The Real Exchange Rate, Productivity, and the Terms of Trade

by

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A Dissertation Submitted in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in the Department of Economics

University of Victoria

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ABSTRACT

The theoretical literature assumes that real variables affect the real exchange rate only through the relative price of nontraded goods. In Chapter 2, I decompose the real Canada-US exchange rate into the relative prices of traded goods and nontraded goods and analyze how real shocks affect these two relative prices. I find that shocks to productivity and commodity prices affect the real exchange rate almost entirely through the relative price of traded goods. This evidence calls for explicit modeling of the transmission mechanism from real shocks to the real exchange rate through the relative price of traded goods.

In Chapter 3, I develop a model that allows the relative price of traded goods to play a role in the transmission mechanism. The model is a generalization of the basic Balassa-Samuelson model that incorporates terms-of-trade and productivity shocks in a unified framework. The generalization is parsimonious since it maintains the law of one price for each traded good. However, the model does not have the law of one price for the composite traded good. This is necessary to allow traded goods to act as a channel in the transmission mechanism. The model implies that domestic productivity shocks depreciate the relative price of tradables, while shocks to world commodity prices appreciate it. The empirical analysis provides some support for the first prediction, but rejects the second prediction.

In Chapter 4, I analyze whether the depreciation of the real Canada-US exchange rate can be a driving force behind the widening of the Canada-US productivity gap in manufacturing since the 1980s. I focus on the factor cost hypothesis, that states that a real exchange rate depreciation can make capital relatively more expensive than labour, causing manufacturing firms to adopt more labour intensive technologies.

Using a Vector Error Correction Model, I find that a real depreciation of the Canadian dollar reduces the relative Canada-US capital-labour ratio and labour productivity in manufacturing in accordance with the hypothesis. However, the contribution of this channel in explaining movements of the relative productivity in manufacturing is only about ten per cent at a five year horizon.

Keywords: real exchange rate; terms-of-trade; productivity; traded goods; nontraded goods.

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Acknowledgement

This dissertation could not have been completed without the help of many people to whom I would like to express my deep gratitude.
I would like to thank Dr. Judith Clarke, Dr. Merwan Engineer and Dr. Graham Voss for useful comments and suggestions. I started working on Chapter 4 when I was on a co-op position with the Bank of Canada. I thank the Vancouver Regional Office for hospitality. This part of the dissertation is co-authored with Dr. Farid Novin and Mrs. Brigit Brady, Bank of Canada.

Chapter 1

Introduction

This dissertation analyzes the relationship between productivity, terms-of-trade, and the real exchange rate. The real exchange rate is defined as the relative price of foreign goods and services in terms of domestic goods. The real exchange rate depreciates when foreign goods and services become relatively more expensive than domestic goods; it takes more domestic goods to purchase one foreign good. The real exchange rate is a broad measure of the relative price. The goods and services included in the aggregate price levels may be traded or nontraded, they may be produced domestically or imported. A related measure, the terms of trade, applies only to traded goods and looks at the relative price of a country's exports in terms of its imports. It shows how many domestic units are necessary to buy one foreign unit.

The dissertation consists of two parts that are distinguished by the assumption of exogeneity among the variables. In the first part, I analyze the channels through which productivity and terms-of-trade affect the real exchange rate. This analysis contributes to the literature on exchange rate determination. In the second part, I analyze whether exchange rate fluctuations affect productivity. This analysis contributes to the discussion of economic factors that explain recent divergence in productivity in manufacturing between Canada and the United States.

The issue of exchange rate determination is prominent in international economics. The oldest approach to exchange rate determination is based on the idea that trade in goods determines the real exchange rate in the long run. An example of this approach is the theory of purchasing power parity (PPP) which states that countries' price levels should be equal when measured in the same currency. If the price levels are not equal, arbitrage opportunities imply an increased demand for cheaper goods and increased demand for the currency of the country with cheaper goods. The nominal exchange rate and prices have to adjust to eliminate these arbitrage opportunities. PPP implies that the real exchange rate, the relative price of goods of the two countries, should be equal to one. Empirically, real exchange rates are not equal to one and the evidence in favour of PPP is rather weak (for a review see Rogoff, 1996).

