(t) r(t) XN(t) C(t) Q(t)
CC = [ 0,      0,      wy_bar,      0,      0,      0,      0,      0
1,      0,      0,      0,      0,      -1,      0,      theta/(1-gamma)
-1,      0,      0,      0,      0,      0,      1,      0
0,      0,      -1,      0,      0,      0,      -1/sigma,      0
gamma,      (1-gamma),      0,      0,      0,      0,      -1,      0
0,      0,      0,      0,      0,      0,      0,      1
0,      0,      0,      0,      1,      0,      0,      0
0,      0,      0,      -1,      0,      0,      0,      0 ];

%Order: TOT(t) if(t) z(t)
DD = [ 0,      0,      0
0,      0,      -1
0,      0,      0
0,      0,      0
0,      0,      0
0,      0,      0
0,      -1,      0
0,      0,      0 ];

%order: PN(t+1), i(t+1), P(t+1), B(t+1), PT(t+1)
FF = [ 0,      0,      0,      0,      0
1,      0,      0,      0,      0
0,      0,      -1,      0,      0
0,      0,      0,      0,      1
0,      0,      0,      -1,      0 ];

%order: PN(t), i(t), P(t), B(t), PT(t)
GG = [ 0,      0,      0,      0,      0
-2,      0,      0,      0,      0
0,      1,      1,      0,      0
0,      -1,      0,      0,      -1
0,      0,      0,      (1+rate),      -YT_bar/B_bar ];

%order:PN(t-1), i(t-1), P(t-1), B(t-1), PT(t-1)
HH = [ 0,      0,      0,      0,      0
1,      0,      0,      0,      0
0,      0,      0,      0,      0

```



```

0,      0,      0,      0,      0
0,      0,      0,      0,      0 ];

%order: CT(t+1)   CN(t+1)   YN(t+1)  Pi(t+1)  r(t+1)   XN(t+1)  C(t+1)  Q(t+1)
JJ = [ 1,        0,        0,        0,        -sigma,   0,        0,        theta-sigma
0,        0,        0,        0,        0,        0,        0,        0
0,        0,        0,        0,        0,        0,        0,        0
0,        0,        0,        0,        0,        0,        0,        0
0,        0,        0,        0,        0,        0,        0,        0 ];

%order: CT(t)     CN(t)     YN(t)     Pi(t)     r(t)     XN(t)     C(t)     Q(t)
KK = [ -1,        0,        0,        0,        0,        0,        0,        sigma-theta
0,        0,        0,        0,        0,        lambda,   0,        0
0,        0,        0,        0,        -1,        0,        0,        0
0,        0,        0,        0,        0,        0,        0,        0
0,        0,        0,        0,        1+rate, 0,        -CT_bar/B_bar, 0 ];

LL = [ 0, 0, 0
0, 0, 0
0, 0, 0
0, 0, 0
0, 0, 0 ];

MM = [ 0,      0, 0
0,      0, 0
0,      0, 0
0,      1, 0
-YT_bar/B_bar, 0, 0 ];

NN = [psi      0      0
0      psi_nu  0
0      0      psi_z];

Sigma = [ sigma_eps^2, 0, 0
0,      sigma_nu^2, 0
0,      0,      sigma_z^2 ];

% Setting the options:

[l_equ,m_states] = size(AA);
[l_equ,n_endog ] = size(CC);
[l_equ,k_exog  ] = size(DD);

PERIOD      = 4; % number of periods per year, i.e. 12 for monthly, 4 for quarterly
GNP_INDEX   = 3; % Index of output among the variables selected for HP filter
IMP_SELECT  = [1:7]; % a vector containing the indices of the variables to be plotted
DO_SIMUL    = 1; % Calculates simulations
SIM_LENGTH  = 150;
DO_MOMENTS  = 1; % Calculates moments based on frequency-domain methods
HP_SELECT   = 1:(m_states+n_endog+k_exog); % Selecting the variables for the HP Filter
calcs.
% DO_COLOR_PRINT = 1;

```

% Starting the calculations:

do_it;

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