Three Essays in International Macroeconomics and Macroeconomics

by

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To my parents and sister

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Chapter I

Introduction

This dissertation consists of three essays studying various issues in international macroeconomics and macroeconomics.

The second chapter investigates the dynamics of the relative price of nontradable to tradable goods at business cycle frequencies and finds that the relative price displays unusual dynamics along business cycles: First, the relative price of nontradable goods displays an S-shaped cross correlation structure with GDP. The cross correlation structure implies that the relative price of nontradable goods tends to be negatively correlated with past GDP but positively correlated with future GDP. Second, the relative price is highly persistent but its volatility is quite modest.

Since the S-shaped cross correlation structure is hard to reconcile with existing models, this paper introduces heterogeneity in price stickiness into a standard NOEM (New Open Economy Macroeconomic) model to explain the regularity. As the estimates based on recent micro evidence on heterogeneity in price stickiness suggest, price stickiness in the nontradable sectors is assume to be twice as large as in the tradable sectors.

Simulations of the model clearly show that heterogeneity in price stickiness is the primary force of the dynamics of the relative price of nontradable goods at business cycle frequencies. When the model considers the heterogeneity, it can successfully replicate the S-shaped cross correlation structure and generate similar magnitudes of volatility and persistence of the relative price as observed in data. However, the heterogeneity does not help improve the results in the existing literature with regard to the real exchange rate puzzles. The volatility and persistence of the real exchange rate are virtually the same whether the heterogeneity is considered or not.

In the third chapter, the implications of the presence of rule-of-thumb consumers on international business cycles are examined, particularly with respect to international business cycle puzzles. For the purpose, the chapter introduces rule-of-thumb consumers into an otherwise standard international real business cycle model and studies its implications.

The main finding of the third chapter is that independent of restrictions on the types of available assets for international risk sharing, the introduction of rule-of-thumb consumers can contribute to explaining the consumption correlation puzzle. In addition, the effects of introducing rule-of-thumb consumers depend on the specification of the productivity process. Specifically, the effects are more salient when the process is less persistent but more spill-over.

The fourth chapter attempts to explain theoretically the dynamic properties of labor share. According to recent empirical studies, fluctuations of factor shares are quantitatively considerable and have systematic relationships with other major macroeconomic variables. However, the empirical dynamics of factor shares seem to be at odds with standard business cycle models, which imply constant factor shares.

To address the gap between empirical evidence and theory, the chapter develops a theoretical model in which laborers and entrepreneurs can share their income risks via an implicit labor contract and shows that the model can replicate many of the dynamics of labor share, including the ‘overshooting’ property. This result implies that risk-sharing between laborers and entrepreneurs may be one of the primary forces determining the dynamics of labor share at business cycle frequencies and that the risk-sharing mechanism can serve as a building block to model the dynamics of labor share.

Chapter II

Dynamics of relative price of nontradable goods and heterogeneity in price stickiness

2.1 Introduction

Since Mussa's classical work (1986), explaining the volatility and persistence of real exchange rates has been one of the biggest challenges in international macroeconomics. There has been a long lasting debate on whether fluctuations in real exchange rates are driven mainly by movements in the relative price of tradable goods across countries, or by fluctuations in the relative price of nontradable to tradable goods. However, international macroeconomists have yet to reach a consensus on the main source of real exchange rate movements.

For instance, Engel (1999) and Chari, Kehoe, and Mcgrattan (2002) provide some evidence that almost all fluctuations of real exchange rates in developed countries can be attributed to changes in the relative price of tradable goods across countries, and, based on those observations, conclude that abstracting from the relative price of nontradable to tradable goods in understanding real exchange rate fluctuations is innocuous. Meanwhile, Burstein, Eichenbaum, and Rebelo (2006) and Betts and Kehoe (2006) show that the relative price of nontradable to tradable goods can explain a significant portion of real exchange rate movements depending on measures of the relative price and bilateral trade relationship. They argue that it is too-hasty a conclusion that we can discard the relative price as one of major sources of real exchange rate fluctuations.

From this perspective, it is still worth investigating further the relative price of nontradable goods to improve our understanding of real exchange rate movements. Reflecting it, there has been accumulated a huge body of literature which examines the relative price of nontradable goods and its implications on real exchange rate movements, both theoretically and empirically. However, most of the previous studies have concentrated on analyzing the relative price of nontradable goods with regard to its long run implications (the famous Balassa-Samuelson model).[1]

In contrast, surprisingly, only little attention has been paid to the dynamic properties of the relative price of nontradable goods at *business cycle frequencies*. Burstein, Eichenbaum, and Rebelo (2005) and Stockman and Tesar (1995) appear to be the only noteworthy exceptions. The former emphasizes the importance of the sluggish adjustment of nontradable good prices in understanding real exchange rate movements after large devaluations in developing countries, while the latter studies the relationship between the relative price and relative quantity of tradable and nontradable goods at business cycle frequencies. However, even though those studies provide valuable information on movements of the relative price of nontradable goods, only little seem to be known about its dynamics.

Hence, this paper focuses on the *dynamics* of the relative price of nontradable to tradable goods specifically at *business cycle frequencies*. At first, this paper tries to establish empirical regularities of the relative price of nontradable to tradable goods and then proposes a model with a new feature to explain some of these regularities which seem to be at odds with existing models. I then investigate the implications

[1] Asea and Mendoza (1994), Gregorio, Giovannini, and Wolf (1994), and Canzoneri, Cumby, and Diba (1999) can be counted as typical examples .

of the model with regard to the real exchange rate puzzles (the famous volatility and persistence puzzles).

To investigate the relative price of nontradable goods empirically, a number of advanced economies (U.S., Japan, Canada, France, German, Italy, and U.K.) are considered. As is well known among international macroeconomists, there is controversy as to the proper measurement of tradable and nontradable good prices, because these prices do not exist as ready to use. However, since there is no ideal established way of measuring those prices, this paper simply follows conventions in the existing literature and uses three different data sets to measure tradable and nontradable good prices. The first one is the same data set used in Engel (1999). The second consists of more disaggregated CPI series, which come from different sources in different countries. The last one combines CPI and PPI series.

The empirical findings of this paper can be summarized as follows: First, the relative price of nontradable goods displays an interesting dynamics at business cycle frequencies. It shows an S-shaped cross correlation structure with GDP, although there are some cross-country variations. In other words, the relative price tends to be negatively correlated with lagged GDP and positively correlated with future GDP. Second, the relative price is highly persistent but its volatility is quite low.

Some of the empirical regularities discussed above seem to be at odds with standard international macroeconomic models. Specifically, the S-shaped cross correlation structure of the relative price with GDP seems to be hard to reconcile with existing models. Hence, this paper introduces heterogeneity in price stickiness into a standard international monetary model to explain the regularity based on recent micro evidence on heterogenous price stickiness across sectors.

Results from simulations are as follows: First, only when heterogeneity in price stickiness is incorporated does the model successfully replicate the empirical regularities of the relative price of nontradable goods. In other words, only with heterogeneity can the model generate the S-shaped cross correlation structure and similar magnitudes of volatility and persistence of the relative price as observed in data. Based on this, it is clear that heterogeneous price stickiness is the primary force of the dynamics of the relative price of nontradable goods. Second, with regard to the real exchange rate puzzles, introducing heterogeneity does not improve upon the existing literature at all. The volatility and persistence of real exchange rate are virtually the same irrespective of the existence of heterogeneity.

The remainder of the paper is organized as follows: in the next section, the data sets and main empirical findings are discussed. In section 2.3, the theoretical model is described in detail. The parameterization and the solution method are discussed in section 2.4. Simulations and theoretical findings are presented and discussed in section 2.5. The final section concludes with a brief summary of the major findings and a discussion of possible extension of this paper.

2.2 Data Analysis

In this section, I try to establish empirical regularities of the relative price of nontradable to tradable goods. As discussed above, special attention will be paid to the dynamic properties at business cycle frequencies.

2.2.1 Data

In order to investigate the relative price empirically, it is necessary to measure tradable and nontradable good prices properly since they do not exist as ready to use. However, as well known among international macroeconomists, there is no ideal way available for measuring those prices correctly. Hence, rather than confronting the measurement issue, this paper simply follows the existing approaches from previous studies, while recognizing that each one has its own pros and cons.[2] Based on these approaches, three different data sets are constructed. In each data set, seven advanced economies (U.S., Japan, Canada, France, Germany, Italy, and U.K.) are considered respectively. In what follows, I briefly describe the data sets and explain how to measure both prices.

The first one is the identical data set used in Engel (1999).[3] It originally included six countries but Germany is dropped because it is unclear how the German unification is treated in the data set. For each country, the data set consists of four price indices, which are 'food', 'all goods less food', 'shelter' and 'all service less shelter'. Following Engel (1999), the first two components are classified as tradable goods and the last two as nontradable goods.

The second data set can be regarded as an extended version of the previous one. For each country, the most disaggregated CPI series available are collected. For the U.S., the CPI series are obtained directly from the Bureau of Labor Statistics while for Canada and Japan, similar series are obtained through Datastream. As for the European countries, the Eurostat's nonharmonzied CPI series is used. The same data set is used in Imbs, Mumtaz, Ravn, and Rey (2005). Once again, Germany is dropped because of the same reason stated above. To classify tradable and nontradable goods, this paper simply follows conventions in the literature. Approximately, all goods are considered as tradable goods and services and utilities as nontradable goods.[4]

The third data set is related with the ratio of CPI to PPI, which is another popular way of measuring the relative price. In the data set, CPI and PPI measure

[2]See Engel (1999) and Betts and Kehoe (2006) for details of the debate on measurement problem. Also, see Burstein et al (2006) for an alternative way of measuring the prices.

[3]The data set cannot be extended either in cross section or in time series due to changes in OECD CPI series.

[4]The details of the classification for each country is available upon request.

nontradable and tradable goods prices respectively. All series are drawn from the International Monetary Fund's IFS (International Financial Statistics). Since there is no proper PPI series available, France is excluded from the data set. But, as for Germany, Western Germany is considered because the series for unified Germany begins with the first quarter of 1991.

2.2.2 Empirical regularities

After measuring both prices in each data set, the relative price of nontradable to tradable goods is simply defined as the ratio of nontradable good prices to tradable good prices, P_N/P_T. Since this paper focuses on dynamic properties of the relative price at business cycle frequencies, to extract its business cycle components, the relative price for each country is detrended using Hodrick-Prescott filter on $\log(P_N/P_T)$.

Table 2.1 provides basic summary statistics of the relative prices across countries at business cycle frequencies. As shown in the table, although there are minor variations across data sets and countries, overall, the volatility of the relative prices is quite low. Average standard deviations of the relative prices are only about 1.6%. Given that even a conservative estimate of the standard deviation of real exchange rates is around 4%, the volatility of the relative price seems to be quite low.[5] Meanwhile, the relative price is very persistent uniformly across data sets and countries. Average autocorrelation coefficients amount to approximately 0.8.

However, examining summary statistics is insufficient to identify dynamics of the relative price of nontradable goods. Hence, to further study the dynamic properties of the relative price at business cycle frequencies, I investigate its co-movements with detrended real GDP, similar to Stock and Watson (1999). Following their approach, I examine the cross correlation structure of the relative price with GDP. In other

[5] See Burstein et al (2006). Meanwhile, Chari et al (2002) report that it is around 7-8 %.

Table 2.1: Volatility and persistence of the relative price of nontradable to tradable goods

	Standard Deviation (%)	Standard Deviation relative to GDP	Autocorrelation
Engel (1999)'s data set			
U.S.	1.26	0.75	0.83
Japan	1.97	1.30	0.80
Canada	1.69	1.19	0.89
France	1.24	1.16	0.86
Italy	1.39	1.53	0.73
Average	1.46	1.00	0.82
Disaggregated CPI series data set			
U.S.	1.19	0.71	0.76
Japan	2.07	1.36	0.83
Canada	1.93	1.35	0.87
France	1.45	1.37	0.78
Italy	2.39	2.63	0.65
U.K.	2.16	1.57	0.81
Average	1.61	1.15	0.78
CPI/PPI data set			
U.S.	1.68	1.00	0.86
Japan	2.17	1.43	0.88
Canada	1.96	1.37	0.90
W. German	1.23	0.89	0.86
Italy	1.36	1.49	0.88
U.K.	1.69	1.23	0.69
Average	1.72	1.15	0.85

Note: The statistics are based on logged and H.P. filtered data. The "Average"s are calculated with country size weights for each data set.

words, I calculate correlations of the relative price not only with contemporaneous GDP but also with some lagged and future GDP. The investigation of the cross correlation structure leads to a noticeable regularity.

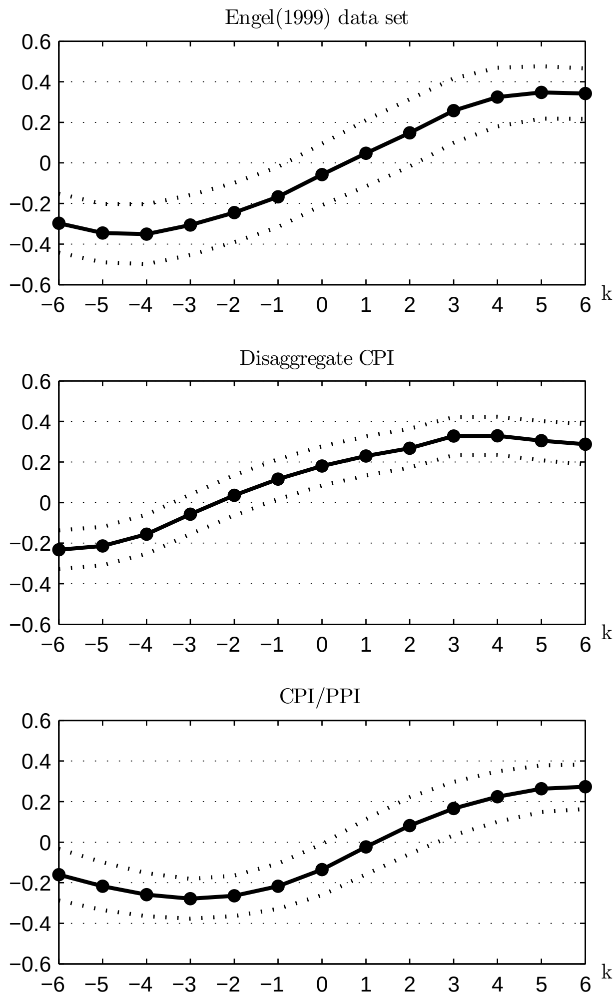
Figures 2.1 through 2.4 summarize the regularity figuratively. Each graph draws a cross correlation structure with a band of one standard error. In each graph, the vertical axis represents the correlation coefficient, $Corr(Y_{t+k}, (P_N/P_T)_t)$, between the relative price and real GDP with some lags or leads. The horizontal axis, k, represents the number of quarters in lag or lead where negative numbers denote lags.

At first, Figure 2.1 draws the average cross correlation structure over countries with a band of average standard error.[6] As the figure clearly shows, the relative price of nontradable goods displays an S-shaped cross correlation structure with real GDP along k.

More specifically, at $k = 0$, the correlation coefficients are quite small and even have different signs depending on which data set is used. This implies that the relative price does not have any clear contemporaneous relationship with GDP. In contrast, the relative price of nontradable goods and GDP shows more notable systematic co-movements with some lead and lag, and the overall pattern is robust to different data sets. The correlation coefficients of the relative price with lagged GDP displays a inverted hump-shaped pattern. More concretely, as the lag gets larger, the relative price becomes more negatively correlated with GDP up to 3 to 5 quarters of lag, at which point the trend is reversed. At the peak, the correlation coefficient amounts to approximately -0.3. On the other hand, with regard to future GDP, the relative price shows a similar correlation pattern but with opposite signs. Put together, the relative price of nontradable goods has an S-shaped cross correlation structure with

[6] Average correlations and average standard errors are respectively calculated with weights of economic size in each data set.

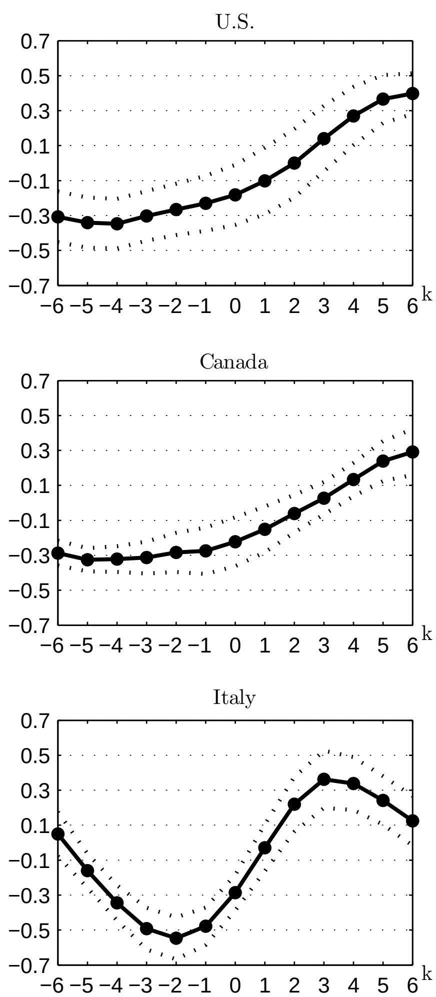
Figure 2.1: Average cross correlation structure ($Corr(Y_{t+k}, (P_N/P_T)_t)$) in advanced economies



Note: All GDPs and relative prices are detrended using H.P. filter. Each figure draws the average of cross correlation structures over countries with a band of one standard error. All standard errors are Newey-West standard errors. Average correlations and standard errors are calculated with weights of economic size.

GDP along lead and lag.

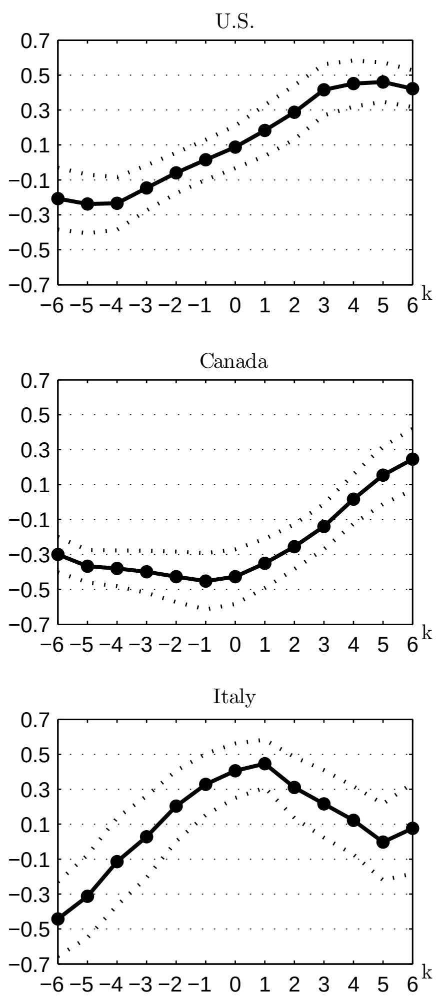
Figure 2.2: Cross country variation: Engel (1999)'s data set



Note: All GDPs and relative prices are detrended using H.P. filter. Each figure draws each country's cross correlation structures over countries with a band of one standard error. All standard errors are Newey-West standard errors.