The story changes a little if we take transportation costs into account. Now prices of goods can be different as long as the difference does not exceed transportation costs. If the difference exceeds transportation costs then it is profitable to ship goods until prices are equalized. Thus, there is a "band of inaction" within which individual prices can deviate from the law of one price. Since transaction costs vary for individual commodities this band of inaction is different for each commodity. When all commodities are aggregated to obtain the aggregate price index, which is used to construct the real exchange rate, these different bands imply nonlinearity in the adjustment of deviations from the level consistent with PPP. In accordance with this line of argument, Taylor, Peel, and Sarno (2001) reject the hypothesis of a unit root in exchange rates in favour of nonlinearly mean-reverting exchange rates.

Arbitrage need not eliminate inequality in prices if some goods are nontraded. Even if some goods or services are cheaper somewhere, high transportation costs make it impossible to take advantage of the price inequality. It is possible to decompose the real exchange rate into two relative prices: the relative price of traded goods and the relative price of nontraded goods.[1] Since arbitrage applies to traded goods, their relative price should be always equal to one. Therefore, the real exchange rate should be determined by the relative price of nontraded goods. Consequently, factors that affect the relative price of nontraded goods are treated as long-run determinants of real exchange rates.

There are several factors affecting the relative price of nontraded goods that are discussed in the literature. Balassa (1964) and Samuelson (1964) consider productivity shocks in the tradable sector. Since prices of traded goods are pinned down by arbitrage, productivity shocks drive wages up. Producers of nontraded goods have to increase their prices to compensate for increased labour costs. The overall price level increases and the real exchange rate appreciates.

Another strand of the literature has looked at the terms-of-trade. Dornbusch (1980), Edwards (1989), and Neary (1988) analyze the impact of export and import

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[1] The details of the decomposition can be found in Section 2.2.

prices on the demand for nontradables and the real exchange rate. A positive shock to export prices improves the terms-of-trade and increases the demand for all goods due to an income effect. The substitution effect favours imported and nontraded goods as they are relatively cheaper now. Consequently, the relative price of nontradables increases to clear the market. This increase in the price of nontradables cannot be arbitraged away, and consequently the overall domestic price level increases relative to the foreign price level. The real exchange rate appreciates. A positive shock to import prices affects the demand for nontradables ambiguously. The income effect reduces the demand for nontradables as the terms-of-trade worsen. The substitution effect, however, increases the demand for nontradables, as they are relatively cheaper than imported traded goods. The total effect of import prices on the demand for nontradables, and the real exchange rate, is ambiguous. It is usually assumed that the substitution effect dominates, and, thus the real exchange rate appreciates in response to a positive shock to import prices.

Real shocks affect the real exchange rate in the long-run through the relative price of nontraded goods only. Any impact of real shocks on the relative price of traded goods is washed away by arbitrage. On the other hand, nominal shocks are supposed to have no effect on the real exchange rate in the long-run. This prediction follows from the expected impact of nominal shocks on the relative prices. If prices of traded and nontraded goods increase by the same amount in response to nominal shocks then the relative price of nontraded goods does not change. Any impact on the relative price of traded goods is annihilated in the long-run by goods arbitrage so that the nominal exchange rate and prices of traded goods adjust to maintain the parity.

Nominal and real shocks, however, are expected to affect the real exchange rate in the short-run. This is because both types of shocks are expected to affect the nominal exchange rate. If prices and the nominal exchange rate are slow to return to the long-run equilibrium level, it is possible that the relative price of traded goods, and consequently the real exchange rate, deviate from one. It is assumed in the literature that nominal shocks are more important in the short-run than real shocks. Recent studies on exchange rate volatility, including Obstfeld and Rogoff (1995), Chari et al. (2002), and Devereux and Engel (2002), use dynamic general equilibrium models to analyze the impacts of nominal shocks only.

Even though volatility of real exchange rates can be explained in a theoretical model with only nominal shocks, the other empirical feature of real exchange rates, persistence, cannot be explained. This is what Rogoff (1996, p. 647) calls the PPP puzzle: "How can one reconcile the enormous short-term volatility of real exchange rates with the extremely slow rate at which shocks appear to damp out?" To resolve the puzzle, Chen and Rogoff (2003) go back to real shocks. They analyze whether productivity differentials and terms-of-trade can explain persistence for New Zealand, Australia, and Canada. Chen and Rogoff find that the real exchange rates are still persistent even when accounting for real shocks. Benigno (2004) looks at other explanations of the puzzle.

The story that emerges from the above discussion is that real and nominal shocks affect the real exchange rate in the short-run through the relative price of traded goods, and nominal shocks dominate. In the long-run, the real exchange rate is only determined by real shocks propagating through the relative price of nontraded goods. Engel (1999) decomposes US real exchange rates into the relative price of traded and nontraded goods. He finds that the relative price of nontraded goods accounts for almost no volatility of the real exchange rate at different horizons. This contradicts with theoretical considerations that assign an important role to this relative price. This finding can be potentially explained by the importance of nominal shocks. Thus, Engel's finding that the relative price of traded goods is more important may imply that nominal shocks are more important for real exchange rates. As goods arbitrage eliminates differences in prices among traded goods, one should find lower contribution of the relative price of traded goods to the real exchange rate as the horizon widens. Engel (1999), however, finds that the contribution of the relative price of traded goods does not decline over time.

Since Engel's finding that the relative price of traded goods is more important than the relative price of nontraded goods may imply that nominal shocks are more important than real shocks, it is interesting to review empirical studies on the importance of shocks. The empirical evidence on importance of real versus nominal shocks for the real exchange rate is mixed. Earlier studies by Clarida and Gali (1994), Eichenbaum and Evans (1995), and Lastrapes (1992) using structural VARs assign only small contributions to nominal shocks. Rogers (1999) and Chen (2004), using longer spans of data and several VAR specifications, give a higher range for the contribution of monetary shocks.

In my dissertation, I test the propagation of real shocks through the relative price of traded goods and the relative price of nontraded goods explicitly. I add real shocks to the model and analyze whether real shocks propagate through the relative price of traded or nontraded goods. If real shocks propagate mostly through the relative price of nontraded goods, then my evidence, combined with Engel's results, imply that real shocks do not matter for the real exchange rate. If, however, real shocks propagate through the relative price of traded goods, then theoretical studies need to be revised to reflect such empirical evidence. I find (i) that real shocks propagate mostly through the relative price of traded goods; (ii) the contribution of real shocks through the relative price of traded goods does not decline with time.

I propose a model that explains these empirical findings. The model is a generalization of the basic Balassa-Samuelson model that incorporates terms-of-trade and productivity shocks in a unified framework. The generalization is not a drastic change in the specification relative to the Balassa-Samuelson model since it maintains the law of one price for each traded good. However, the model does not have the law of one price for the composite traded good. This is necessary to allow traded goods to act as a channel in the transmission mechanism. In the model, the relative price of traded goods is as important as the relative price of nontraded goods. I test other predictions from the model. The model implies that productivity shocks depreciate the relative price of tradables, while shocks to commodity prices appreciate it. The empirical analysis shows some support for the first prediction, but rejects the second prediction.

The above discussion, which outlines the first part of my dissertation, assumes that real shocks are exogenous with respect to real exchange rates. There are, however, reasons to believe that the causation may run in the opposite direction. In the second part of my dissertation, I analyze whether exchange rate movements may affect productivity in Canadian manufacturing. This question arises because labour productivity in Canada has fallen relative to that in the United States since the 1980s, with the relative decline being particularly large in the manufacturing sector. Canadian relative productivity in manufacturing has fallen by approximately 25 per cent since the mid-1980s with much of this decline occurring since 1993 (for a review of recent trends in productivity, see Crawford, 2002).

At the same time, there have been two episodes of significant Canadian dollar depreciation, first between 1976-1986 and second between 1991-2002. One hypothesis, which explains how an exchange rate depreciation can affect labour productivity in

Canadian manufacturing, is known as the factor-cost hypothesis. It states that a real exchange rate depreciation would make imported capital goods expensive relative to labour, and domestic producers would adopt more labour intensive technologies in response to a higher relative price of capital. Labour intensive technologies in turn would make labour less productive. Since about 70% of machinery and equipment is imported to Canada, this hypothesis is especially relevant for Canada. The real exchange rate depreciation during the periods 1976-1986 and 1991-2002 could make capital relatively more expensive than labour, and firms could decide to substitute labour for capital. Both the capital-to-labour ratio and labour productivity could fall as a result of the real exchange rate depreciation. Lafrance and Schembri (2000), Harris (2001), and Bernstein et al. (2002) consider this channel as a possible contributing factor in explaining the gap.

I find that a depreciation of the Canadian dollar reduces the relative Canada-US capital-labour ratio and labour productivity in manufacturing in accordance with the hypothesis. However, the contribution of this channel in explaining movements of the relative productivity in manufacturing is only about 10 per cent at a five year horizon. Thus, real exchange rate movements are not so important for productivity.