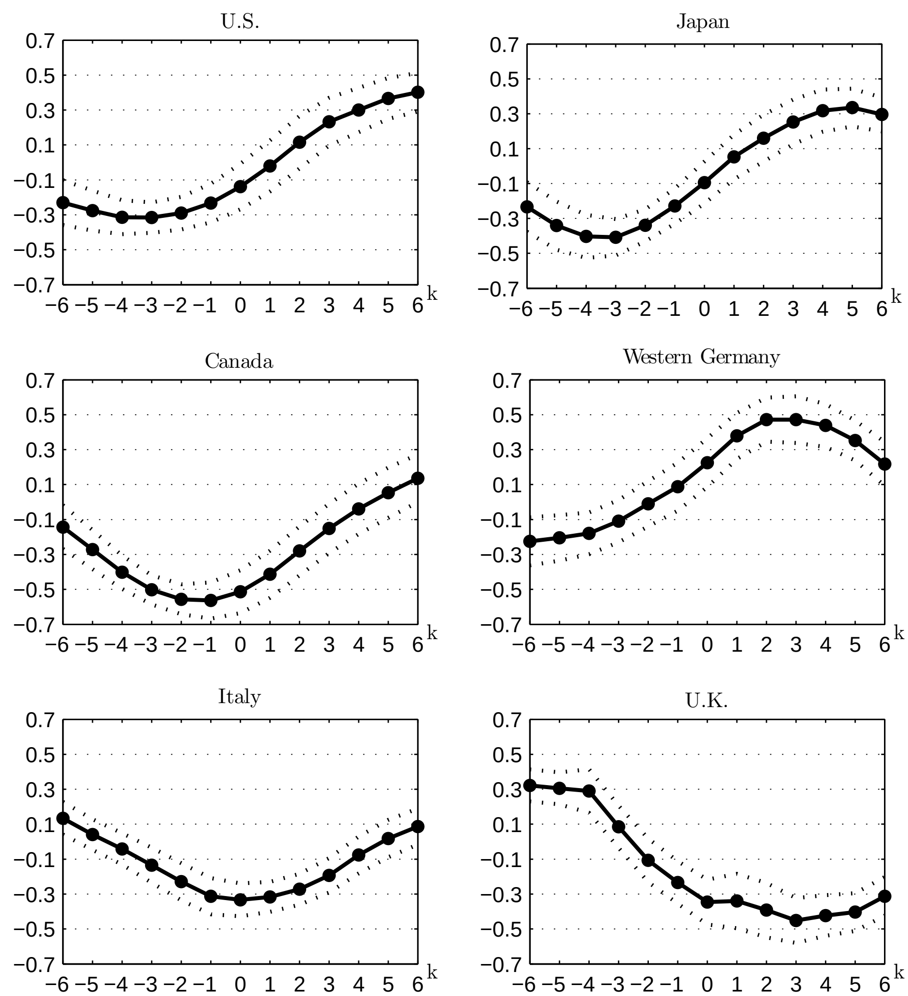
So far, I have discussed only the average cross correlation structure over countries. However, before establishing it as an empirical regularity, it is worth investigating the affection of cross-country variations on the shape of the average cross correlation structure. For this purpose, Figures 2.2, 2.3 and 2.4 plot similar cross correlation structures of the individual countries in each data set.

Figure 2.3: Cross country variation: Disaggregated CPI series data set



Note: All GDPs and relative prices are detrended using H.P. filter. Each figure draws each country's cross correlation structures over countries with a band of one standard error. All standard errors are Newey-West standard errors.

Figure 2.4: Cross country variation: CPI/PPI data set



Note: All GDPs and relative prices are detrended using H.P. filter. Each figure draws each country's cross correlation structures over countries with a band of one standard error. All standard errors are Newey-West standard errors.

As shown in the figures, in most countries the cross correlation structures share the S-shaped pattern with one exception. The pattern is more salient in the U.S. and the Japan than in other countries. The exception is the U.K. As Figures 2.3 and 2.4 show, the shape of the U.K.'s cross correlation structure is exactly opposite to those of the other countries in both cases. However, the overall results suggest that the S-shaped cross correlation structure is quite robust among advanced economies in data sets and can be taken as an empirical regularity.

2.2.3 Discussion

From empirical analyses above, two empirical regularities about the dynamics of relative price of nontradable goods at business cycle frequencies are identified. First, the relative price of nontradable goods is highly persistent but its volatility is quite modest. Second, it displays an S-shaped cross correlation structure with GDP.

The S-shaped cross correlation structure is particularly interesting because it suggests unusual dynamics of the relative price of nontradable goods along business cycles. The direct interpretation of the correlation structure is that the current relative price of nontradable goods tends to move in the opposite direction with past economic condition while it moves in the same direction with future economic condition. More intuitively, according to the regularity, if the economy is in a boom in the current period, the relative price of nontradable goods is expected to fall gradually in the future. On the other hand, if the economic condition is expected to become more favorable, the relative price tends to rise up in the current period.

The dynamics of the relative price of nontradable goods has drawn little attention from international macroeconomists. In most of previous theoretical literature, the relative price of nontradable goods has been abstracted away or even when considered, its dynamics has never been studied seriously. Considering the theoretical importance of the relative price in real exchange rate theory, this lack of attention seems strange. In this perspective, the S-shaped cross correlation structure of the relative price deserves theoretical examination and a plausible explanation needs to be provided for it.

To identify potential explanations for the dynamics of the relative price, it will be useful to log-linearize the expression of the relative price of nontradable to tradable goods as follows:

$$\widehat{\frac{P_N}{P_T}} = \hat{P}_N - \hat{P}_T \approx \hat{P}_N - \left(\Psi_H \hat{P}_H + \Psi_F \hat{P}_F\right), \tag{2.1}$$

where P_H and P_F represent price indices for domestic and imported tradable goods, respectively and Ψ_H and Ψ_F denote corresponding weights in the price index for tradable goods. Finally, a caret denotes the percentage deviation from the steady state of the variable. Note that the price index for tradable goods combines both price indices for domestically produced and imported tradable goods. Also note that the price index for imported tradable goods can be affected by nominal exchange rate fluctuations even though the equation does not express so explicitly.

As equation (2.1) shows clearly, the S-shaped cross correlation structure implies differences among the dynamics of price indices in the equation along business cycles. Specifically, the dynamics of the price index for nontradable goods must be quite different from those of both price indices for domestic and imported tradable goods. Because, if they have similar dynamics along business cycles, it is hard to imagine such a distinctive cross correlation structure with GDP. In that sense, for explaining the S-shaped cross correlation structure, some mechanism is necessary which can make each price index have different dynamics along business cycles.

To identify potential mechanisms, it is helpful to first revisit the existing international macroeconomic models, including International Real Business Cycle (hereinafter IRBC) and New Open Economy Macroeconomic (hereinafter NOEM) models. Interestingly, most of the models share a common feature in that all prices are assumed to be adjusted with the same degree of flexibility. In a typical IRBC model, all prices are adjusted with full flexibility while in a NOEM model, with the same degree of rigidity. As a result, in either case, it is hard to expect different dynamics of sectoral prices if sector neutral shocks prevail in the economy. There do, however, seem to be two possible ways in which traditional international macroeconomic models can be used to address the dynamics.

One obvious possibility is the introduction of sector specific productivity shocks. In other words, the S-shaped cross correlation structure can be simply a reflection of the dynamics of productivity difference between tradable and nontradable sectors due to sector specific productivity shocks. If business cycles are driven mainly by sector specific productivity shocks, then the dynamics of the relative price simply follows the dynamics of productivity differences since all prices can be adjusted with similar speeds.

A second possibility is related to the nominal exchange rate pass-through. As discussed above, nominal exchange rate fluctuations can affect the domestic relative price of nontradable goods through the price index for imported tradable goods, P_F, depending on the degree of pass-through. Particularly, this mechanism will be more powerful in the case where exporters set their prices in terms of their home currencies (Producer Currency Pricing), so that export prices in markets abroad can fully reflect nominal exchange rate movements.

This paper considers a third possibility. As discussed above, traditional models commonly assume that all prices adjust with the same speed. But, the assumption is clearly at odds with recent micro evidence supporting heterogeneity in price stickiness.[7] Specifically, with regard to the dynamics of the relative price of nontradable goods, estimates based on Nakamura and Steinsson (2007) suggests that price stickiness in nontradable sectors is twice as large as that in tradable sectors.[8] From the empirical estimates, it is very clear that speed of price adjustments in tradable sectors is much faster than in nontradable sectors. This difference may account for the dynamics of the relative price of nontradable goods. This paper proposes heterogeneity in price stickiness as another mechanism to explain the S-shaped cross correlation structure.[9]

In what follows, I examine which mechanism can successfully replicate the empirical dynamics of the relative price of nontradable goods. For this purpose, a standard international monetary model with nontradable sectors is considered. After that, I will investigate the implications of more realistic dynamics of the relative price of nontradable goods with regard to the real exchange rate puzzles.

2.3 Model

To explain the dynamics of the relative price of nontradable to tradable goods, a two-country monetary business cycle model is developed. Obviously, to get endogenous fluctuations of the relative price, the model includes nontradable sectors. However, its most distinctive feature from existing models is that tradable and nontradable sector are allowed to face different degrees of price stickiness. Details of the model are described below.

The world consists of two countries, *home* and *foreign,* of identical size. In each

[7] For details of recent micro evidences on heterogeneous price stickiness, see Bils and Klenow (2004) and Nakamura and Steinsson (2007) for the U.S. and Alvarez et al (2005) for the Euro area.

[8] Burstein, Eichenbaum, and Rebelo (2005) report similar estimates.

[9] A similar approach has been taken in Carvalho (2006) to analyze the real effect of monetary shocks in a closed economy environment.

country, there are two types of intermediate goods, tradable and nontradable. Each intermediate good producing firm in each sector is a monopolistic competitor and indexed by its product, which is in a continuum of varieties. Only tradable intermediate goods can be traded internationally. However, the home and foreign markets are segmented and price differences cannot be arbitraged away. As a result, each tradable intermediate goods producing firm can charge different prices in different markets.

Meanwhile, there are two types of final goods (N and T), which are associated with each type of intermediate good. The final good T is produced using a combination of domestic and imported tradable intermediate goods while the final good N is produced using only domestic nontradable intermediate goods.

For notation, all foreign variables have an asterisk (*) to be distinguished from their home equivalent. H or F in subscripts of variables, which represent the quantities and prices of tradable intermediate goods, denotes their origins. In addition, s_t denotes a particular state of the world at time t and the history of events up to period t is represented by $s^t = (s_o, \cdots, s_t)$. The probability of any particular history of s^t is $\pi(s^t)$.

Each agent's optimization problem will be discussed in turn in following subsections. I will discuss those optimization problems only for agents in the home country for convenience. The foreign counterparts can be easily analyzed in the same way due to the symmetric nature of the model.

2.3.1 Final good producing firms

There are two types of final goods in each country and both are assumed not to be traded. These final good producing sectors are both perfectly competitive markets.

Final good *N*

Final good Ns are produced using domestic nontradable intermediate goods according to the following production function

$$Y_N\left(s^t\right)=\left(\int_0^1 Y_N\left(i,s^t\right)^\theta\,di\right)^{\frac{1}{\theta}}, \tag{2.2}$$

where $i\in[0,1]$ is a variety index for nontradable intermediate goods in the home country and θ measures the elasticity of substitution among nontradable intermediate goods. $Y_N(s^t)$ and $Y_N(i,s^t)$ represent respectively the quantity of the final good N and the quantity of a nontradable intermediate good indexed as i. $P_N(s^t)$ and $P_N(i,s^t)$ are the associated prices.

From the profit maximization problem of each final good N producing firms, given $P_N(i,s^t)$ for $i\in[0,1]$, the price of a final good N and the demand for each nontradable intermediate good can be obtained as follows:

$$Y_N(i,s^t)=\left(\frac{P_N\left(i,s^{t-1}\right)}{P_N\left(s^t\right)}\right)^{\frac{1}{\theta-1}}Y_N(s^t), \tag{2.3}$$

where $P_N\left(s^t\right)=\left(\int_0^1 P_N(i,s^t)^{\frac{\theta}{\theta-1}}di\right)^{\frac{\theta-1}{\theta}}$ is the price of a final good N.

Final good *T*

A representative final good T producing firm in the home country aggregates both domestic and imported tradable intermediate goods according to the following production function

$$Y_T(s^t)=\left[a\left(\int_0^1 Y_H(j,s^t)^\theta dj\right)^{\frac{\rho}{\theta}}+(1-a)\left(\int_0^1 Y_F\left(j^*,s^t\right)^\theta\,dj^*\right)^{\frac{\rho}{\theta}}\right]^{\frac{1}{\rho}}, \tag{2.4}$$

where $j\in[0,1]$ and $j^*\in[0,1]$ are indices for home and foreign tradable intermediate goods, respectively. ρ measures the elasticity of substitution between domestic and imported tradable intermediate goods and a determines the degree of home bias in the demand of tradable intermediate goods. $Y_T(s^t)$, $Y_H(j, s^t)$, and $Y_F(j^*, s^t)$ represent the quantity of the final good T and the quantities of the domestic and imported tradable intermediate goods. $P_T(s^t)$, $P_H(j, s^t)$, and $P_F(j^*, s^t)$ are the corresponding prices.

As in the previous subsection, given $P_H(j, s^{t-1})$ for $i \in [0, 1]$ and $P_F(j^*, s^{t-1})$ for $j \in [0, 1]$, the demand for each tradable intermediate good is derived as follows:

$$Y_H(j, s^t) = a^{\frac{1}{1-\rho}} \left(\frac{P_H(j, s^{t-1})}{P_H(s^t)} \right)^{\frac{1}{\theta-1}} Y_T(s^t) \tag{2.5}$$

$$Y_F(j^*, s^t) = (1-a)^{\frac{1}{1-\rho}} \left(\frac{P_F(j^*, s^{t-1})}{P_F(s^t)} \right)^{\frac{1}{\theta-1}} Y_T(s^t), \tag{2.6}$$

where $P_H(s^t)$ and $P_F(s^t)$ are domestic and imported tradable intermediate good price indices and they are obtained as

$$P_H\left(s^t\right) = \left(\int_0^1 P_H(j, s^{t-1})^{\frac{\theta}{\theta-1}} dj \right)^{\frac{\theta-1}{\theta}} \tag{2.7}$$

$$P_F\left(s^t\right) = \left(\int_0^1 P_F(j^*, s^{t-1})^{\frac{\theta}{\theta-1}} dj^* \right)^{\frac{\theta-1}{\theta}}. \tag{2.8}$$

Simultaneously, the price of a final good T in the home country is derived as

$$P_T\left(s^t\right) = \left[a^{\frac{1}{1-\rho}} P_H\left(s^t\right)^{\frac{\rho}{\rho-1}} + (1-a)^{\frac{1}{1-\rho}} P_F\left(s^t\right)^{\frac{\rho}{\rho-1}} \right]^{\frac{\rho-1}{\rho}}. \tag{2.9}$$

2.3.2 Intermediate good producing firm

As in standard international monetary models, all intermediate good producing firms are assumed to face nominal rigidity with regard to their prices. The price stickiness is introduced following Calvo (1983). Thus, for each intermediate good producing firm, an opportunity of re-optimizing its price is drawn from a Poisson distribution. However, differentiated from existing models, it is assumed that the price stickiness can be different across the tradable and nontradable sectors.

Another important assumption in this class of models is about the invoicing behavior of tradable intermediate good producing firms for exports, because it determines the degree of nominal exchange rate pass-through in a theoretical economy. In most cases, literature takes just one of two extreme assumptions.

The first one is the 'Local Currency Pricing' (hereinafter LCP) assumption under which firms set their export prices in terms of importer's currency. This leads to insensitivity of export prices in the abroad markets to nominal exchange rate fluctuations. The other extreme case is 'Producer Currency Pricing' (hereinafter PCP) assumption. Under this assumption, firms set their export prices in terms of their home currencies. Note that with PCP assumption, the actual prices in the market abroad are given by

$$P_H^*(j, s^t) = \frac{\bar{P}_H^*(j, s^t)}{e(s^t)} \tag{2.10}$$

$$P_F(j^*, s^t) = e(s^t)\bar{P}_F(j^*, s^t), \tag{2.11}$$

where $e(s^t)$ is the nominal exchange rate and $\bar{P}_H^*(j, s^t)$ and $\bar{P}_F(j^*, s^t)$ are set by the firms in terms of their home currency. As equations (2.10) and (2.11) indicate clearly, the actual prices in the markets abroad fully reflect nominal exchange rate movements. As I discuss below, these two assumptions have starkly contrasting implications on nominal exchange rate pass-through. However, there is no consensus yet on the issue among international economists.[10] Hence, I will consider both cases separately when simulating the model.[11]

Finally, all intermediate good prices are assumed to be set before the realization of

[10]For details of the debate, see Obstfeld and Rogoff (2000) and Engel (2002).

[11]In either case, the invocing behavior of the firms in both countries are symmetric. However, according to Gopinath and Rigobon (2006), for the U.S., PCP prevails in exports whereas LCP prevails in imports. However, this asymmetric case is not considered in this paper.

shocks at time t similar to Chari, Kehoe, and Mcgrattan (2002).[12] In addition, it is assumed that both tradable and nontradable sectors share common factor markets.[13]

Tradable intermediate good producing firm

With the PCP assumption, when the opportunity to re-optimize its prices arrives, a representative tradable intermediate good producing firm in the home country chooses its prices, $P_H(j, s^{t-1})$ and $\bar{P}_H^*(j, s^{t-1})$, for the home and foreign markets and the inputs of labor and capital, $N_T(j, s^t)$ and $K_T(j, s^t)$, to solve the following profit maximization problem:

$$\begin{aligned} \max \sum_{\tau=0}^{\infty} \sum_{s^{t+\tau}} \Gamma(s^{t-1}, s^{t+\tau}) \varphi_T^{\tau} [P_H\left(j, s^{t-1}\right) Y_H(j, s^{t+\tau}) + \bar{P}_H^*(j, s^{t-1}) Y_H^*(j, s^{t+\tau}) \\ -P(s^{t+\tau}) W(s^{t+\tau}) N_T(j, s^{t+\tau}) - P(s^{t+\tau}) Z(s^{t+\tau}) K_T(j, s^{t+\tau})], \end{aligned} \tag{2.12}$$

subject to the demand functions in the home and foreign markets and the following constraints

$$Y_H(j, s^{t+\tau}) + Y_H^*(j, s^{t+\tau}) = F\left(A_T(s^{t+\tau}), N_T(j, s^{t+\tau}), K_T(j, s^{t+\tau})\right), \tag{2.13}$$

where $\Gamma(s^{t-1}, s^{t+\tau})$ is a proper stochastic discounting factor and φ_T is the probability of not re-optimizing its prices at each period in the tradable intermediate good producing sector. Note that $P(s^{t+\tau})$, $W(s^{t+\tau})$, and $Z(s^{t+\tau})$ denote respectively the overall price index (CPI), the real wage rate of labor and the real rental rate of capital in the home country. Also, $A_T(s^{t+\tau})$ represents sector specific productivity. From the optimization problem, optimal reset prices for the home and foreign markets are

[12] Obviously, this assumption can help generate large fluctuations of the real exchange rates because fluctuations of the nominal exchange rate can result in bigger deviations from PPP given predetermined prices. However, even though I will not report details, the main results of this paper do not depend on the assumption.

[13] As well known among monetary economists, the degree of real ridigity (or strategic complemetarity) is usually small with common factor markets. In this perspective, Steinsson (2007) is interesting. Because it shows that the real ridigity due to heterogenous factor markets can be an important element in fluctuations of the real exchange rates. However, so far, this paper haven't considered it. For details of implications of common factor markets on real rigidity, see Kimball (1995) and Woodford (2003).

given by

$$(2.14)\qquad P_H^{\#}(j,s^{t-1}) = \frac{1}{\theta}\frac{\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\Lambda_T(s^{t+\tau})MC_T^n(s^{t+\tau})P_H\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}}Y_H(s^{t+\tau})}{\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\Lambda_T(s^{t+\tau})P_H\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}}Y_H(s^{t+\tau})}$$

$$(2.15)\qquad \bar{P}_H^{*\#}(j,s^{t-1}) = \frac{1}{\theta}\frac{\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\Lambda_T(s^{t+\tau})MC_T^n(s^{t+\tau})\bar{P}_H^*\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}}Y_H^*(s^{t+\tau})}{\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\Lambda_T(s^{t+\tau})\bar{P}_H^*\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}}Y_H^*(s^{t+\tau})},$$

where $\Lambda_T(s^{t+\tau}) \equiv \Gamma(s^{t-1}, s^{t+\tau})\varphi_T^{\tau}$ and $MC_T^n(s^{t+\tau})$ is the nominal marginal cost in the tradable intermediate good producing sector.[14] $\bar{P}_H^*\left(s^{t+\tau}\right)$ is the price index of tradable intermediate goods exported to the foreign country, denominated in the home currency.

With the LCP assumption, since the firm charges its price in the foreign market in terms of the foreign currency, the revenue term from the foreign market in the optimization problem is changed from $\bar{P}_H^*(j,s^{t-1})Y_H^*(j,s^{t+\tau})$ to $e(s^t)P_H^*(j,s^{t-1})Y_H^*(j,s^{t+\tau})$ and the firm chooses $P_H^*(j,s^t)$ instead of $\bar{P}_H^*(j,s^t)$. The problem is otherwise identical. As a result, the optimal reset price for the foreign market is obtained as

$$(2.16)\qquad P_H^{*\#}(j,s^{t-1}) = \frac{1}{\theta}\frac{\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\Lambda(s^{t+\tau})MC_T^n(s^{t+\tau})P_H^*\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}}Y_H^*(s^{t+\tau})}{\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\Lambda(s^{t+\tau})e(s^{t+\tau})P_H^*\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}}Y_H^*(s^{t+\tau})}.$$

Nontradable intermediate goods producing firm

Similarly in the tradable intermediate good producing sector, with an opportunity to re-optimize its price, a representative nontradable intermediate good producing firm in the home country chooses its price, $P_N(i,s^t)$, and the inputs of labor and capital, $N_N(i,s^t)$ and $K_N(i,s^t)$, to solve the following profit maximization problem:

$$\max\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\Gamma(s^{t-1},s^{t+\tau})\varphi_N^{\tau}[P_N\left(i,s^{t-1}\right)Y_N(i,s^{t+\tau})$$
$$(2.17)\qquad -P(s^{t+\tau})W(s^{t+\tau})N_N(i,s^{t+\tau}) - P(s^{t+\tau})Z(s^{t+\tau})K_N(i,s^{t+\tau})],$$

[14]Note that as a theoretical result of common factor markets, sectoral marginal cost differentials come only from sectoral productivity differentials.

subject to the demand function and the following constraint

$$Y_N(i, s^{t+\tau}) = F\left(A_N(s^{t+\tau}), N_N(i, s^{t+\tau}), K_N(i, s^{t+\tau})\right) \tag{2.18}$$

where $\Gamma(s^{t-1}, s^{t+\tau})$ is a proper stochastic discounting factor and φ_N is the probability of not re-optimizing its price at each period in the nontradable intermediate good producing sector. The optimization problem leads to the following optimal reset price for the representative nontradable intermediate good producing firm:

$$P_N^{\#}(i, s^t) = \frac{1}{\theta} \frac{\sum_{\tau=0}^{\infty} \sum_{s^{t+\tau}} \Lambda_N(s^{t+\tau}) MC_N^n(s^{t+\tau}) P_N\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}} Y_N(s^{t+\tau})}{\sum_{\tau=0}^{\infty} \sum_{s^{t+\tau}} \Lambda_N(s^{t+\tau}) P_N\left(s^{t+\tau}\right)^{\frac{1}{1-\theta}} Y_N(s^{t+\tau})}, \tag{2.19}$$

where $\Lambda_N(s^{t+\tau}) \equiv \Gamma(s^t, s^{t+\tau})\varphi_N^{\tau}$ and $MC_N^n(s^{t+\tau})$ is the nominal marginal cost of the nontradable intermediate good producing sector.

2.3.3 Household

I assume that there exists a complete market for contingent nominal bonds which are denominated in the home currency. In addition, all capital and firms in each country are owned by domestic households. Under the environment, a representative household in the home country chooses consumption, labor, investment, capital, money holding, and contingent nominal bond holding, $C(s^t)$, $N(s^t)$, $I(s^t)$, $K(s^t)$, $M(s^t)$, and $B(s^{t+1})$, to solve the following utility maximization problem:

$$\max \sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t) U\left(C(s^t), \frac{M(s^t)}{P(s^t)}, N(s^t)\right), \tag{2.20}$$

subject to sequence of budget constraints

$$\begin{aligned} & P(s^t)C(s^t) + P(s^t)I(s^t) + M(s^t) \\ & \qquad + \sum_{s^{t+1}} Q\left(s^{t+1}|s^t\right) B(s^{t+1}) + P(s^t)\frac{\eta}{2}\left(\frac{I\left(s^t\right)}{K\left(s^{t-1}\right)} - \delta\right)^2 K\left(s^{t-1}\right) \\ \leq\ & P(s^t)W(s^t)N(s^t) + P(s^t)Z(s^t)K(s^{t-1}) \\ & \qquad + B(s^t) + \Pi(s^t) + M(s^{t-1}) + T(s^t) \end{aligned} \tag{2.21}$$

and the law of motion for capital

$$K(s^t) = (1-\delta)\, K\left(s^{t-1}\right) + I\left(s^t\right) \tag{2.22}$$

where β, η, and δ are the time discount factor, the scale parameter of investment adjustment cost, and the depreciation rate of capital. $Q(s^{t+1}|s^t)$ represents the price of contingent bonds, each of which gives one unit of the home currency in the realization of state s^{t+1}. $\Pi(s^t)$ and $T(s^t)$ denote the aggregate profits from all firms in the home country and transfers from the government. Since the household's utility maximization problem leads to very standard first order conditions, I will not list them here.

Finally, for convenience, consumption and investment are assumed to use a same aggregator combining the final good N and T, which are given by

$$C(s^t) = \left[bC_T(s^t)^{\chi} + (1-b)C_N(s^t)^{\chi}\right]^{\frac{1}{\chi}} \tag{2.23}$$

$$I(s^t) = \left[bI_T(s^t)^{\chi} + (1-b)I_N(s^t)^{\chi}\right]^{\frac{1}{\chi}}, \tag{2.24}$$

where b is the weight of the final good T in the aggregations and χ is the parameter for the elasticity of substitution between the final good N and T. $C_T(s^t)$, $C_N(s^t)$, $I_T(s^t)$, and $I_N(s^t)$ are the inputs of the final good N and T in the consumption and investment. From the optimality conditions of the aggregation problem, $C_T(s^t)$ and $C_N(s^t)$ are obtained as

$$C_T\left(s^t\right) = b^{\frac{1}{1-\chi}} \left(\frac{P_T\left(s^t\right)}{P\left(s^t\right)}\right)^{\frac{1}{\chi-1}} C\left(s^t\right) \tag{2.25}$$

$$C_N\left(s^t\right) = (1-b)^{\frac{1}{1-\chi}} \left(\frac{P_N\left(s^t\right)}{P\left(s^t\right)}\right)^{\frac{1}{\chi-1}} C\left(s^t\right). \tag{2.26}$$

$I_T(s^t)$ and $I_N(s^t)$ are derived similarly and the overall price index (CPI) is given by

$$P(s^t) = \left[b^{\frac{1}{1-\chi}} P_T(s^t)^{\frac{\chi}{\chi-1}} + (1-b)^{\frac{1}{1-\chi}} P_N(s^t)^{\frac{\chi}{\chi-1}}\right]^{\frac{\chi-1}{\chi}}. \tag{2.27}$$

2.3.4 The government

The government in each country is assumed to play a simple role in the economy. It is responsible only for the country's monetary policy. Following Chari, Kehoe and Mcgrattan (2002), the policy is assumed to be an exogenous process for monetary growth rates, which is given by

$$M(s^t) = \mu(s^t)M(s^{t-1}), \tag{2.28}$$

where μ follows a stochastic process to be discussed in detail below.

The government's budget constraint is simply

$$T(s^t) = M(s^t) - M(s^{t-1}), \tag{2.29}$$

where $T(s^t)$ represents transfers from the government to households.

2.4 Parameterization

In this section, I discuss how I choose functional forms for technology and household preferences, as well as how parameter values are calibrated in simulations.

2.4.1 Preference and Technology

As discussed above, preference and technology are identical in both countries. The preferences of consumers for each country are given by the instantaneous utility function

$$U\left(C, \frac{M}{P}, N\right) = \frac{1}{1-\gamma}C^{1-\gamma} + a_m \frac{1}{1-\gamma_m}\left(\frac{M}{P}\right)^{1-\gamma_m} - a_n \frac{1}{1+\gamma_n}N^{1+\gamma_n}, \tag{2.30}$$

where C, M/P, and N represent consumption, real balance and labor supply in each period and γ, γ_m, and γ_n respectively determine risk aversion, the elasticity of money demand, and the elasticity of labor supply.

Turning to the production function, the technology of intermediate good producing firms is given by a standard Cobb-Douglas production function

$$F(A, N, K) = AN^{\alpha}K^{1-\alpha} \tag{2.31}$$

where A, N, and K represent the productivity level, labor, and capital. The labor share is represented by α.

2.4.2 Parameter values

Most of the parameters in the model are calibrated using standard values from the existing literature. They are summarized in Table 2.2. However, some parameters merit a brief discussion.

Table 2.2: Parameters

Preference	risk aversion = 5	γ=5
	elasticity of labor supply = 1	γ_n=1
	elasticity of money demand = 1	γ_m=1
Technology	labor share	α=2/3
	depreciation rate	δ=0.021
Aggregator	elasticity of substitution between tradable intermediate goods from different countries = 1.5	ρ=0.33
	elasticity of substitution between tradable intermediate goods from the same country = 6	θ=0.83
	elasticity of substituion between final goods N and T = 0.44	χ=-1.27
Others	frequency of price change in tradable goods: prob.of not reoptimize price	φ_T=0.55;0.66;0
	frequency of price change in nontradable goods: prob. of not reoptimizing price	φ_N=0.76;0.66;0
	time discount factor	β=0.99

Note: a and b are calibrated to make $P_TY_T/(P_TY_T + P_NY_N) = 0.5$ and $P_HY_H/P_TY_T = 0.8$ at the steady state, which implies the ratio of trade volume to GDP is 0.2 at the steady state. η is calibrated such that the ratio of the standard deviation of investment to that of output is around 2.7.

First of all, consider parameters related to aggregating technologies at various levels. Following Stockman and Tesar (1995), I use an elasticity of substitution $(1/(1-\chi))$ between the final good N and T of 0.44 and calibrate weighting parameters a and b in the tradable intermediate good aggregators and the final consumption and investment aggregator such that the share of the final good T in output

$(P_T Y_T/(P_T Y_T + P_N Y_N))$ and the share of imported tradable intermediate goods in the final good T $(P_F Y_F/P_T Y_T)$ are respectively 0.5 and 0.8 at the steady state. These values of a and b lead to a ratio of trade volume to GDP of 0.2 at the steady state.

With regard to price stickiness, three different cases will be considered in later simulations to investigate implications of price stickiness on the dynamics of the relative price. They are respectively (i) the 'flexible price', (ii) 'same price stickiness', and (iii) 'heterogeneous price stickiness' case. Accordingly, Calvo parameters, φ_N and φ_T are calibrated differently in each case. For the 'flexible price' case, obviously, they are both calibrated at zero. Meanwhile, for the 'same price stickiness' case, I follow the existing literature and assign both a value of 0.66, which implies that prices are fixed for 3 quarters on average. The last case assumes heterogeneity in price stickiness between the tradable and nontradable sector. Since there is no reference literature about the case, I estimate φ_N and φ_T from data.

The estimation is essentially based on the recent work of Nakamura and Steinsson (2007). Table 2.3 summarizes all relevant information. The monthly median frequencies and weights for the CPI major groups in the table are borrowed directly from Table 1 in their work. To calculate empirical counterparts of φ_N and φ_T, at first, I classify each item as being in the tradable or nontradable sector. I simply follow conventions in the literature, where 'Service less travel' and 'Utilities' are classified as nontradable and all other items as tradable. I then convert monthly frequencies to quarterly frequencies using a simple formula, $F_Q = 1 - (1 - F_M)^3$, where F_Q and F_M denote respectively a quarterly and monthly frequency for each CPI group. To calculate frequencies in the tradable and nontradable sectors, I take an average of frequencies with given expenditure weights for each sector. As a result, I get 0.45 for the tradable sector and 0.24 for the nontradable sector. These estimates clearly suggest that the price stickiness in the nontradable sectors is approximately twice as large as in the tradable sectors. Based on these estimates, I calibrate φ_N and φ_T as 0.76 and 0.55 respectively.

Table 2.3: Frequency of price change by CPI major group 1998-2005

	Tradability	Expenditure weights	Median frequency	
			Monthly	Quarterly
Processed food	T	0.082	0.11	0.28
Unprocessed food	T	0.059	0.25	0.58
Household furnishing	T	0.050	0.06	0.17
Apparel	T	0.065	0.04	0.10
Transportation goods	T	0.083	0.31	0.68
Recreation goods	T	0.036	0.06	0.17
Other goods	T	0.054	0.15	0.39
Utilities	N	0.053	0.38	0.76
Vehicle fuel	T	0.051	0.88	1.00
Travel	T	0.055	0.42	0.80
Service less travel	N	0.385	0.06	0.17
Tradable goods		0.438		0.45
Nontradable goods		0.535		0.24

Note: This table is based on Table 1 in Nakamura and Steinsson (2007). Tradability and quarterly frequency are added by the author. To convert a monthly frequency to a quarterly frequency, a simple formula $F_Q = 1 - (1 - F_M)^3$ is used. In the formula, F_Q and F_M are a quarterly and a monthly frequency respectively.

As I discuss above, whether productivity shocks are sector specific or neutral is very important because sector specific productivity shocks themselves can be an explanation for the dynamics of the relative price of nontradable goods. So, in simulations, both types of productivity shocks are exploited. Following Kehoe and Perri (2002), the sector neutral productivity shocks are specified to follow a stochastic process given by

$$\begin{bmatrix} \log(A_t) \\ \log(A_t^*) \end{bmatrix} = \begin{bmatrix} 0.95 & 0.00 \\ 0.00 & 0.95 \end{bmatrix} \begin{bmatrix} \log(A_{t-1}) \\ \log\left(A_{t-1}^*\right) \end{bmatrix} + \begin{bmatrix} \varepsilon_A \\ \varepsilon_{A^*} \end{bmatrix}, \tag{2.32}$$

where the productivity innovations, ε_A and ε_{A^*}, have zero means, are serially uncorrelated, and are uncorrelated with other types of shocks. Their second moments are given by $var(\varepsilon_A) = var(\varepsilon_{A^*}) = (0.007)^2$ and $corr(\varepsilon_A, \varepsilon_{A^*}) = 0.250$. And, sectoral productivity shocks are simply defined as

$$A_{T,t} = A_{N,t} = A_t \tag{2.33}$$

$$A^*_{T,t} = A^*_{N,t} = A^*_t. \tag{2.34}$$

As for sector specific productivity shocks, there is a critical obstacle in that sector specific productivity shocks are available only on an annual basis, due to data availability. However, considering that the main objective of this paper is to match up with empirical regularities based on quarterly data, quarterly sector specific productivity shocks are necessary. Hence, I approximate the sectoral shocks in an admittedly crude way.[15] The approximation strategy is quite simple. I simply take an annual productivity shock process which is given by

$$A_{t+4} = \Phi A_t + \Lambda_{t+4}, \tag{2.35}$$

where A and Λ are vectors which collect sector specific productivity shocks and corresponding innovations respectively and $Var(\Lambda_{t+4})$ is given by Ω.[16] From the annual process, I approximate a corresponding quarterly productivity shock process as

$$A_{t+1} = \Phi^{1/4} A_t + \varepsilon_{t+1} \tag{2.36}$$

and $Var(\varepsilon_{t+1})$ as $\Omega/4$. After applying the approximation procedures for the annual sector specific productivity shock process in Stockman and Tesar (1995), I obtain quarterly sector specific productivity shocks following a stochastic process which is given by

[15] Another attempt to approximate a quarterly sector specific productivity shocks can be found in Corsetti, Dedola, and Leduc (2006). Even when their approximation is used in the model, overall results are almost same.

[16] Note that the time unit in the equation is a quater.

$$\begin{bmatrix} \log(A_{T,t}) \\ \log(A_{N,t}) \\ \log(A^*_{T,t}) \\ \log(A^*_{N,t}) \end{bmatrix} = \begin{bmatrix} 0.602 & 0.047 & -0.165 & 0.154 \\ -0.096 & 0.906 & -0.077 & 0.066 \\ -0.165 & 0.154 & 0.602 & 0.047 \\ -0.077 & 0.066 & -0.096 & 0.906 \end{bmatrix} \begin{bmatrix} \log(A_{T,t-1}) \\ \log(A_{N,t-1}) \\ \log(A^*_{T,t-1}) \\ \log(A^*_{N,t-1}) \end{bmatrix} + \begin{bmatrix} \varepsilon_{T,t} \\ \varepsilon_{N,t} \\ \varepsilon^*_{T,t} \\ \varepsilon^*_{N,t} \end{bmatrix}, \tag{2.37}$$

and the covariance matrix of innovations $\varepsilon = (\varepsilon_{T,t}, \varepsilon_{N,t}, \varepsilon^*_{T,t}, \varepsilon^*_{N,t})$ in the process,

$$\begin{bmatrix} 0.00905 & 0.00308 & 0.00303 & 0.00128 \\ 0.00308 & 0.00498 & 0.00128 & 0.00068 \\ 0.00303 & 0.00128 & 0.00905 & 0.00308 \\ 0.00128 & 0.00068 & 0.00308 & 0.00498 \end{bmatrix}.$$

The quarterly sector specific productivity shocks in the model are specified to follow the process obtained above.

Given those parameters, the model is solved numerically using a standard first order approximation method.

2.5 Findings

In this section, I discuss the theoretical findings. At first, I discuss the dynamics of the relative price of nontradable goods, specifically an explanation of the S-shaped cross correlation structure. I then examine its implications with regard to the real exchange rate puzzles.

2.5.1 Flexible price and same price stickiness

When I discussed empirical regularities in previous section, I argued that for explaining the dynamics of the relative price of nontradable goods, some additional mechanism is needed to generate different dynamics of tradable and nontradable prices along business cycles. In addition, I enumerated some theoretical mechanisms which can generate such dynamics. They are sector specific productivity shocks, nominal exchange rate pass-through and heterogeneous price stickiness. In what follows, I investigate which mechanism is the main driving force of the dynamics of the relative price of nontradable goods.

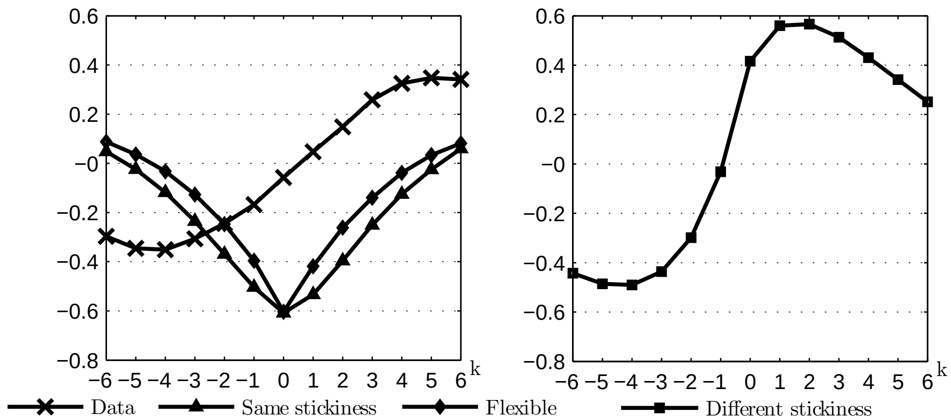
For this, I simulate the model with different sets of assumptions. Figures 2.5 and 2.6 summarize the results. Each graph in both figures is based on the average of 100 simulations of l00 periods and cross correlation structures are calculated in the same way as their empirical counterparts. For an easy comparison with the empirical regularity, some graphs include a series titled ‘Data’, which is borrowed from panel (a) of Figure 2.1. Finally, the panels (a) and (b) in each figure separately show cross correlation structures based on the assumption of PCP and LCP.

Figure 2.5 collects simulated cross correlation structures generated with sector neutral productivity shocks. The graphs on the left side of panel (a) show two simulated cross correlation structures based on different assumptions on nominal rigidity. From the graphs, it is clear that the model fails to replicate the empirical dynamics of the relative price of nontradable goods both under the ‘flexible price’ and ‘same price stickiness’ assumptions. Furthermore, as the corresponding graphs in panel (b) show, this result does not change even after I replace the PCP assumption with the LCP assumption. In all cases, cross correlation structures display the same pattern that at $k = 0$, the correlation coefficient is approximately -0.6 but increases gradually as k moves away from zero. In sum, the cross correlation structures look more V-shaped than S-shaped.