The organization of the thesis is the following. Chapter 2 tests the importance of the relative price of traded and the relative price of nontraded goods for the transmission mechanism from real shocks to the real exchange rate. Chapter 3 develops a model to explain these empirical findings. Tests of the model reveal that some predictions of the model are rejected. Chapter 4 focuses on the other opposite causation, from the real exchange rate to productivity. Chapter 5 concludes.

Chapter 2

Real variables and the real exchange rate: An inquiry into the transmission mechanism

2.1 Introduction

The seminal work of Balassa (1964) and Samuelson (1964) on productivity shocks in the tradable sector, and Dornbusch (1980), Edwards (1989), and Neary (1988) on terms-of-trade shocks has generated a large literature examining the impact of real variables on the real exchange rate. This literature postulates that real variables affect the real exchange rate only through the relative price of *nontraded* goods. This is because the other component of the real exchange rate, the relative price of *traded* goods, is determined by the law of one price.

If the law of one price holds for traded goods, the relative price of traded goods should be equal to one. It is possible that there are short-term deviations from the law of one price for traded goods. In this case the relative price of traded goods is not constant all the time but it should be stationary. If, on the other hand, the real exchange rate and the relative price of nontraded goods are nonstationary, then they have to be cointegrated. Consequently, evidence in favour of the Balassa-Samuelson hypothesis is based mainly on cointegration studies.[1] Amano and van Norden (1995) use commodity prices as proxies for terms-of-trade shocks and find some long-run

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[1] See Chinn and Johnston (1996) and Begum (2000) among others.

relationship between commodity prices and real exchange rates. While the above studies test cointegration between the real exchange rate and real variables, other studies look at the underlying assumption that the relative price of nontraded goods is cointegrated with real variables. Kakkar (2003) finds that the price of nontraded goods relative to the price of traded goods is cointegrated with sectoral factor productivities for a set of countries.[2] Canzoneri et al. (1999) test whether the price of nontraded goods relative to the price of traded goods reflects the relative productivity of labour and whether purchasing parity holds for traded goods. While the first prediction of the Balassa-Samuelson model is supported by the data, the second prediction has less support.

The underlying assumption of the above models is that the law of one price holds for traded goods. A large body of empirical evidence seems to support the failure of the law of one price; possible explanations include transportation costs, tariffs, nontariff barriers, and pricing to market (see Rogoff, 1996). If international markets are segmented, exporters invoice in the currency of consumers, and prices are sticky, then exchange rate fluctuations do not pass through to import prices. Thus, the law of one price does not hold under these assumptions. This form of pricing to market is known as local currency pricing. A theoretical treatment of pricing to market in combination with local-currency sticky prices (LCP) is given in Betts and Devereux (2000) among others (see Lane, 2001 for a review). Feenstra and Kendal (1997) and Engel and Rogers (2001) find that a significant portion of deviations from the law of one price can be explained by local currency pricing. The Betts-Devereux model replicates some empirical regularities such as nominal and real exchange rate variability, and comovements of consumption and output in face of monetary disturbances.

In light of this evidence, recent theoretical models emphasize nominal rather than real shocks. Local currency pricing implies that nominal shocks should propagate through the relative price of traded goods only. Indeed, exchange rate fluctuations in response to nominal shocks do not pass through to import prices in the short-run. Chari et al. (2002, p. 533), who develop a general equilibrium model of the interaction of nominal shocks and sticky prices, say in the introduction to the pa-

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[2] The price of nontraded goods relative to the price of traded goods should not be confused with the relative price of nontraded goods. The latter price is the relative price between two countries: the price of traded goods relative to the price of traded goods in one country versus the same price ratio in the other country. These prices are defined formally in Section 2.2.

per: "In constructing our model, we need to choose the source of real exchange rate fluctuations: deviations from the law of one price for traded goods across countries or fluctuations in the relative price of nontraded to traded goods across countries or both. We choose to abstract from nontraded goods and focus on fluctuation in real exchange rates arising solely from deviations from the law of one price for traded goods."

A shift from the relative price of nontraded goods to the relative price of traded goods raises an interesting question: which relative price is more important for the real exchange rate? Engel (1999) answers this question by analyzing the importance of the two relative prices for US real exchange rates. He finds that the relative price of traded goods almost entirely accounts for persistence and volatility of US real exchange rates. Therefore, a possible interpretation of Engel's results is that nominal shocks are more important than real shocks and that, for those wishing to model the real exchange rate, real variables such as productivity and terms of trade are unlikely to be important. This result may give support to local currency pricing assumed in the theoretical literature.