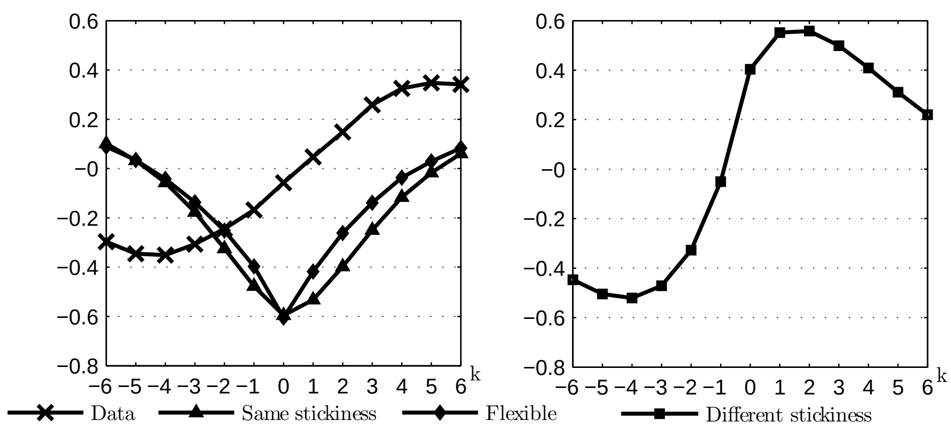
Imported tradable good prices play an important role in the result. Let’s consider

Figure 2.5: Simulated cross correlation structure ($Corr(Y_{t+k}, (P_N/P_T)_t)$) with sector neutral productivity shocks

(a) PCP case



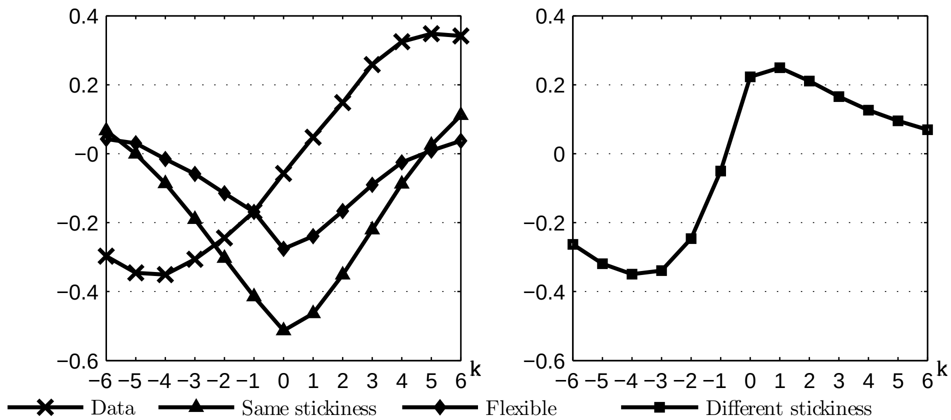
(b) LCP case



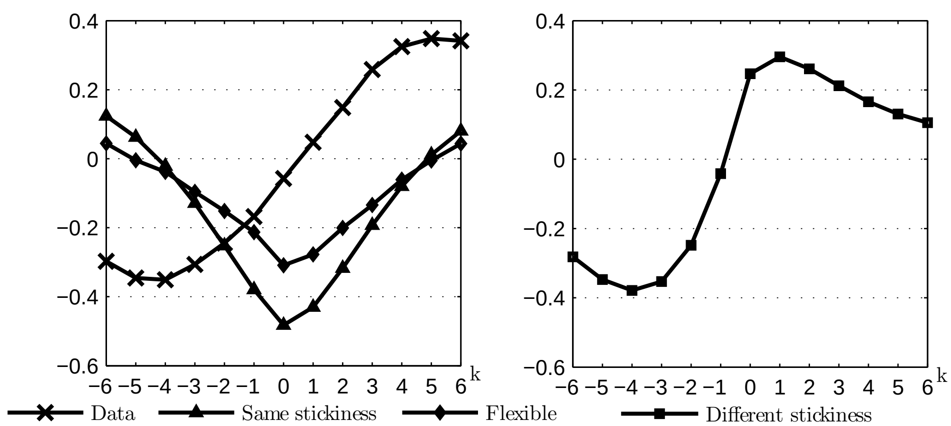
Note: 'Data' series is borrowed from the panel (a) in Figure 1. Each graph is based on the averages of 100 simulations of 100 periods. All simulated GDPs and relative prices are detrended using H.P. filter.

Figure 2.6: Simulated cross correlation structure ($Corr(Y_{t+k},(P_N/P_T)_t)$) with sector specific productivity shocks

(a) PCP case



(b) LCP case



Note: 'Data' series is borrowed from the panel (a) in Figure 1. Each graph is based on the averages of 100 simulations of 100 periods. All simulated GDPs and relative prices are detrended using H.P. filter.

the 'flexible price' case first. Assume that a positive sector neutral productivity shock occurs in the home country. Due to flexible price adjustments, both nontradable good and domestically produced tradable good prices will drop immediately with similar magnitudes after the shock. However, imported tradable good prices are unlikely to make a big movement because they will depend more on productivity in the foreign countries.[17] Hence, the price index for tradable goods will fall less than the price index for nontradable goods due to imported tradable goods. Consequently, the relative price of nontradable goods falls at the impact moment. Once the shock starts to decay, the relative price will increase gradually and eventually return to its original level. In sum, as a result of the shock, the relative price of nontradable goods initially falls but later increases continuously until it returns to the original level. Meanwhile, output moves in the exactly opposite direction after the shock. It jumps up at the impact moment, but subsequently declines continuously. These contemporaneous co-movements in opposite directions of output and the relative price are responsible for the V-shaped cross correlation structure with a sector neutral productivity shock. From the co-movements, it follows that GDP and the relative price of nontradable goods has a V-shaped cross correlation structure.

A similar inference can work for the 'same price stickiness' case. The only difference is that in the 'same price stickiness' case, both output and the relative price of nontradable goods display hump-shaped adjustments after a productivity shock due to price stickiness. But, output and the relative price of nontradable goods move in opposite directions after the shock for the same reasons they did in the 'flexible price' case. As a result, a V-shaped cross correlation structure emerges again in the

[17]To simplify the explanation, I ignore the channel through which nominal exchange rate movements can affect imported tradable good prices. However, the consideration of the channel won't change the whole story. Because simulations suggest that nominal exchange rate movements associated with productivity shocks are almost ignorable. This also explain why the results are almost identical with the PCP and LCP assumption.

case.

As Figure 2.5 suggests, the model cannot generate the S-shaped cross correlation structure with sector neutral productivity shock either in the 'flexible price' case or in 'same price stickiness' case. Meanwhile, as I point out above, sector specific productivity shocks can be an explanation for the dynamics of the relative price of nontradable goods because they can potentially generate different dynamics of tradable and nontradable good prices along business cycles. To investigate the possibility, I simulate the model again in a similar way above but with sector specific productivity shocks. Figure 2.6 summarizes the results.

The graphs on the left side of panels (a) and (b) in Figure 2.6 show the cross correlation structures associated with the 'flexible price' and 'same price stickiness' assumption, respectively. An interesting observation from these graphs is that they provide a very similar pattern as in Figure 2.5. The model produces a V-shaped cross correlation structure with both the 'flexible price' and with the 'same price stickiness' assumption. Furthermore, the result does not depend on the nominal exchange rate pass-through. The only difference is that as a whole, correlation coefficients are smaller compared with those with sector neutral productivity shocks. But the overall results do not support the possibility that the S-shaped cross correlation structure results from sector specific productivity shocks.[18]

2.5.2 Heterogeneous price stickiness

The simulation results in the previous subsection deliver two interesting implications on international macroeconomic theory. First, the results imply that existing standard international business cycle models cannot explain the dynamics of the relative price of nontradable goods. Note that the 'flexible price' and 'same price

[18]Taking it into account that the sector specific productivity shocks used in simulations are approximated in a very crude way, this result should not be taken as a conclusive evidence.

stickiness' case can be considered respectively as approximations of a standard IRBC and NOEM model. However, in both cases, the model fails to replicate the S-shaped cross correlation structure, irrespective of sectoral neutrality of productivity shocks and nominal exchange rate pass-through. Second, to explain the S-shaped cross correlation structure, sectoral differences in the speed of price adjustment seem to be needed to explain the regularity. As I discussed above, both cases share a common feature in that all price can be adjusted with the same speed. However, the feature is not only at odds with recent micro evidences supporting the heterogeneity in price stickiness, but cannot explain the dynamics of the relative price of nontradable goods properly. In that vein, this paper suggests heterogeneity in price stickiness as an explanation of the S-shaped cross correlation structure.

To investigate whether the heterogeneity can successfully the empirical regularity, I simulate the model with the 'heterogeneous price stickiness' assumption under which the price stickiness in nontradable sectors is assumed to be twice as large as in tradable sectors. Simulation results are summarized again in Figures 2.5 and 2.6.

At first, let's look at the graphs on the right side of panels (a) and (b) of Figure 2.5. These graphs show the cross correlation structures simulated with sector neutral productivity shocks when heterogeneity is considered. From these graph, it is clear that the model can successfully replicate the S-shaped cross correlation structure. In addition, cross correlation structures in two graphs look almost identical. This implies that the result is robust to different assumptions on nominal exchange rate pass-through.

The result is basically an outcome of two contradictory effects. One comes from the heterogeneity in price stickiness and the other one from the existence of imported tradable goods. To explain the results in detail, let's consider a favorable sector neutral productivity shock that hits the home country. With the shock, the relative price of nontradable goods goes up at the impact moment because of bigger price stickiness in the nontradable sectors.[19] However, as nontradable good prices reflect the shock gradually, the relative price of nontradable goods begins to decrease, eventually falling below the original level due to imported tradable good prices, which are unlikely to change much after the shock. Meanwhile, output follow a hump-shaped path because of overall price stickiness. It is easy to infer the S-shaped cross correlation structure from these paths of the relative price and output. For instance, output increases at the impact moment but the relative price falls with some delays. That is the reason why the relative price of nontradable goods is negatively correlated with lagged GDP.

The same result can be found in Figure 2.6, which implies that the result does not depend on the sectoral neutrality of productivity shocks. Again, the only difference is that overall correlation coefficients with sector specific productivity shocks are smaller compared to those with sector neutral productivity shocks. In sum, Figures 2.5 and 2.6 clearly suggest that the model can successfully replicate the S-shaped cross correlation structure only when heterogeneity in price stickiness in tradable and nontradable sectors is considered.

Considering the theoretical importance of the relative price of nontradable goods in real exchange rate theory, it is natural to ask what implications a more realistic dynamics of the relative price of nontradable goods has on real exchange rate fluctuations. For this purpose, the model is simulated using sector neutral productivity shocks and monetary shocks. Monetary shocks are incorporated in the growth rate

[19]The direction of movement of the relative price at the impact moment is dependent on some parameters. Particularly, the parameter which determines the relative importance of imported tradable goods in total tradable goods is crucial. However, with realistic parameterizations including one in this paper, the relative price is expect to jump up at the impact moment.

of money supplies. Following Chari, Kehoe and Mcgrattan (2002), the growth rates of the money stock for both countries are specified to follow a process which is given by

$$\begin{bmatrix} \log \mu_t \\ \log \mu_t^* \end{bmatrix} = \begin{bmatrix} 0.680 & 0 \\ 0 & 0.680 \end{bmatrix} \begin{bmatrix} \log \mu_{t-1} \\ \log \mu_{t-1}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_\mu \\ \varepsilon_{\mu^*} \end{bmatrix}, \tag{2.38}$$

where $\varepsilon_\mu = (\varepsilon_\mu, \varepsilon_\mu^*)$ are normally distributed disturbances with mean zero and their correlation coefficient is 0.5. Note that the variance of monetary shocks is calibrated such that the simulated correlation coefficient of the relative price of nontradable goods and contemporaneous output is equal to about zero to match up with data.[20] The cross correlation structures from the calibration are shown in Figure 2.7.

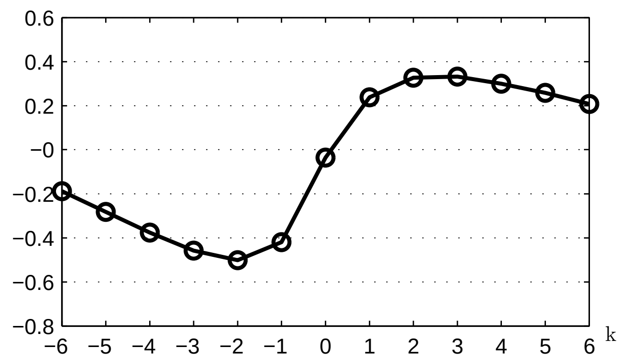
Table 2.4 provides standard summary statistics of the real exchange rate and the relative price of nontradable goods for various simulations. To investigate the implications of heterogeneous price stickiness, I simulate the model separately with the 'heterogeneous price stickiness' and the 'same price stickiness' assumption.

Before investigating the implications of heterogeneous price stickiness on the real exchange rate puzzles, I examine whether the heterogeneity can replicate as well the other empirical regularity of the relative price of nontradable goods. The empirical results in previous section suggest that the relative price is highly persistent but its volatility is quite modest. As shown in Table 2.4, the model can generate similar magnitudes of volatility and persistence as observed in data only when the heterogeneity is considered. Particularly, the volatility of the relative price is increased significantly with the assumption of heterogeneity. Without the assumption, the relative standard deviation to GDP of the relative price is merely 0.45 and 0.25 in

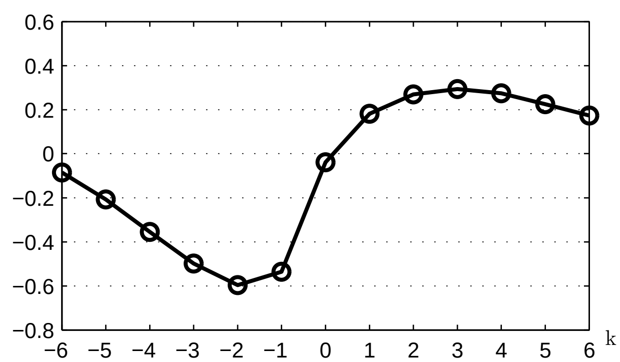
[20]Recall that as Figure 2.1 suggests, the relative price of nontradable goods doesn't have any clear contemporaneous relationship with GDP in data.

Figure 2.7: Simulated cross correlation structure ($Corr(Y_{t+k}, (P_N/P_T)_t)$) with sector neutral productivity shocks and monetary shocks

(a) PCP case



(b) LCP case



Note: Each graph is based on the averages of 100 simulations of 100 periods. All simulated GDPs and relative prices are detrended using H.P. filter. Tha variance of monetary shocks is calibrated such that the simulated contemporaneous correlation between relative price of nontradable goods and GDP is close to zero.

the PCP and LCP case, respectively while it is 1.1 in data. However, the relative standard deviation of the relative price increases to 1.15 and 1.03 in the PCP and LCP cases, respectively when the heterogeneity is considered. Meanwhile, the model generates comparable persistence to that in data as a whole, irrespective of different assumptions on nominal rigidity and nominal exchange rate pass-through.

Table 2.4: Real exchange rate and relative price of nontradable good statistics

	Data	PCP		LCP	
		Heterogeneous price stickiness	Same price stickiness	Heterogeneous price stickiness	Same price stickiness
Standard deviations relative to GDP					
real exchange rate	4.36	1.77	1.81	2.38	2.37
ratio to nominal ex. rate	0.93	0.89	0.92	0.92	0.93
relative price of nontradable goods	1.10	1.15	0.45	1.03	0.25
Autocorrelation					
real exchange rate	0.83	0.61	0.60	0.53	0.54
relative price of nontradable goods	0.82	0.78	0.60	0.78	0.85
Cross correlation					
nominal and and real exchange rate	0.99	0.50	0.47	0.72	0.69

Note: The statistics are based on logged and H.P. filtered data. Numbers are with nominal and real exchange rate in the "Data" column are borrowed from Table 6 of Chari et al. (2002). Numbers associated with relative price of nontradable goods are averages of cross country averages in each data set in Table 1 of this paper. The ratio to nominal exchange rate is defined as the ratio of standard deviation of real exchange rate to that of nominal exchange rate.

Along with previous result on the S-shaped cross correlation structure, this result clearly suggests that the model can successfully replicate both empirical regularities of the relative price of nontradable goods only with the heterogeneous price stickiness. Based on this, it is clear that the heterogeneity is the primary force of the dynamics of the relative price of nontradable goods at business cycle frequencies.[21]

However, the heterogeneity in price stickiness does not help improve the results in the existing literature with regard to real exchange rate puzzles. As Table 2.4 reports, the volatility and persistence of real exchange rate are virtually the same whether the

[21] Burstein, Eichenbaum, and Rebelo (2005) also emphasize heterogeneity in price stickiness in tradable and nontradable sectors as an explanation for the large drops in real exchange rates and low rates of inflation after large devaluations.

heterogeneity is considered or not. In the PCP case, the relative standard deviation to GDP and autocorrelation coefficient of real exchange rate are approximately 1.8 and 0.6, respectively while in the LCP case, 2.38 and 0.54.

Finally, Table 2.5 reports summary statistics of other major macroeconomic variables. As the table shows, the result is overall consistent with existing business cycle literature and data.

Table 2.5: Business cycle statistics

		PCP		LCP	
	Data	Heterogeneous price stickiness	Same price stickiness	Heterogeneous price stickiness	Same price stickiness
Standard deviations relative to GDP					
consumption	0.83	0.43	0.44	0.48	0.48
investment	2.78	2.76	2.80	2.79	2.78
employment	0.67	2.44	2.45	1.87	1.85
net export	0.11	0.17	0.15	0.17	0.16
terms of trade	0.67	3.63	3.62	2.11	1.90
Autocorrelation					
GDP	0.88	0.55	0.56	0.48	0.51
consumption	0.89	0.62	0.63	0.51	0.54
investment	0.91	0.49	0.50	0.45	0.48
employment	0.90	0.40	0.41	0.40	0.43
net export	0.82	0.60	0.62	0.60	0.63
terms of trade	0.81	0.52	0.56	0.89	0.91
Cross correlations					
between home and foreign					
GDP	0.60	0.20	0.22	0.24	0.24
consumption	0.38	0.67	0.66	0.52	0.52
investment	0.33	0.64	0.63	0.51	0.52
employment	0.39	0.26	0.26	0.49	0.48
between net exports and					
GDP	-0.41	0.62	0.60	0.54	0.57
between real exchange rate and					
GDP	0.08	0.62	0.61	0.60	0.61
net exports	0.14	0.95	0.99	0.78	0.89

Note: The statistics are based on logged and H.P. filtered data. Numbers are with nominal and real exchange rate in the "Data" column are borrowed from Table 6 of Chari et al. (2002).

2.6 Conclusion

There has been a long lasting debate among international macroeconomists on whether fluctuations in real exchange rates are driven mainly by deviations from the law of one price for tradable goods across countries or by fluctuations in the relative price of nontradable to tradable goods across countries. However, international macroeconomists have yet to reach a consensus on the main source of real exchange rate movements. In that sense, as Betts and Kehoe (2001) argue, a successful theory of real exchange rate determination *still* needs the relative price of nontradable to tradable goods as one of key components.

From this perspective, this paper investigates the dynamic properties of the relative price of nontradable goods at business cycle frequencies and finds that the relative price displays unusual dynamics along business cycles: First, the relative price of nontradable goods displays an S-shaped cross correlation structure with GDP. In other words, the relative price tends to be negatively correlated with past GDP and positively correlated with future GDP. Second, the relative price is highly persistent but its volatility is quite low.

This paper shows that standard international macroeconomic models have difficulty in explaining the S-shaped cross correlation structure and argues that the reason for the difficulty lies at their implicit assumption of the sectoral price adjustments with the same speed. On the contrary, to explain the S-shaped cross correlation structure, this paper introduces heterogeneity in price stickiness into an otherwise standard NOEM model. As the estimates based on recent micro evidence on heterogeneous price stickiness suggest, price stickiness in the nontradable sectors is assumed to be twice as large as in the tradable sectors.

Simulation results clearly show that heterogeneity in price stickiness is the primary force of the dynamics of the relative price of nontradable goods at business cycle frequencies. When the model considers the heterogeneity, it can successfully replicate the S-shaped cross correlation structure and generate similar magnitudes of volatility and persistence of the relative price as observed in data. However, the heterogeneity does not help to improve the results in the existing literature with regard to the real exchange rate puzzles. The volatility and persistence of the real exchange rate are virtually the same whether the heterogeneity is considered or not.

This paper can be extended both empirically and theoretically. In the empirical direction, I will consider an additional data set which is recently constructed by Burstein, Eichenbaum, and Rebelo (2006). The data set is appealing because tradable good prices are measured using weighted average of import and export price indices and as a result, distributional costs are expected more effectively excluded. It will provide another opportunity to check the robustness of the empirical regularities established in this paper.

Another extension is related to the implications of the heterogeneous factor markets. Recently, Steinsson (2007) provides an interesting insight with regard to real exchange rate puzzles. He shows that the model can generate comparable magnitudes of volatility and persistence of real exchange rate as observed in data when the heterogenous factor markets are considered and argues that the real rigidity (or strategic complementarity) due to the heterogeneous factor markets is the driving mechanism of the dynamics of the real exchange rate. On the contrary, in this paper, I simply assume that all firms in both sectors share common factor markets. In this regard, it will be an interesting attempt to introduce heterogenous factor markets into the model with the heterogeneity price stickiness and study implications on the dynamics of the relative price of nontradable goods and real exchange rate.

Chapter III

Rule-of-thumb consumer and international business cycles

3.1 Introduction

Typical business cycle models assume a single representative consumer who can make optimal intertemporal decisions using financial assets. However, many empirical studies suggest that this assumption is at odds with the data. For example, Campbell and Mankiw (1989) report that about half of consumers simply consume their current incomes without intertemporal considerations while Wolff (1998) reports that a significant portion of households hold nearly zero net wealth. Given such empirical results, the usual assumption of a single, rational and forward-looking representative consumer in a standard business cycle model appears to be unrealistic and relaxing the assumption may be helpful in understanding various macroeconomic phenomena.

The assumption of a representative consumer has also been prevalent in international business cycle literature and most international business cycle models are built on it. van Wincoop (1996) is an exception. He introduces rule-of-thumb consumers into a standard international business cycle model and tries to solve various international macroeconomic puzzles including the consumption correlation puzzle.[1]

Although he succeeds in reducing the consumption correlation between countries,

[1] In Galí, López-Salido, and Vallés (2004), similar rule-of-thumb consumers can be found.

some problems still remain. First, he only considers an economy with one tradable good. Given the simplicity of the model, he is unable to analyze the effects of rule-of-thumb consumers on other aspects of the economy, including the dynamics of the terms of trade and the real exchange rate. Second, the paper considers a specific productivity process with high persistence (the autocorrelation coefficient of the process on a quarterly basis is about 0.99) but no international spill-over effects. It is quite similar to the process used by Baxter and Crucini (1995). As is well known among international macroeconomists, the main finding in Baxter and Crucini (1995) is that an economy with incomplete markets can produce a negative consumption correlation when the specified productivity process follows a random walk without spill-overs. Therefore, it is natural to ask whether the inclusion of the rule-of-thumb behavior or the restricted asset trade generates van Wincoop's (1996) results.

This paper extends van Wincoop (1996) in two ways. First, I use a richer international real business cycle model to investigate the effects of rule-of-thumb consumers on various aspects of the international macroeconomy, including international price variables. Following Backus et al (1995, below BKK) and other standard international real business cycle researches, I study an economy which assumes one tradable intermediate good and one nontradable final good in each country. Second, I consider various asset market restrictions in order to isolate the independent effects of rule-of-thumb consumers. It is common practice in international macroeconomics to impose restrictions on the types of available assets for international risk sharing.[2] Following that practice, I consider respectively an economy with a complete set of contingent bonds, an economy with only uncontingent bonds, and an economy with no internationally tradable financial assets (i.e. a financial autarky). I then compare

[2]Baxter and Crucini (1995), Arvanitis and Mikkola (1996), Kollman (1996), Kehoe and Perri (2002), and Heathcote and Perri (2002) represent this class of models.

the results from each theoretical economy.

The main results of this paper can be summarized as follows: First, the introduction of rule-of-thumb consumers can explain some international macroeconomic puzzles, independent of restrictions on available assets for international risk sharing. In particular, it explains the consumption correlation puzzle. When rule-of-thumb consumers are added in an otherwise standard international business cycle model, the consumption correlation falls while the output, labor, and investment correlations increase. This result suggests that the overall performance of the model improves with respect to quantity correlations when rule-of-thumb consumers are introduced. However, the volatilities of the terms of trade and the real exchange rate decrease slightly. Second, the effects of rule-of-thumb consumers depend on the specification of the productivity process. The rule-of-thumb behavior is more important when the process is less persistent and spill-over effects are large.

The paper is organized as follows: In section 3.2, I describe the theoretical economies in detail. The parameterization and the solution method of the model are discussed in section 3.3. I examine the results produced by the model in section 3.4, and conclude with a summary of major findings and a discussion of some possible extensions.

3.2 Theoretical Economies

To investigate the effects of rule-of-thumb consumers on international business cycles, I consider a standard international real business cycle model. The main innovation of my approach is that the assumption of a single representative consumer is relaxed by adding rule-of-thumb consumers to standard rational consumers.

In each country, there are two kinds of consumers: One is the standard rational consumer who holds financial assets and optimizes her consumption profile intertemporally, while the other is the rule-of-thumb consumer who is assumed not to hold any financial assets and consume her wage income in each period. Following van Wincoop (1996) and Galí, López-Salido, and Vallés (2004), I assume that each country is populated by an identical mix of rational and rule-of-thumb consumers, with λ representing the fraction of rational consumers in the population.

Turning to the production side of the model, there are two types of firms in each country. They are intermediate good producing firms and final good producing firms. The intermediate good producing firms are involved with producing the country specific intermediate goods. For notational convenience, I denote the intermediate good produced in the home country by a and the intermediate good produced in the foreign country by b. Meanwhile, the final good producing firms combine these intermediate goods to produce final goods. Their technologies are given by $G_H(a_H, b_H)$ and $G_F(a_F, b_F)$, where subscripts H and F represent the home country and the foreign country respectively.

Prior to discussing each agent's optimization problem, the following notation should be noted. In each period t, one event $s_t \in S$ is realized, where S is possibly an infinite set. s^t represents the history of events up to and including date t. The probability of any particular history at date 0 is given by $\pi(s^t)$. Consumers and firms make their consumption and investment decisions after the specific state is realized.

3.2.1 Households

In order to isolate the independent effects of rule-of-thumb consumers from the effects of financial market incompleteness, this paper considers three different specifications of the financial market with regard to assets available for international risk sharing. Those are the '*contingent bond economy*', the '*uncontingent bond economy*', and the '*financial autarky*'. In each case, rational consumers face a different budget constraint depending on the available assets. For simplicity, I assume that each intermediate good producing firm is fully owned by domestic rational consumers.[3]

Optimizing Consumer

A rational consumer in the country j chooses her consumption and labor supply, $C_j^{PIH}(s^t)$ and $N_j^{PIH}(s^t)$, for all s^t and all $t \geq 0$ to maximize the sum of expected discounted lifetime utility,

$$\sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t) U\left(C_j^{PIH}(s^t), N_j^{PIH}(s^t)\right), \tag{3.1}$$

subject to the proper budget constraint corresponding to each economy, which are discussed below. Note that the superscript PIH are associated with rational consumers and $j = H$ or F.

Contingent bonds economy If a complete set of contingent bonds are allowed to be traded, perfect risk sharing can be obtained among rational consumers in both countries. Following Heathcote and Perri (2002), I assume that a complete set of contingent bonds are denominated in units of good a and traded among rational consumers. Let $B_j(s^t, s_{t+1})$ be the quantity of bond purchased by a rational consumer in country j after history s^t that pays one unit of good a in period $t+1$ if and only if the state s_{t+1} of the economy is realized and let $Q(s_{t+1}|s^t)$ be the price in units of good a of the bond. Then, a representative rational consumer's budget constraint in

[3]While the home bias in international equity portfolio is severe in this model, it is not as bad as it appears. First, rational consumers can access other asset markets. Therefore, even without trading equities, they can achieve sufficient risk sharing. Second, as Heathcote and Perri (2004a) show, in a similar two country and two good model, when only equities are allowed to trade internationally, international equity portfolios are still severely home biased. According to their explanation, the reason for the result is that the movements of the terms of trade provide considerable insurance against country specific idiosyncratic shocks. For details, see Cole and Obstfeld (1991) and Heathcote and Perri (2004).

the home country is given by

$$
\begin{aligned}
&C_H^{PIH}(s^t) + q_H^a(s^t) \sum_{s_{t+1}} Q\left(s_{t+1}|s^t\right) B_H(s^t, s_{t+1}) \\
&\qquad \leq q_H^a(s^t) \left\{W_H(s^t) N_H^{PIH}(s^t) + \Pi_H(s^t)\right\} + q_H^a(s^t) B_H(s^{t-1}, s_t),
\end{aligned} \tag{3.2}
$$

where $W_H(\cdot)$ and $\Pi_H(\cdot)$ represent wages and dividends also in units of good a and $q_H^a(\cdot)$ denotes the price of intermediate good a in the home country.

The budget constraint for a representative rational consumer in the foreign country is analogous.

Uncontingent bond economy In this case, only a single uncontingent bond is allowed to be traded for international risk sharing purposes. Again, I assume that the bond is denominated in units of good a. Let $B_j(s^t)$ denote the quantity of the bond purchased by a rational consumer and $Q(s^t)$ denote its price in units of good a. The bond pays one unit of good a in period $t+1$ irrespective of the state in $t+1$. Then, a representative rational consumer's budget constraint in the home country is given by

$$
\begin{aligned}
&C_H^{PIH}(s^t) + q_H^a(s^t) Q\left(s^t\right) B_H(s^t) \\
&\qquad \leq q_H^a(s^t) \left\{W_H(s^t) N_H^{PIH}(s^t) + \Pi_H(s^t)\right\} + q_H^a(s^t) B_H(s^{t-1}).
\end{aligned} \tag{3.3}
$$

A similar budget constraint holds for a representative rational consumer in the foreign country.[4]

Financial autarky In the financial autarky economy, no cross-border trade of financial assets is allowed. Hence, all international transactions should occur through

[4] As Letendre (2000) points out, an international real business cycle model with incomplete market can have an infinite number of steady state equilibria. To close the model with the unique steady state equilibrium, I assume a small cost of bond holdings. For alternative ways of addressing this issue, see Schmitt-Grohé and Uribe (2002).

the trade of intermediate goods. Under this environment, the budget constraint for a representative rational consumer in the home country is given by

$$C_H^{PIH}(s^t) \leq q_H^a(s^t)\left\{W_H(s^t)N_H^{PIH}(s^t) + \Pi_H(s^t)\right\}. \tag{3.4}$$

A representative rational consumer in the foreign country faces a similar budget constraint.

Rule-of-Thumb Consumers

Following van Wincoop (1996) and Galí, López-Salido, and Vallés (2004), a rule-of-thumb consumer is assumed not to hold any financial assets and to simply consume her current wage income. As a result, a representative rule-of-thumb consumer in each country chooses her consumption and labor supply, $C_j^{Rule}(s^{t+\tau})$ and $N_j^{Rule}(s^{t+\tau})$, for all $s^{t+\tau}$ and all $\tau \geq 0$ to maximize the sum of expected discounted lifetime utility,

$$\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}} \beta^{\tau}\pi(s^{t+\tau})U\left(C_j^{Rule}(s^{t+\tau}), N_j^{Rule}(s^{t+\tau})\right), \tag{3.5}$$

subject to sequence of simple budget constraints

$$C_j^{Rule}(s^{t+\tau}) \leq W_j(s^{t+\tau})N_j^{Rule}(s^{t+\tau}) \tag{3.6}$$

where $j = H$ or F. It is easy to see that the rule-of-thumb consumer cannot smooth her consumption intertemporally because she cannot hold any financial or physical assets.[5]

3.2.2 Firms

A representative intermediate goods producing firm in the home country faces the following dynamic optimization problem. It chooses the inputs of labor and

[5] Admittedly, the rule-of-thumb behavior assumed in this paper is one special case. For the empirical and theoretical justifications of the specified behavior, see Mankiw (2000). Many different forms of rule-of-thumb behavior can be proposed, such as a constant saving rate rule. For example, Krusell and Smith (1996) discuss various forms of rule-of-thumb behavior and study their implications in a standard business cycle model.

capital and investment, $K_H(s^t)$, $N_H(s^t)$, and $I_H\left(s^t\right)$, to maximize the sum of expected discounted profits,

$$\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\beta^t\pi(s^t)\Gamma_H\left(s^t,s^{t+\tau}\right)q_H^a(s^{t+\tau})\times$$

$$\left[F(K_H(s^{t+\tau-1}),N_H(s^{t+\tau}))-W_H(s^{t+\tau})N_H(s^{t+\tau})-\frac{1}{q_H^a(s^{t+\tau})}I_H(s^{t+\tau})\right], \tag{3.7}$$

subject to

$$K_H(s^{t+\tau})=(1-\delta)K_H(s^{t+\tau-1})+I_H(s^{t+\tau}), \tag{3.8}$$

where $\Gamma_H\left(s^t,s^{t+\tau}\right)$ is a proper stochastic discounting factor. Note that since all firms in the home country are owned by home rational consumers, the proper stochastic discounting factors need to be derived from the consumers' intertemporal decisions.

Meanwhile, a representative final good producing firm in the home country maximizes the sum of expected discounted profits,

$$\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\beta^t\pi(s^t)\Gamma_H\left(s^t,s^{t+\tau}\right)\times$$

$$\left[G_H\left(a_H(s^{t+\tau}),b_H\left(s^{t+\tau}\right)\right)-q_H^a(s^{t+\tau})a_H(s^{t+\tau})-q_H^b(s^{t+\tau})b_H(s^{t+\tau})\right], \tag{3.9}$$

by determining the quantaties of the home and foreign intermediate goods, $a_H(\cdot)$ and $b_H(\cdot)$, for producing final goods.

The intermediate and final good producing firms in the foreign country face analogous optimization problems.

3.2.3 Market Clearings and Equilibrium

An equilibrium is defined as a set of prices and quantities for all s^t and for all $t\geq 0$ such that all consumers and firms solve their optimization problems and all markets clear. The equilibrium can be described by the optimality conditions from the consumers' and firms' optimization problems above and various market clearing conditions for good and financial markets.

Market clearing conditions for intermediate good a and b require that

$$a_H(s^t) + a_F(s^t) = F(A_H(s^t), K_H(s^{t-1}), N_H(s^t)) \tag{3.10}$$

and

$$b_H(s^t) + b_F(s^t) = F(A_F(s^t), K_F(s^{t-1}), N_F(s^t)). \tag{3.11}$$

Market clearing conditions for final goods require that

$$C_j(s^t) + I_j(s^t) = G_j(a_j(s^t), b_j(s^t)), \tag{3.12}$$

where $j = H$ or F.

Finally, the financial market should also clear. If contingent bonds are traded, then bond market clearing requires that

$$B_H(s_{t+1}|s^t) + B_F(s_{t+1}|s^t) = 0 \tag{3.13}$$

for all $s_{t+1} \in S$. If only an uncontingent bond is traded, then bond market clearing requires that

$$B_H(s^t) + B_F(s^t) = 0. \tag{3.14}$$

3.2.4 Other interested variables

Aggregate consumption and aggregate labor services in each country are the sum of consumption and labor services by the two types of consumers respectively. Aggregate consumption and labor services in the home country are defined as

$$C_H(s^t) = \lambda C_H^{PIH}(s^t) + (1-\lambda) C_H^{Rule}(s^t) \tag{3.15}$$

and

$$N_H(s^t) = \lambda N_H^{PIH}(s^t) + (1-\lambda) N_H^{Rule}(s^t), \tag{3.16}$$

where λ is the fraction of rational consumers in the population. Their foreign counterparts are defined analogously.

Finally, GDP, net exports, the terms of trade, and the real exchange rate are defined as follows:

$$Y_H(s^t) = q_H^a(s^t) F(A_H(s^t), K_H(s^{t-1}), N_H(s^t)), \tag{3.17}$$

$$NX_H(s^t) = \frac{q_H^a(s^t) a_F(s^t) - q_H^b(s^t) b_H(s^t)}{Y_H(s^t)}, \tag{3.18}$$

$$ToT(s^t) = \frac{q_H^b(s^t)}{q_H^a(s^t)}, \tag{3.19}$$

and

$$RX(s^t) = \frac{q_H^a(s^t)}{q_F^a(s^t)} = \frac{q_H^b(s^t)}{q_F^b(s^t)}, \tag{3.20}$$

where Y_H represents real GDP in the home country and NX, ToT, and RX represent net exports, the terms of trade, and the real exchange rate respectively. Again, their foreign counterparts are defined in similar fashions.

3.3 Parameterization and computation

3.3.1 Preference and Technology

The preferences of consumers are the same across countries and types and are given by an instantaneous utility function

$$U(C, N) = \frac{1}{1-\gamma} C^{1-\gamma} - a_n \frac{1}{1+\frac{1}{\eta}} N^{1+\frac{1}{\eta}}, \tag{3.21}$$

where C and N represent consumption and labor supply in each period. Both types of consumers are assumed to supply labor to the perfectly competitive labor market in their country and earn wage income.[6]

The production side of the model is specified as standard in the international business cycle literature. An intermediate good producing firm's technology is given by a standard Cobb-Douglas production function with internationally immobile capital and labor

$$F(A,K,N) = A\,(N)^{\alpha}\,(K)^{1-\alpha}, \tag{3.22}$$

where A, N, and K represent the productivity level, labor, and capital respectively.

The production function for final good producing firms is given as a simple CES aggregator,

$$G_H(a_H, b_H) = \left[\omega a_H^{(\sigma-1)/\sigma} + (1-\omega) b_H^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)} \tag{3.23}$$

and

$$G_F\left(a_F, b_F\right) = \left[(1-\omega) a_F^{(\sigma-1)/\sigma} + \omega b_F^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}, \tag{3.24}$$

where σ is the elasticity of substitution between home and foreign intermediate goods (i.e. between a and b) and ω is the degree of home bias in the intermediate good demand and assumed to be greater than 0.5.

3.3.2 Parameter values

Table 3.1 summarizes the benchmark parameterization of the model. Most parameters are standard in real business cycle literature. The most important parameter for this study is λ which represents the fraction of rational consumers in the population. The parameter is calibrated to 0.5 based on Campbell and Mankiw (1989)

[6]In van Wincoop (1996), the whole population is divided into capitalists and laborers and only laborers can provide labor services to the labor market.

and van Wincoop (1996).[7] Following Heathcote and Perri (2002), σ, the elasticity of substitution between intermediate good a and b is calibrated to 0.9 and ω which determines the degree of home bias in the intermediate good demand is calibrated such that the ratio of imports to gross domestic product is equal to 0.15 at the steady state.[8]

Table 3.1: Parameters

Preference	risk aversion = 5	γ=1
	elasticity of labor supply = 1	η=1
Technology	labor share	α=0.65
	depreciation rate	δ=0.025
Others	fraction of rational consumer	λ=0.5
	elasticity of substitution between intermediate goods	σ=0.9
	degree of home bias in final goods composition	ω=0.89

For the productivity process, I use estimates from Heathcote and Perri (2002) as a benchmark. The process is given by

$$\begin{bmatrix} \log\left(A_{H,t}\right) \\ \log\left(A_{F,t}\right) \end{bmatrix} = \begin{bmatrix} 0.970 & 0.025 \\ 0.025 & 0.970 \end{bmatrix} \begin{bmatrix} \log\left(A_{H,t-1}\right) \\ \log\left(A_{F,t-1}\right) \end{bmatrix} + \begin{bmatrix} \varepsilon_{H,t} \\ \varepsilon_{F,t} \end{bmatrix}, \tag{3.25}$$

where the productivity innovations, ε_H and ε_F, have zero means and are serially uncorrelated. Their second moments are given by $var(\varepsilon_H) = var(\varepsilon_F) = (0.0073)^2$ and $corr(\varepsilon_H, \varepsilon_F) = 0.290$.

Since, as Baxter and Crucini (1995) emphasize, the implications of models with incomplete market depend heavily on the specification of the productivity process, I also consider other productivity processes which are employed in BKK (1995) and Baxter and Crucini (1995).[9]

[7] I have estimated the same equation as Campbell and Mankiw (1989) using updated data. Even though the estimated coefficients vary over different periods, they are estimated to be about 0.5 in most cases.

[8] For details of the calibration of σ and ω, see Heathcote and Perri (2002).

[9] The salient differences among different productiviy processes lie at the assumed coefficients of persistence and spill-over in productivity transition matrices. Compared with the benchmark process, BKK (1995) assume a process which is less persistent (0.906) but has larger spill-over effects (0.088). Meanwhile, Baxter and Crucini (1995) assume a random walk process without spill-over.

3.3.3 Computation method

I solve the model by a first order linear approximation method. After linearizing the equations which characterize equilibrium around the steady state, I solve the linear difference equations using the AIM algorithm.

3.4 Results

Since the main purpose of this paper is to investigate the effects of introducing rule-of-thumb consumers to an international business cycle model, I focus on the effect of varying λ, the fraction of rational consumers. However, for comparison with other literature, I report major business cycle statistics as well.

3.4.1 Benchmark parameterization

The main results of simulations under the benchmark parameterization are summarized in Table 3.2. Recall that half of the consumers are assumed to be a rule-of-thumb consumer. By way of comparison with the results of a standard international business cycle model in which all consumers are assumed to be rational, I also report in Table 3.3 the corresponding statistics under the assumption that $\lambda = 1$.

As shown in those tables, with respect to domestic business cycle properties, volatilities and correlations are quite consistent with the data but not affected much either by different restrictions on types of available assets for international risk sharing or by the presence of rule-of-thumb consumers. The only exception is net exports. In the financial autarky economy, the volatility and the correlation of net exports with output turn out to be quite lower than in the data. This is because, by definition, the trade balance should always be equal to zero in a financial autarky economy.

Another interesting finding with regard to domestic business cycle properties is

Table 3.2: Business cycle statistics(λ=0.5)

	Data	Contingent Bonds	Noncontingent bonds	Financial autarky
Standard deviations relative to GDP				
Consumption	0.81	0.58	0.57	0.58
Investment	2.84	2.75	2.75	2.33
Employment	0.66	0.21	0.21	0.21
Net exports	0.27	0.16	0.14	0.01
Correlation with GDP				
Consumption	0.86	0.99	0.98	0.98
Investment	0.95	0.96	0.96	0.99
Employment	0.87	0.98	0.97	0.97
Net exports	-0.49	-0.57	-0.56	-0.02
Terms of Trade	-0.24	0.52	0.52	0.46
Real exchange rate	0.13	0.52	0.52	0.46
Cross-correlation between countries				
GDP	0.58	0.34	0.36	0.58
Consumption	0.36	0.47	0.53	0.75
Investment	0.30	-0.13	-0.11	0.42
Employment	0.42	0.14	0.10	0.30
Rule-of-thumb consumption	N.A.	0.39	0.42	0.64
Volatilities of international prices				
Terms of trade	2.99	0.52	0.63	1.49
Real exchange rate	3.73	0.38	0.46	1.10

Note: All economies are simulated under the assumption that half of the consumers are rule-of-thumb consumers. The data statistics are borrowed from Table 2 of Heathcote and Perri (2002). They are calculated from time series for the period 1973:1-1998:4. All series have been logged (except for net exports) and H.P. filtered with a smoothing parameter of 1600. The statistics from the model are averages of 20 simulations of 100 periods.

Table 3.3: Business cycle statistics(λ=1)

	Data	Contingent Bonds	Noncontingent bonds	Financial autarky
Standard deviations relative to GDP				
Consumption	0.81	0.48	0.47	0.48
Investment	2.84	3.12	3.12	2.67
Employment	0.66	0.28	0.29	0.28
Net exports	0.27	0.15	0.14	0.01
Correlation with GDP				
Consumption	0.86	0.96	0.95	0.95
Investment	0.95	0.96	0.96	0.99
Employment	0.87	0.97	0.97	0.96
Net exports	-0.49	-0.57	-0.56	-0.02
Terms of Trade	-0.24	0.53	0.53	0.46
Real exchange rate	0.13	0.53	0.53	0.46
Cross-correlation between countries				
GDP	0.58	0.33	0.34	0.57
Consumption	0.36	0.60	0.66	0.84
Investment	0.30	-0.16	-0.15	0.36
Employment	0.42	0.03	0.00	0.23
Volatilities of international prices				
Terms of trade	2.99	0.60	0.70	1.58
Real exchange rate	3.73	0.44	0.52	1.16

Note: All economies are simulated under the assumption that all consumers are rule-of-thumb consumers. The data statistics are borrowed from Table 2 of Heathcote and Perri (2002). They are calculated from time series for the period 1973:1-1998:4. All series have been logged (except for net exports) and H.P. filtered with a smoothing parameter of 1600. The statistics from the model are averages of 20 simulations of 100 periods.

that while the volatility of consumption increases when rule-of-thumb consumers are introduced, the volatility of investment decreases. Compared with the case of $\lambda = 1$, under the benchmark parameterization (i.e. $\lambda = 0.5$), the relative volatility of consumption to that of output increases by about 20 % and the relative volatility of investment decreases by about 10 % irrespective of asset market restrictions. Also, the correlation of aggregate consumption with output increases slightly.

These results are induced directly by the presence of rule-of-thumb consumers. Note that rule-of-thumb consumers are unable to smooth their consumptions because they are assumed not to hold any financial assets. This means that their consumption is more closely tied with output. Since, under the benchmark parameterization, one half of consumers follow the rule-of-thumb behavior, the aggregate consumption is more volatile and more correlated with output than in the case of $\lambda = 1$. Since the volatility of output does not change significantly in the table, the volatility of investment has to decrease.

However, the most interesting result, as shown in Table 3.2 and Table 3.3, is clearly on international correlations. First of all, irrespective of the fraction of rule-of-thumb consumers, the consumption correlation in the financial autarky is higher than in the contingent bond economy. For example, under the assumption of $\lambda = 1$, it is only 0.60 in the contingent bond economy while 0.84 in the financial autarky. It is quite puzzling because usual economic intuitions would suggest that as the opportunity of international risk sharing increases, the consumption correlation should also increase.

However, this counter-intuitive result seems to be common among this class of models. Similar patterns can be found in Heathcote and Perri (2002, 2004b). According to Heathcote and Perri (2004b), it can be explained with the additional role of the financial market in a two good model is to minimizes the deviation from the efficient mix between home and foreign intermediate good. Considering the home bias in the intermediate good demand, it is easy to see that the minimization can be obtained by reducing idiosyncratic output fluctuations while increasing idiosyncratic consumption fluctuations. This means higher output correlations and lower consumption correlations.

With the overall pattern, the comparison between Table 3.2 and Table 3.3 shows that introducing rule-of-thumb consumers reduces the consumption correlation by approximately 15-20 % in each economy. For instance, in the contingent bond economy, with rule-of-thumb consumers, the consumption correlation falls from 0.60 to 0.47. Also, the labor correlation increases even though the number is still much smaller than in the data. Meanwhile, the output correlation and the investment correlation increase only slightly in each economy when rule-of-thumb consumers are introduced, but the investment correlations are still negative except in the financial autarky, which is not in the data.[10]

However, the presence of rule-of-thumb consumers turns out to reduce the volatilities of the terms of trade and the real exchange rate.[11] As is common in this class of models, the volatilities of the terms of trade and the real exchange rate are quite small compared with in the data. Furthermore, when rule of thumb consumers are considered, those numbers are even smaller.

This result can be explained by the fact that the aggregate absorption volatility tends to increase with rule-of-thumb consumers. After a positive technology shock in the domestic intermediate good sector, the price of domestic intermediate good will fall. However, the domestic aggregate demand increases simultaneously due to the

[10]When I simulate one good model with similar specifications, I obtain very similar results.

[11]Note that after log-linearization and some manipulations, the real exchange rate can be shown to be a linear function of the terms of trade in the economies. Hence, the volatility of the terms of trade is the same as that of the real exchange rate. But, it is not the case in the data. For details, see the appendix of Heathcote and Perri (2002)

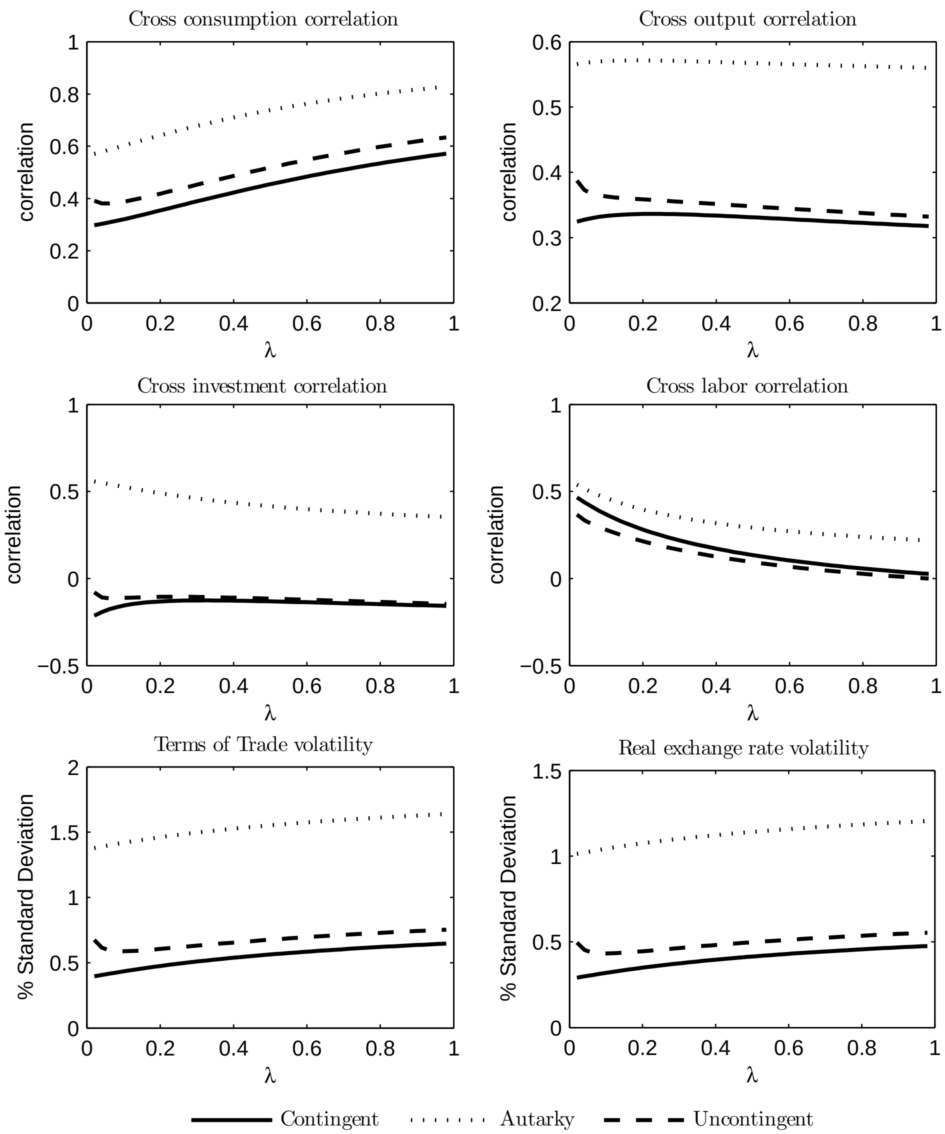
wealth effect of the shock. Due to the home bias in the intermediate good demand, the demand for the home intermediate good increases disproportionally compared with that of foreign intermediate good. So, the demand effect increases the price of home intermediate good and partially offsets the initial fall of the price. Note that the presence of rule-of-thumb consumers tends to increase the volatility of domestic absorption. Clearly, as the volatility increases, the demand effect is larger. Then, it is easy to see that with rule-of-thumb consumers, volatilities of the terms of trade and the real exchange rate fall in this class of models.

3.4.2 Varying the fraction of rational consumers

In previous section, I compared the results of the benchmark parameterization (i.e. $\lambda = 0.5$) with those of a standard real business cycle model (i.e. $\lambda = 1$). In this section, I investigate how international correlations and volatilities of prices are quantitatively affected as the fraction of rule-of-thumb consumers is changed. I compute averages of various correlations and volatilities for 20 simulations of 100 periods with varying λ. Those second moments are summarized in Figures 3.1, 3.2 and 3.3. As Baxter and Crucini (1995) point out, the overall performances of international business cycles model with incomplete financial market depend crucially on the specification of the international productivity process. With this in mind, I draw each figure based on different specifications of the productivity process. I consider three different productivity processes with differing degrees of persistence and spill-over, which are frequently used in previous studies. Note that *Contingent*, *Uncontingent*, and *Autarky* in the figures represent, respectively, economies with contingent bonds, an uncontingent bond, and financial autarky.

As Figure 1 shows, under the benchmark specification of the productivity process (persistence coefficient: 0.97, spill-over coefficient: 0.025), as the fraction of rule-of-

Figure 3.1: Benchmark productivity process



thumb consumers increases (i.e. as λ decreases), the overall performance of the model improves monotonically for the reasonable interval of λ over all economies. The consumption correlation and the labor correlation improve more relative to other aspects of the economies. Meanwhile, the output correlation and the investment correlation improve only modestly and the volatilities of the terms of trade and the real exchange rate even deteriorate.

Another interesting observation in Figure 3.1 is that introducing rule-of-thumb consumers improves more the overall performance of the model, except volatilities of international prices, than a mild restriction on asset trades (i.e. allowing an uncontingent bond only). The consumption correlation falls merely by 0.04 and the output correlation increases by 0.01 when only an uncontingent bond is allowed to be traded and all consumers are assumed to be rational (i.e. $\lambda = 1$). However, the volatilities of the terms of trade and the real exchange rate increase only slightly. In summary, the overall performances of a standard model do not improve much with a mild restriction on asset trades under the benchmark specification of the productivity process.

Meanwhile, when I consider a contingent bond economy and change λ from 1 to 0.5, the overall performance of the model improves impressively, especially for quantity correlations. Recall that the comparison is already made in part (3) of Table 3.2. As shown in the part, the consumption correlation falls by 0.13 and the labor correlation increases by 0.11 while the output correlation and the investment correlation increase only by 0.01 and 0.03 respectively. However, the volatilities of the terms of trade and the real exchange rate fall by 0.08 and 0.06 respectively.

Figure 3.2 is based on the less persistent but more spilling over productivity process (persistence coefficient: 0.906 spill-over coefficient: 0.088), which is used in

BKK (1994, 1995). The overall pattern of Figure 3.2 is identical with that of Figure 3.1. The main difference between the figures is that the mild restriction on asset trade does not make any difference over all values of λ under the specification of the productivity process. The reason is, as Baxter and Crucini (1995) point out, that if the international spill-overs of technology shocks are large enough, the wealth effects from the shocks are small, and as a consequence, rational consumers can achieve as much risk sharing with uncontingent bonds as with complete set of contingent bonds. In such a case, introducing rule-of-thumb consumers is a more fruitful way of solving international macroeconomic puzzles. As seen in part (3) of Table 3.2, merely by changing the fraction from 1 to 0.5 in the contingent bond economy, the consumption correlation decreases by almost 0.2 and the output correlation increases by about 0.05. Also, the labor correlation and the investment correlation increase more than under the benchmark specification of productivity process. However, once again, the volatilities of the terms of trade and the real exchange rate decrease slightly as in Figure 3.1.

In Figure 3.3, quite different patterns emerge. The specification of the productivity process can be interpreted as being more persistent and less spilling over relative to the benchmark specification (persistence coefficient: 1 spill-over coefficient: 0). It is easy to see that the wealth effects from technology shocks are the largest with this specification of the productivity process. Hence, economies with different asset market structures display big discrepancies. Under this specification of the productivity process, introducing rule-of-thumb consumers plays a minor role and seems to be negligible.

Finally, another interesting pattern emerges when Figures 1, 2, and 3 are compared. As the productivity process becomes more persistent but less spilling over, the

Figure 3.2: BKK case: less persistent and more spill-over

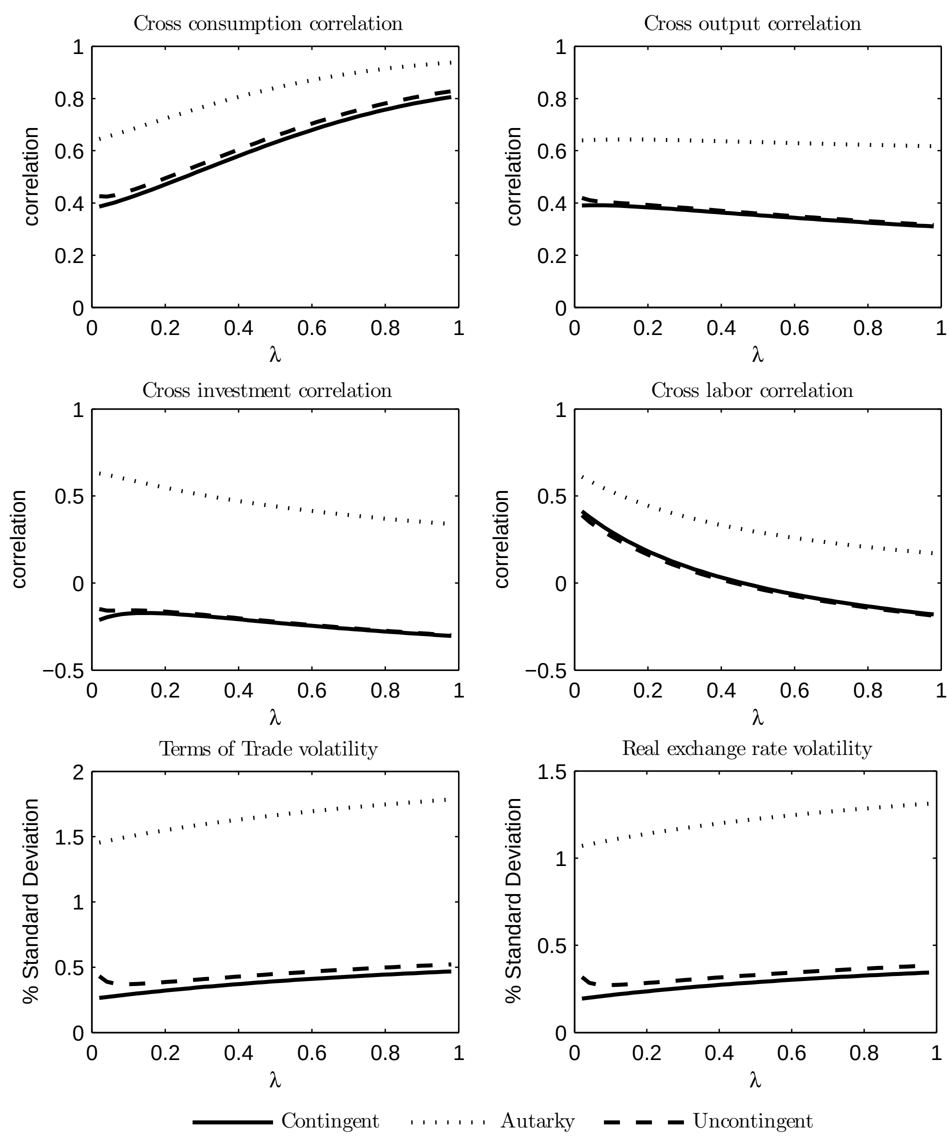
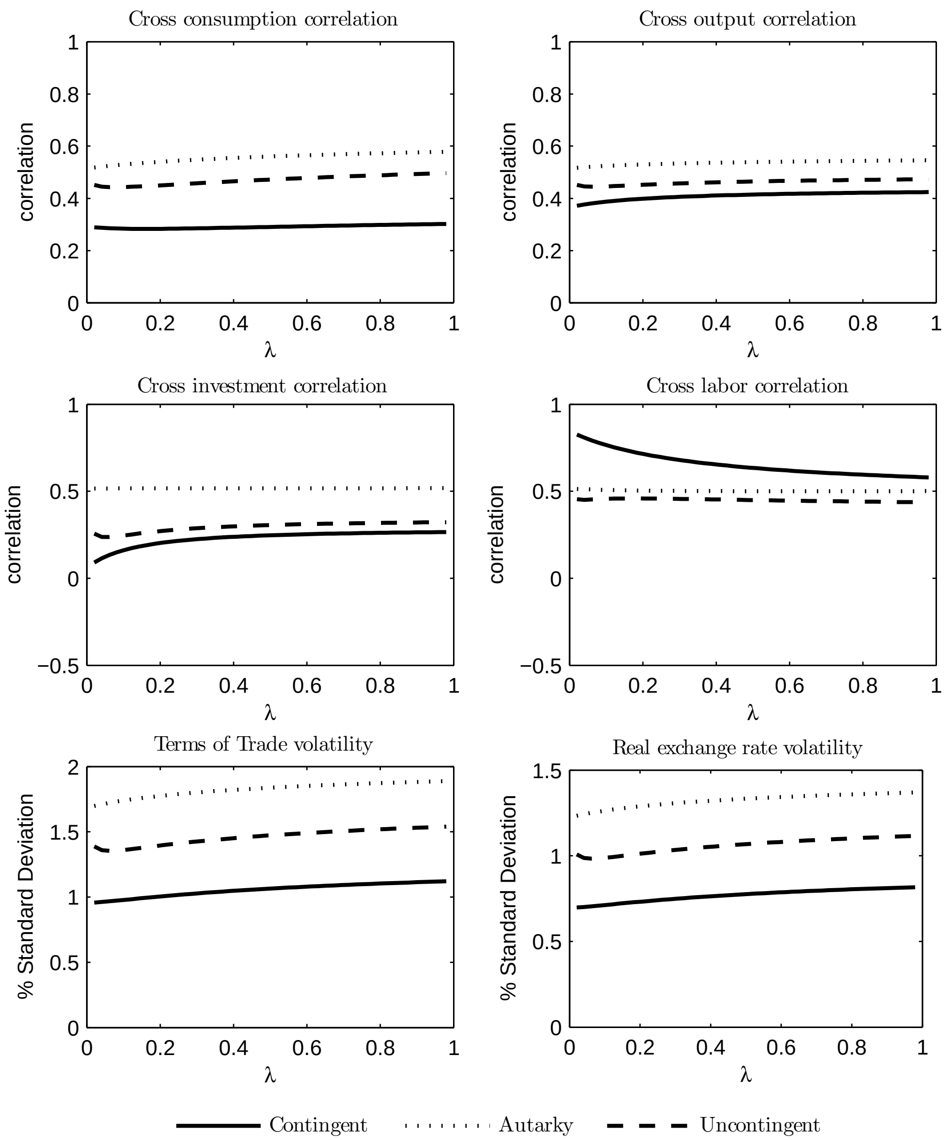


Figure 3.3: Baxter and Crucini case: a unit root and no spill-over



restrictions on the types of available assets for international risk sharing tend to play more of a role in the overall performance of the model. However, in the opposite case, introducing rule-of-thumb consumers plays a significant role irrespective of the types of available assets. This pattern suggests that the effects of rule-of-thumb consumers depend on the specification of the productivity process and matters especially for the case in which the wealth effect is small. In other words, the productivity process is less persistent but more spilling over.[12]

3.5 Conclusion

In this paper, I introduce rule-of-thumb consumers into a standard international real business cycle model and investigate its effects on various international macroeconomic variables. The results can be summarized as follows: First, in addition to restrictions on available assets for international risk sharing, the presence of rule-of-thumb consumers can independently contribute to explaining some international macroeconomic puzzles, especially the consumption correlation puzzle. When I incorporate rule-of-thumb consumers into the model, the consumption correlation falls significantly but the output, labor, and investment correlations increase. However, with regard to the volatilities of the terms of trade and the real exchange rate, the performance of the model deteriorates slightly with rule-of-thumb consumers. Second, the effects depend on the specification of the productivity process. They are more prominent when the process is less persistent but more spilling over.

An interesting extension of this paper would be to consider nontradable intermediate goods to improve the model with respect to the volatilities of the terms

[12]Note that the productivity process assumed in van Wincoop (1996) is similar to the one in Figure 3. Considering that introducing rule-of-thumb consumers in the figure does not make a significant difference, his results should be interpreted more carefully, as they may be driven by the specification of the productivity process, not by the inclusion of rule-of-thumb consumers.

of trade and the real exchange rate. In addition, this would break down the unrealistically tight relationship between those two international prices. Stockman and Tesar (1995) and Tesar (1993) show that the existence of nontradable goods is crucial in explaining various international macroeconomic puzzles. In addition, the importance of nontradable goods has recently been emphasized in understanding the real exchange rate dynamics by many researchers.

Chapter IV

Implicit labor contract and dynamics of labor share

4.1 Introduction

Standard business cycle models have been constructed based on a notion that factor shares of income are constant over business cycles. However, recently this notion has been challenged by several empirical studies. According to these studies, fluctuations in the factor shares are quantitatively considerable and have systematic relationships with other major macroeconomic variables.

More specifically, as Ríos-Rull and Santaeulàlia-Llopis (2008) document in detail, the labor share in the U.S. is quite volatile and persistent at business cycle frequencies. The variance of labor share is about 20% of the variance of output and its autocorrelation coefficient is 0.78. Furthermore, the labor share displays systematic co-movements with other major macroeconomic variables including output. In particular, the labor share exhibits an interesting cross correlation structure with output. While the labor share is only slightly negatively correlated with contemporaneous output, it tends to be positively correlated with past output but negatively correlated with future output. Finally, the labor share overshoots after a productivity shock. The labor share falls immediately after a productivity shock, but in subsequent periods rises to higher than its original level. These empirical regularities suggest that the cyclical fluctuations of factor shares are too large and systematic for macroeconomists to treat them as ignorable noise and abstract them from business cycle analyses.

Many macroeconomists have attempted to reconcile theory with this evidence. Early contributions to this area mainly focus on the countercyclical property of labor share. Gomme and Greenwood (1995) and Ambler and Cardia (1998) can serve as typical examples.[1] Gomme and Greenwood (1995) argue that the risk-sharing between laborers and entrepreneurs can be responsible for the countercyclicality and show that an otherwise standard RBC model with markets for contingent claims between laborers and entrepreneurs can successfully generate a negative correlation between labor share and output. Ambler and Cardia (1998) attribute the countercyclicality to a specific market structure. They show that a model with monopolistically competitive firms which can freely enter and exit from the market can replicate the countercyclicality.[2]

Meanwhile, more recently, Choi and Ríos-Rull (2008) extend the existing literature and try to replicate broader dimensions of the dynamics of labor share with special attention to the 'overshooting' property. They incorporate search frictions in the labor market and noncompetitive wage setting via Nash bargaining into a standard RBC model but report that the model fails to generate the 'overshooting' response of labor share. However, they find that the theoretical impulse response of labor share becomes closer to its empirical counterpart when a CES production function is assumed instead of a Cobb-Douglas production function. Based on this observation,

[1] Similar analyses can be found in Hornstein (1993) and Boldrin and Horvath (1995) even though the cyclicality of factor shares is not a main issue in these studies.

[2] There are several papers addressing this issue in a different perspective. They commonly take the fluctuations of factor shares as given (redistributive shocks) and use them to explain other macroeconomic or financial phenomena. Young (2004), Danthine, Donaldson, and Siconolfi (2005) and Ríos-Rull and Santaeulàlia-Llopis (2008) are representative.

they argue that departing from a Cobb-Douglas production function may be a more promising way of explaining the dynamics of factor shares.

In a similar vein, this paper attempts to explain theoretically the dynamics of labor share at business cycle frequencies. Particularly, it focuses on the implications of risk-sharing between laborers and entrepreneurs for the cyclical fluctuations of labor share. For this purpose, the paper introduces an implicit labor contract between laborers and entrepreneurs in the spirit of Azariadis (1983) into a standard RBC model to allow the laborers and entrepreneurs to share their income risks.[3]

The findings of this paper can be summarized as follows: The model generates a magnitude of volatility and persistence of labor share similar with their empirical counterparts and also succeeds in replicating the 'overshooting' property. However, it fails to match quantitatively the empirical cross correlation structure. Particularly, the labor share and contemporaneous output in the model are more negatively correlated than they are in the data. In sum, despite some unsatisfactory aspects, the overall results suggest that the risk-sharing between laborers and entrepreneurs via the implicit labor contract may be one of primary forces determining the dynamics of factor shares and can serve as a building block to model the dynamics of factor shares in future research.

The remainder of the paper is organized as follows: In the next section, the theoretical model is described in detail. For comparison with standard RBC models, equilibria with and without the labor contract will be discussed. Then, the parameterization and the solution method are discussed in section 4.3. Simulations and theoretical findings are presented and discussed in section 4.4. The final section concludes with a brief summary of the major findings and a discussion of possible

[3]Boldrin and Horvath (1995) and Danthine and Donaldson (2002) use similar models to analyze different issues.

extension of this paper.

4.2 Model

This paper studies the following simple economic environment. There are two types of infinitely lived agents in the theoretical economy. They are laborers and entrepreneurs and both are homogeneous respectively. The laborers supply their labor services for firms and earn wage incomes. They are assumed not to have access to financial markets. As a result, they cannot smooth their consumption intertemporally by trading financial assets. Meanwhile, the entrepreneurs have the whole ownership of all the firms in the economy and own all the capital. The firms produce a homogeneous final good and behave competitively. Finally, the laborers are assumed to be permanently employed by the firms.[4]

The main distinction between the model considered in this paper and a standard RBC model is that the laborers and entrepreneurs can share their income risks through an implicit labor contract.[5] For a better understanding of the implications of the feature, it will be useful to compare the model with standard RBC models. First, I will present the competitive equilibrium in which the risk-sharing feature is not included. Then, I will describe the equilibrium with the optimal labor contract, which can be derived from a Nash bargaining problem, and compare both equilibria.

For notation, s_t denotes a particular state of the world at time t and the history of events up to period t is represented by $s^t = (s_o, \cdots, s_t)$. The probability of any particular history of s^t is $\pi(s^t)$.

[4]Consequently, the dynamics of unemployment are abstracted away in this paper.

[5]In sum, the model considered in this paper is close to the one presented in Boldrin and Horvath (1995) and Danthine and Donaldson (2002).

4.2.1 Equilibrium without labor contract

When the theoretical economy does not allow any labor contract arrangement between the laborers and entrepreneurs, the labor market is perfectly competitive and both parties simply accept the market wage rate as given. In this environment, the decision problems of both agents become simple.

A representative laborer chooses consumption and leisure, $C^L(s^{t+\tau})$ and $1 - N^L(s^{t+\tau})$, given the market wage rate, $W(s^{t+\tau})$, to solve the following utility maximization problem:

$$\max \sum_{\tau=0}^{\infty} \sum_{s^{t+\tau}} \beta^{\tau} \pi(s^{t+\tau}) U\left(C^L(s^{t+\tau}), 1 - N^L(s^{t+\tau})\right) \tag{4.1}$$

subject to sequence of budget constraints

$$C^L(s^{t+\tau}) \leq W(s^{t+\tau}) N^L(s^{t+\tau}) \tag{4.2}$$

where $U(\cdot)$ denotes the laborer's instantaneous utility function over consumption and leisure. β represents a time discount factor.

The optimality conditions of the laborer's optimization problem are summarized in the following equation

$$\frac{U_2\left(C^L(s^{t+\tau}), 1 - N^L(s^{t+\tau})\right)}{U_1\left(C^L(s^{t+\tau}), 1 - N^L(s^{t+\tau})\right)} = W(s^{t+\tau}). \tag{4.3}$$

As (4.3) indicates, only intratemporal optimality matters for laborers since they are assumed not to use any financial assets for smoothing their consumption intertemporally.

Meanwhile, the entrepreneurs are assumed to own all the capital and firms in the economy but not to supply labor services to the firms. Hence, their consumption is simply equivalent to the sum of total profits and total capital rental fees. Hence, a representative entrepreneur chooses simply investment and labor inputs, $I(s^{t+\tau})$ and $N^L(s^{t+\tau})$, given the market wage rate, capital stock, and productivity level, $W(s^{t+\tau})$, $K(s^{t+\tau-1})$, and $A(s^{t+\tau})$, to maximize the sum of discounted expected utilities from consumption

$$\sum_{\tau=0}^{\infty}\sum_{s^{t+\tau}}\beta^{\tau}\pi(s^{t+\tau})V\left(C^E(s^{t+\tau})\right) \tag{4.4}$$

subject to sequence of budget constraints

$$\begin{aligned} & C^E(s^{t+\tau}) \\ \le\ & F\left(A(s^{t+\tau}), K(s^{t+\tau-1}), N^L(s^{t+\tau})\right) - W(s^{t+\tau})N^L(s^{t+\tau}) - I(s^{t+\tau}) \\ & -\frac{1}{2}\phi_K\left(\frac{I(s^{t+\tau})}{K(s^{t+\tau-1})}-\delta\right)^2 K(s^{t+\tau-1}) \end{aligned} \tag{4.5}$$

and the law of motion for capital

$$K(s^{t+\tau}) = (1-\delta)K(s^{t+\tau-1}) + I(s^{t+\tau}) \tag{4.6}$$

where $V(\cdot)$ and $F(\cdot)$ denote the entrepreneur's instantaneous utility function and production function respectively. δ and ϕ_K are the depreciation rate of capital and the scaling factor of capital adjustment cost.

From the utility maximization problem, optimality conditions can be derived as follows:

$$W(s^{t+\tau}) = F_3\left(A\left(s^{t+\tau}\right), K(s^{t+\tau-1}), N^L(s^{t+\tau})\right) \tag{4.7}$$

and

$$\begin{aligned} P_K(s^{t+\tau}) = & \sum_{s^{t+\tau+1}}\Gamma(s^{t+\tau}, s^{t+\tau+1})\{F_2\left(A(s^{t+\tau+1}), K(s^{t+\tau}), N^L(s^{t+\tau+1})\right) \\ & +\frac{\phi_K}{2}\left(\frac{I(s^{t+\tau})}{K(s^{t+\tau-1})}-\delta\right)\left(\frac{I(s^{t+\tau})}{K(s^{t+\tau-1})}+\delta\right) + (1-\delta)\,P_K(s^{t+\tau+1})\}, \end{aligned} \tag{4.8}$$

where

$$\Gamma(s^{t+\tau}, s^{t+\tau+1}) \equiv \beta \frac{\pi(s^{t+\tau+1})V'\left(C^E(s^{t+\tau+1})\right)}{\pi(s^{t+\tau})V'\left(C^E(s^{t+\tau})\right)} \tag{4.9}$$

and

$$P_K(s^{t+\tau}) \equiv 1 + \phi_K \left(\frac{I(s^{t+\tau})}{K(s^{t+\tau-1})} - \delta \right). \tag{4.10}$$

Although these two equations are quite familiar in this type of optimization problem, (4.7) deserves a brief discussion because it has an important implication for fluctuations of factor shares. As is well known, the combination of (4.7) and a Cobb-Douglas production function implies that the factor shares are constant. In contrast, as will be shown in the next subsection, this relationship does not hold when risk-sharing between the laborers and entrepreneurs via an implicit labor contract is allowed.

In addition to the optimality conditions described above, the following two equations determine jointly the competitive equilibrium in the theoretical economy.

$$\begin{aligned} & F\left(A(s^{t+\tau}), K(s^{t+\tau-1}), N^L(s^{t+\tau})\right) \\ & = C^E(s^{t+\tau}) + C^L(s^{t+\tau}) + I(s^{t+\tau}) + \frac{1}{2}\phi_K \left(\frac{I(s^t)}{K(s^{t-1})} - \delta \right)^2 K(s^{t-1}) \end{aligned} \tag{4.11}$$

$$K(s^{t+\tau}) = I\left(s^{t+\tau}\right) + (1-\delta)\, K(s^{t+\tau-1}) \tag{4.12}$$

4.2.2 Equilibrium with labor contract

As emphasized earlier, the key feature of the model considered in this paper is that the laborers and entrepreneurs are allowed to share their income risks through an implicit labor contract. Below, I describe the equilibrium when the implicit labor contract is introduced into the model.

The contract specifies pairs of wage rates and labor hours for every state over the contract period such that a Pareto efficient allocation can be achieved given the allocation of negotiating powers between two parties. Hence, the optimal contract is simply the solution to the following Nash bargaining problem:

$$\max \sum_{\tau=1}^{T} \sum_{s^{t+\tau}} \beta^{\tau} \pi(s^{t+\tau}) \times \\ \left[\chi U\left(C^L(s^{t+\tau}), 1 - N^L(s^{t+\tau})\right) + (1-\chi) V\left(C^E(s^{t+\tau})\right)\right] \tag{4.13}$$

subject to the budget constraints of the laborers and entrepreneurs, (4.2) and (4.5), and the law of motion of capital, (4.6), for $\tau = 1, \cdots, T$. χ represents the bargaining power of laborers. Finally, it is assumed that once the contract is agreed and signed by both parties, it is enforceable and holds good for T periods.[6]

The optimality conditions from the problem are as follows:

$$\chi U_1\left(C^L(s^{t+\tau}), 1 - N^L(s^{t+\tau})\right) = (1-\chi) V'\left(C^E(s^{t+\tau})\right), \tag{4.14}$$

$$\frac{U_2\left(C^L(s^{t+\tau}), 1 - N^L(s^{t+\tau})\right)}{U_1\left(C^L(s^{t+\tau}), 1 - N^L(s^{t+\tau})\right)} = F_3\left(A\left(s^{t+\tau}\right), K(s^{t+\tau-1}), N^L(s^{t+\tau})\right), \tag{4.15}$$

and

$$P_K(s^{t+\tau}) = \sum_{s^{t+\tau+1}} \Gamma(s^{t+\tau}, s^{t+\tau+1}) \{F_2\left(A(s^{t+\tau+1}), K(s^{t+\tau}), N^L(s^{t+\tau+1})\right) \\ + \frac{\phi_K}{2}\left(\frac{I(s^{t+\tau+1})}{K(s^{t+\tau})} - \delta\right)\left(\frac{I(s^{t+\tau+1})}{K(s^{t+\tau})} + \delta\right) + (1-\delta) P_K(s^{t+\tau+1})\} \tag{4.16}$$

for $\tau = 1, ..., T$.[7] In addition to these optimality conditions, the resource constraint and the law of motion for capital determine the equilibrium in the model.

To investigate the implications of the implicit labor contract in detail, it will be useful to compare the equilibrium with the competitive equilibrium. Two interesting observations can be made from the comparison. First, as (4.14) shows, when the

[6]The technical details of implicit labor contract will not be discussed at length because the contract itself is not of main interest in this paper. For details, see Azariadis (1975), Rosen (1985), Boldrin and Horvath (1995), and among others.

[7]It is easy to see that the same allocation can be achieved by contingent bond markets. For details, see Gomme and Greenwood (1995).

implicit labor contract is introduced into the model, the ratio of marginal utility of the laborer's consumption to that of the entrepreneur is kept constant as $(1-\chi)/\chi$, which reflects the risk-sharing between the laborers and entrepreneurs. Second, unlike in the competitive equilibrium, the equilibrium wage rate is not necessarily equal to the marginal product of labor. As the system of equations describing the equilibrium suggests, the laborer's consumption and labor hours are determined directly by the equilibrium conditions. Meanwhile, the wage rate can be deduced using the laborer's budget constraint, (4.2), because the laborer's consumption is exactly equal to labor income in the equilibrium. As emphasized above, this non-Walarsian property of factor pricing plays a key role in generating non-constancy of factor shares in the model.

4.3 Parameterization

In this section, I discuss how I choose functional forms for technology and preferences, as well as how parameter values are calibrated in simulations.

4.3.1 Preference and technology

The preferences of laborers and entrepreneurs are given respectively by the following instantaneous utility functions,

$$U\left(C^L, 1-N^L\right) = \frac{1}{1-\gamma}\left[\left(C^L\right)^{\theta}\left(1-N^L\right)^{1-\theta}\right]^{1-\gamma} \tag{4.17}$$

and

$$V\left(C^E\right) = \frac{1}{1-\eta}\left(C^E\right)^{1-\eta}, \tag{4.18}$$

where γ and η determine the degrees of risk aversion of laborers and entrepreneurs respectively and θ denotes the weight of consumption in laborers' utility. Note that the laborers' utility function is intrinsically nonseparable between consumption and leisure. But, the utility function becomes separable in the case of $\gamma = 1$. I choose this case as the benchmark model and consider other cases as sensitivity analyses.

When habit formation in consumption and leisure is introduced as another sensitivity analysis, the utility functions are modified as

$$\begin{aligned} & U\left(C_t^L + aC_{t-1}^L, \left(1 - N_t^L + b\left(1 - N_{t-1}^L\right)\right)\right) \\ & \quad = \frac{1}{1-\gamma}\left[\left(C_t^L + aC_{t-1}^L\right)^{\theta}\left(\left(1 - N_t^L\right) + b\left(1 - N_{t-1}^L\right)\right)^{1-\theta}\right]^{1-\gamma} \end{aligned} \tag{4.19}$$

and

$$V\left(C_t^E + cC_{t-1}^E\right) = \frac{1}{1-\eta}\left(C_t^E + cC_{t-1}^E\right)^{1-\eta}, \tag{4.20}$$

where a, b, and c control respectively the degrees of habit persistence of corresponding consumption and leisure for laborers and consumption for the entrepreneurs.

Turning to the production function, the technology of firms is given by a standard Cobb-Douglas production function

$$F(A, N, K) = AN^{\alpha}K^{1-\alpha} \tag{4.21}$$

where A, N, and K represent the productivity level, labor, and capital. The labor share in production is represented by α.

4.3.2 Parameter values

Most of the parameters in the model are calibrated using standard values from the existing literature. Table 4.1 summarizes the calibration of the parameters in the model. However, some parameters merit a brief discussion.

First, consider parameters related to the preferences of laborers and entrepreneurs. As mentioned above, γ and η represent the degrees of risk aversion of laborers and

Table 4.1: Parameters

Preference	risk aversion of laborer	γ=1;1.5
	risk aversion of entrepreneur	η=1;1.5
	habit persistence	a, b, c=0;-0.7
	weight of consumption in utility function	θ=1/3
Technology	labor share in production function	α=2/3
	depreciation rate	δ=0.021
Others	time discount factor	β=0.99

Note: χ is calibrated to make the labor share equal to 2/3 at the steady state. ϕ_K is calibrated such that the ratio of the standard deviation of investment to that of output is around 3.0.

entrepreneurs and the model allows different degrees of risk aversion. However, it is hard to find any reliable guidance for calibrating different attitudes of laborers and entrepreneurs toward risks from empirical literature. Hence, following Gomme and Greenwood (1995), I assume the same degree of risk aversion.[8] For the benchmark and the habit formation cases, I calibrate γ and η to be 1.0. In such cases, the utility function of laborers becomes separable between consumption and leisure. Meanwhile, for the nonseparability case, γ and η are calibrated as 1.5.

Other parameters related to the preferences are calibrated as follows: For θ, which determines the weights of consumption and leisure in composing the laborer's utility, I use 1/3 following Kydland and Prescott (1982). In addition, when habit formation is considered, the parameters of habit persistence, a, b, and c are all calibrated as -0.7.[9]

Another key parameter in the model is χ, which denotes the relative negotiation power of laborers in the Nash bargaining problem. χ is calibrated such that the labor share is 2/3 at the steady state, which is its historical average value.

Finally, following Cooley and Prescott (1995), the productivity shocks are speci-

[8]Boldrin and Horvath (1995) take a different approach. They assume a bigger risk aversion for laborers than for entrepreneurs. Under their parameterization, the implicit labor contract is equivalent to an insurance for laborers offered by entrepreneurs.

[9]For the parameters related to the habit formation, I loosely refer to Eichenbaum et al (1988), Boldrin et al (2001), and Johri and Letendre (2001). Admittedly, the values are not precisely calibrated, but it is hard to find any reliable reference because the related literature has yet to reach a consensus on the extent and the direction of habit formation.

fied to follow a stochastic process given by

$$\log(A_t) = 0.95 \log(A_{t-1}) + \varepsilon_{A,t}, \tag{4.22}$$

where the productivity innovations, $\varepsilon_{A,t}$, have zero mean and are serially uncorrelated. Their second moments are given by $var(\varepsilon_{A,t}) = (0.007)^2$.

Given those parameters, the model is solved numerically using a standard first order approximation method.

4.4 Findings

In this section, I discuss the theoretical findings. First of all, I will investigate how well the model can replicate the empirical dynamics of labor share. For this, I simulate the benchmark model and its modifications with the parameter values calibrated as described above and compare the simulation results with the data. Also, I will discuss the implications of the results and how the benchmark model can be extended for future research.

4.4.1 Benchmark model

Table 4.2 provides the standard summary statistics of the labor share in the data and simulations. As discussed above, in the data, the labor share is quite volatile and persistent at business cycle frequencies. As the table indicates, its standard deviation is about 40% of that of output and its autocorrelation coefficient is 0.78. The benchmark model replicates these numbers quite well. Labor share's standard deviation ratio to that of GDP is 0.58 and its autocorrelation coefficient is 0.70.

Table 4.3 reports the cross correlation structures between labor share and output in the data and various simulations. As the table shows, in the real economy, the labor share displays an interesting cross correlation structure. More specifically, the

Table 4.2: Business cycle statistics: labor share

	Data	Benchmark	Nonseparability	Habit formation
standard deviation	0.43	0.58	0.55	0.61
Autocorrelation	0.78	0.70	0.63	0.56

Note: The statistics are based on logged and H.P. filtered data. All numbers except for in the "Data" column are averages of 100 simulations of 100 periods. Numbers in the "Data" column are borrowed from Table 4 of Ríos-Rull and Santaeulàlia-Llopis (2008). Standard deviation is the ratio of standard deviation of labor share to that of output in each case.

labor share is slightly negatively correlated with contemporaneous output with a correlation coefficient of -0.24. In contrast, the labor share and output show more distinctive co-movements with some lead and lag. The correlation coefficient of the labor share with the lagged output displays a hump-shaped pattern. More concretely, as the lag gets larger, the labor share becomes more positively correlated with output up to 4 quarters of lags, at which point the trend is reversed. At the peak, the correlation coefficient is 0.47. On the other hand, with regard to future output, the labor share shows a similar correlation pattern but with opposite signs. At the trough, the correlation coefficient is -0.34 with 2 quarters of leads.

However, as the same table reports, the benchmark model fails to mimic the empirical cross correlation structure. Particularly, the labor share is too countercyclical. Its correlation coefficient with contemporaneous output is close to -1, which is not the case in the data.[10] Furthermore, as the lead or the lag increases, the correlation coefficient increases monotonically instead of displaying a hump-shaped pattern as in the data. In sum, the benchmark model generates a quite different cross correlation structure compared with that in the data.

Finally, as Choi and Ríos-Rull (2008) emphasize, the most interesting feature of the dynamics of the labor share identified from empirical studies is that the labor share overshoots after a productivity shock. As Figure 4.1 presents, given a one

[10] This strong countercyclicality between the labor share and output can be also found in Boldrin and Horvath (1995) and in Gomme and Greenwood (1995).

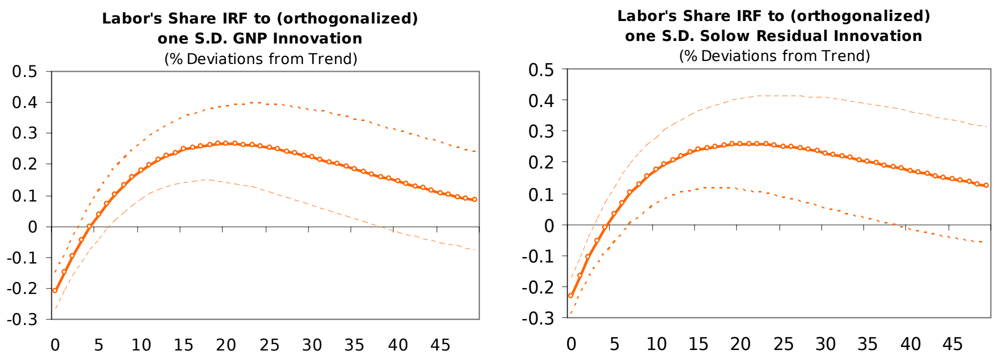
Table 4.3: Cross correlation Structure: output and labor share

	$Corr(Y_{t+k}, LS_t)$										
k	-5	-4	-3	-2	-1	0	1	2	3	4	5
Data	0.44	0.47	0.40	0.25	0.03	-0.24	-0.33	-0.34	-0.32	-0.26	-0.20
Benchmark	0.13	-0.03	-0.20	-0.41	-0.66	-0.99	-0.73	-0.53	-0.35	-0.19	-0.04
Nonseparability	0.19	0.09	-0.07	-0.30	-0.60	-0.99	-0.66	-0.40	-0.18	-0.03	0.06
Habit formation	0.21	0.15	0.05	-0.13	-0.44	-0.91	-0.71	-0.53	-0.38	-0.26	-0.16

Note: The statistics are based on logged and H.P. filtered data. All numbers except for in the "Data" column are averages of 100 simulations of 100 periods. Numbers in the "Data" column are borrowed from Table 4 of Ríos-Rull and Santaeulàlia-Llopis (2008).

standard deviation productivity shock, the labor share in the data falls more than 0.2% from the initial level upon impact. Thereafter it rises continuously in a concave fashion and surpasses its initial level after 6 quarters. Then, it peaks after around 20 quarters about 0.3% above the initial level. After that, it slowly returns to its initial level.[11]

Figure 4.1: Empirical impulse response function of labor share after a productivity shock



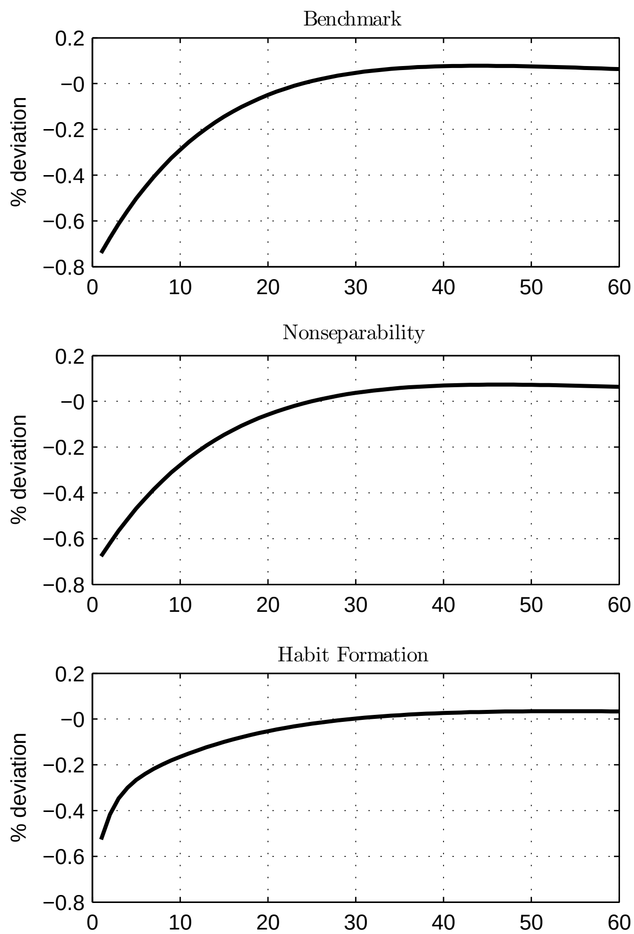
Note: The figures are borrowed directly from Figure 3 in Ríos-Rull and Santaeulàlia-Llopis (2008) for expositional convenience.

To investigate how well the benchmark model performs with regard to the 'overshooting' property, I calculate the impulse response function of labor share by imposing a one standard deviation productivity shock on the model. The result is presented in Figure 4.2. As the figure clearly shows, the benchmark model is successful in generating the 'overshooting' property. As in the data, the labor share falls immediately on impact, then rises above the original level before falling again in subsequent periods.

However, although the impulse response function in the benchmark model mimics the 'overshooting' property of its empirical counterpart, there are still quantitatively noticeable differences between them. First, the labor share falls too much on impact.

[11] Note that the graphs in the figure are not the work of the author but are borrowed from Figure 3 in Ríos-Rull and Santaeulàlia-Llopis (2008) only for expositional convenience.

Figure 4.2: Theoretical impulse response function of labor share after a productivity shock



It plummets by almost 1% in the model while falling by only 0.2% in the data. In addition, it overshoots too slowly and too mildly compared with the data. The labor share takes 20 quarters for the labor share to recover its original level in the benchmark model, which is four times longer than in the data. At its peak, the labor share is only 0.1% higher than its original value in the model while it is 0.3% higher in the data.

As reported so far, the performance of the benchmark model is mixed. While the model can generate a magnitude of volatility and persistence of labor share similar to their empirical counterparts and replicate the 'overshooting' property of the impulse response function, it fails to match quantitatively the cross correlation structure and the impulse response function in the data. However, despite some unsatisfactory aspects, the results can provide interesting theoretical implications for related literature. In what follows, I will discuss the implications and possible extensions of the benchmark model to improve the results.

4.4.2 Discussion

As emphasized earlier, the benchmark model is different from a standard RBC model only in the sense that the laborers and entrepreneurs are allowed to share their income risks via an implicit labor contract. In spite of this modification's simplicity, the model can mimic various dimensions of the dynamics of labor share in the data including the 'overshooting' property. This implies that the risk-sharing between the laborers and entrepreneurs may be one of the primary forces determining the dynamics of labor share and that the risk-sharing mechanism can serve as a building block to model the dynamics of factor shares in future research.

In this regard, this paper contrasts starkly to Choi and Ríos-Rull (2008). In their paper, they report that the impulse response function of labor share in their model displays the 'overshooting' property only when a CES production function is assumed instead of a Cobb-Douglas production function. Based on this observation, they argue that departing from a Cobb-Douglas production function can be a more promising way of explaining the dynamics of factor shares to depart from a Cobb-Douglas production function. However, their argument seems to be too-hasty a conclusion, considering that the benchmark model in this paper uses a Cobb-Douglas production function but is still as successful as the best case in Choi and Ríos-Rull (2008).

Although the benchmark model is successful in replicating various dimensions of the dynamics of labor share in the data, there is still much room for improvements. To identify potential theoretical components for improvements, the basic mechanism of the benchmark model must be studied further. For this, it will be useful to log-linearize the key equations of the benchmark model. As discussed above, the main feature of the model is summarized in (4.14). In the benchmark model, the equation is simply

$$\chi\theta\frac{1}{C_t^L} = (1-\chi)\frac{1}{C_t^E} \tag{4.23}$$

and it can be log-linearized as

$$\hat{C}_t^E = \hat{C}_t^L = \hat{C}_t, \tag{4.24}$$

where C_t represents aggregate consumption and a carat denotes the percentage deviation from the steady state of the variable. As a result of the perfect risk-sharing, the consumption of the laborers and of the entrepreneurs grows at the same rate as aggregate consumption. In addition, the resource constraint condition (4.11) can be manipulated using $Y \equiv F\left(A, K, N^L\right)$ and log-linearized as

$$\hat{Y}_t = \frac{C^E}{Y}\hat{C}_t^E + \frac{C^L}{Y}\hat{C}_t^L + \frac{I}{Y}\hat{I}_t, \tag{4.25}$$

where Y, C^E, C^L, and I are respectively the steady state values of corresponding variables. Because the aggregate labor income is exactly equal to the laborers' consumption in equilibrium, the labor share is defined as C_t^L/Y_t and its log-linearized expression is

$$\widehat{LS}_t = \hat{C}_t^L - \hat{Y}_t, \tag{4.26}$$

where LS_t represents the labor share at time t. Combining (4.24), (4.25), and (4.26) gives

$$\widehat{LS}_t = \left(\frac{I}{Y}\right)\left(\hat{C}_t - \hat{I}_t\right). \tag{4.27}$$

The direct implication of perfect risk-sharing between the laborers and entrepreneurs on the dynamics of labor share is summarized in (4.27). As the equation suggests, the dynamics of the labor share can be determined simply by the dynamics of aggregate consumption and investment. Hence, to understand the dynamics of labor share in the benchmark model, it is enough to recall that consumption is less volatile but more persistent than investment in most standard business cycle models.

More specifically, with a positive productivity shock, investment will jump up immediately on impact, in anticipation of higher returns on capital both in the current period and in the future. Meanwhile, consumption will rise only mildly compared with investment because it can be smoothed intertemporally. As a result, the labor share will drop on impact. These movements of consumption and investment on impact are mainly responsible for the countercyclicality of labor share. In subsequent periods, investment will decrease at a faster rate than consumption due to its lower persistence. As a consequence, beyond some point, $\hat{C}_t$ becomes greater than $\hat{I}_t$, which makes the labor share overshoot.

As reported above, the impulse response function in the benchmark model falls too much on impact and recovers too slowly from the initial drop compared with its empirical counterpart. Hence, as (4.27) clearly suggests, for a more realistic impulse response function, aggregate consumption should be more volatile and persistent while investment should be less volatile and persistent. In this regard, to improve the benchmark results, the model needs to be reinforced with some additional mechanisms which can make aggregate consumption more volatile and persistent but investment less volatile and persistent.

Meanwhile, there is another possibility. The benchmark model assumes a separable utility function between consumption and leisure for laborers. An obvious theoretical consequence of this assumption is that individual consumption risks can be diversified away and as (4.24) indicates, the consumption growth rates are equalized among agents. However, if consumption is nonseparable with other elements in the utility function, (4.24) cannot hold any more and the dynamics of labor share becomes more complicated, as suggested by

$$\widehat{LS}_t = \left(\frac{C^E}{Y}\right)\left(\hat{C}_t^L - \hat{C}_t^E\right) + \left(\frac{I}{Y}\right)\left(\hat{C}_t^L - \hat{I}_t\right). \tag{4.28}$$

Below, a nonseparable preference between consumption and leisure will be introduced into the benchmark model to investigate the model's sensitivity to the assumption of nonseparability.

4.4.3 Sensitivity analysis

In this section, I will investigate the results' sensitivity to modifications to the benchmark model. For this purpose, nonseparability between consumption and leisure and habit formation are considered. Because only laborers are assumed to supply labor services, nonseparability is introduced only into the laborers' utility func-

Table 4.4: Business cycle statistics

	Benchmark	Nonseparability	Habit formation
Standard deviations relative to output			
Consumption-Laborers	0.44	0.46	0.51
Consumption-Entrepreneurs	0.44	0.29	0.51
Investment	3.03	2.97	3.06
Labor Hour	0.70	0.66	0.21
Real Wage	0.33	0.26	0.33
Correlation with output			
Consumption-Laborers	0.98	0.99	0.86
Consumption-Entrepreneurs	0.98	0.97	0.86
Investment	0.99	0.99	0.96
Labor Hour	0.99	0.99	0.68
Real Wage	-0.80	-0.79	0.92
Autocorrelation			
Output	0.70	0.64	0.73
Consumption-Laborers	0.73	0.68	0.91
Consumption-Entrepreneurs	0.73	0.67	0.91
Investment	0.69	0.63	0.61
Labor Hour	0.70	0.63	0.95
Real Wage	0.75	0.69	0.86

Note: The statistics are based on logged and H.P. filtered data. All numbers are averages of 100 simulations of 100 periods.

tion. Meanwhile, habit formation is introduced both to laborers' and entrepreneurs' consumption and to laborers' leisure. Following Constantinides (1990), the internal habit specification is adopted, which links the habit to past consumption and leisure. Finally, when habit formation is considered, consumption and leisure are assumed to be separable in the utility function.

Table 4.2, Table 4.3, and Figure 4.2 summarize the simulation results based on these modifications. The addition of nonseparability changes the simulation results very little. As Tables 4.2 and 4.3 report, the model produces almost the same numbers irrespective of nonseparability. Furthermore, as Figure 4.2 shows, the impulse response function is virtually indistinguishable from that of the benchmark model. This implies that changing the separability assumption does not affect the results much at least for the low degree of nonseparability considered ($\gamma = 1.5$).

Similarly, when the benchmark model is augmented with habit formation, the results do not change much either. As Table 4.3 indicates, the model with habit formation can outperform slightly the benchmark model with regard to the cross correlation structure, but the difference between the cross correlation structure and its empirical counterpart is still quantitatively significant. Furthermore, as Figure 4.2 exhibits, when the habit formation is considered, the performance of the model deteriorates with regard to the impulse response function. Particularly, the degree of overshooting becomes much weaker.

In summary, the sensitivity analysis suggests that these minor modifications of the benchmark model cannot alter the benchmark results significantly.[12] Therefore, it seems that major extensions will be required to improve the benchmark results. Some promising extensions will be briefly discussed in the next section.

4.5 Conclusions

Recent empirical studies report that the fluctuations of the labor share at business cycle frequencies are quantitatively considerable and that they have systematic relationships with other major macroeconomic variables. However, the empirical dynamics of factor shares seem to be odds with standard business cycle models because most models imply the constancy of factor shares. Confronting the gap between empirical evidence and theory, this paper attempts to explain theoretically the dynamics of labor share. Particularly, it focuses on the implications of risk-sharing between laborers and entrepreneurs on the cyclical fluctuations of factor shares.

For this purpose, this paper introduces an implicit labor contract as a risk-sharing mechanism between laborers and entrepreneurs into an otherwise standard RBC model and simulates the model quantitatively. The simulation results are as follows:

[12] The results in the benchmark model are also robust to various theoretical components such as time-to-build investment technology, variable capital utilization, and learning-by-doing labor skill although they are not reported here.

First, the model not only generates a magnitude of volatility and persistence of labor share similar to their empirical counterparts, but also succeeds in replicating the 'overshooting' property of the impulse response function in the data. Second, it fails to match quantitatively with the empirical cross correlation structure between the labor share and output. Particularly, the labor share and contemporaneous output in the model are more negatively correlated than they are in the data.

In sum, the performance of the model is mixed. However, despite some unsatisfactory aspects, the overall results suggest that the risk-sharing between laborers and entrepreneurs may be one of the primary forces determining the dynamics of factor shares. Also, in contrast to the argument of Choi and Ríos-Rull (2008), the results show that it is possible to explain the cyclical movements of labor share even without departing from a Cobb-Douglas production function.

Although the model is successful in explaining various dimensions of the dynamics of labor share, there is still much room for improvement. In this regard, some theoretical extensions of this paper can be considered for future research. As discussed above, the main shortcoming of the benchmark model is that the labor share falls too much on the impact of a productivity shock and the problem seems largely due to the perfect risk-sharing between laborers and entrepreneurs. Hence, as (26) suggests, it will be helpful to improve the benchmark results if the tight link between laborers' and entrepreneurs' consumption can be relaxed and laborers' consumption can be made more volatile.

In this perspective, the following extensions seem to be promising. First, home (or nonmarket) production can be introduced into the benchmark model in the spirit of Benhabib, Rogerson, and Wright (1991). If laborers are involved with nonmarket activities and their preference is nonseparable between consumption and leisure, the laborers' consumption can have different dynamics than those of entrepreneurs' consumption as (4.28) suggests. Second, two types of laborers, for instance inside laborers and outside laborers, can be considered. The entrepreneurs can share their income risks with the inside laborers based on the long-term relationship while not with the outside laborers. The wage rate for the outside laborers is simply set as equal to their marginal productivity. As a consequence, the outside laborers' consumption is more closely tied with their marginal productivity and becomes more volatile than the inside laborer's consumption. This extension will prevent the labor share from falling drastically on the impact of a productivity shock and help to improve the benchmark results.

Chapter V

Conclusion

This dissertation examines various issues in international macroeconomics and macroeconomics.

The second chapter investigates the dynamics of the relative price of nontradable to tradable goods at business cycle frequencies and finds that it displays an S-shaped cross correlation structure with GDP. Confronting the gap between the empirical regularity and the existing international macroeconomic models, the chapter introduces heterogeneity in price stickiness to explain the regularity and shows that a model with heterogeneous price stickiness in tradable and nontradable sectors can successfully replicate it.

In the third chapter, the implications of the presence of rule-of-thumb consumers on international business cycles are studied, particularly with respect to international business cycle puzzles. For this purpose, the chapter considers a standard international real business cycle model with rule-of-thumb consumers and shows that independent of restrictions on the types of available assets for international risk sharing, the introduction of rule-of-thumb consumers helps to explain the consumption correlation puzzle. In addition, the results are more salient when the process is less persistent but more spill-over.

The fourth chapter attempts to explain theoretically the dynamics of labor share that recent empirical studies have identified. The chapter proposes a theoretical model in which laborers and entrepreneurs can share their income risks via an implicit labor contract and shows that the model can replicate many of the dynamics of labor share, including the ‘overshooting’ property. This result implies that risk-sharing between laborers and entrepreneurs may be one of the primary forces determining the dynamics of labor share at business cycle frequencies.

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