There is one aspect that does not accord well with LCP models. Obstfeld and Rogoff (2000) argue that local currency pricing implies that the nominal exchange rate and terms of trade should be negatively correlated: when a currency depreciates, terms of trade improve. This implication of LCP models is counterfactual, as nominal exchange rates and terms of trade are usually positively correlated (Obstfeld and Rogoff, 2000). An alternative to a local currency pricing assumption is producer currency pricing, but the latter implies that the law of one price holds for traded goods. Thus, any shocks affecting the real exchange rate should affect it through the relative price of nontraded goods. But if shocks affect the real exchange rate through the relative price of nontraded goods, then they should not matter for the real exchange rate given Engel's (1999) results.

Engel's results demonstrate the importance of the relative price of traded goods but cannot be used to assess the importance of real and nominal shocks since they are not formally identified. I extend Engel's analysis in this chapter to examine the role of real shocks.[3] I analyze how shocks propagate to the real exchange rate through the relative price of traded and the relative price of nontraded goods explicitly. To my knowledge, this analysis has not been done before.

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[3] The role of nominal shocks, while obviously of interest, is not considered here.

There are several possibilities for the transmission mechanism of real shocks to the real exchange rate through the relative prices. First, real shocks propagate to the real exchange rate mainly through the relative price of nontraded goods. Combined with Engel's (1999) findings that the relative price of nontraded goods is not important, this result would imply that real shocks should not matter for the real exchange rate, contributing to the literature on the importance of real versus nominal shocks. Second, real shocks propagate through the relative price of traded goods. This result would call for a re-thinking of theoretical models and assigning an important role to the relative price of traded goods in the transmission mechanism. Finally, real shocks may affect equally the two relative prices. In this cases, interesting possibilities arise if shocks act in opposite directions nullifying their impact on the real exchange rate.

The chapter is organized in the following manner. Section 2 discusses the proposed methodology. Section 3 discusses the construction of data. Section 4 presents forecast error variance decompositions that are used to assess the transmission mechanism. Section 5 concludes.

2.2 Methodology

Engel (1999) decomposes the log real exchange rate q, $q = s + p^* - p$, into the log relative prices of traded goods x and nontraded goods y according to:

$$q = x + y \tag{2.1}$$

where

$$x = s + p_T^* - p_T \tag{2.2}$$

$$y = \alpha^*(p_N^* - p_T^*) - \alpha(p_N - p_T) \tag{2.3}$$

and s is the log of the nominal exchange rate (home currency price of the foreign currency), p is the log of the home price level, and p^* is the log of the foreign price level.[4] Subscripts T and N indicate the price index for traded and nontraded goods respectively. Parameters α and α^* indicate the share of nontraded goods in the overall price index at home and abroad, respectively.

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[4] This decomposition is consistent with my model discussed in Chapter 3. It assumes that aggregate price levels are indices constructed as geometric averages with constant share-weighting parameters.

Most empirical studies work with the real exchange rate directly. The contribution of Engel's decomposition is that the two components of the real exchange rate can be now analyzed separately. This provides a useful test of theoretical models that assume the importance of the relative price of nontraded goods. The objective here is to decompose the variance of the real exchange rate into the contributions of the relative price of traded and nontraded goods and analyze the importance of the relative prices at different horizons. Since the real exchange rate and the relative prices are found to have a unit root, the appropriate approach to a decomposition is to work with variables in differences. Since the contributions of the relative prices may vary at different horizons, differences are constructed at different lags, i.e. the analysis of $q_t - q_{t-n}$, $x_t - x_{t-n}$, and $y_t - y_{t-n}$ is conducted for n varying from one month up to 30 years.

Since Engel (1999) finds that the null hypothesis that x and y are independent random walks cannot be rejected, the decomposition of the variance of $q_t - q_{t-n}$ assumes that $x_t - x_{t-n}$ and $y_t - y_{t-n}$ are uncorrelated at different horizons n. Thus, the contribution of $x_t - x_{t-n}$ to the variance of $q_t - q_{t-n}$ at different horizons n is calculated according to:

$$\frac{var(x_t - x_{t-n})}{var(x_t - x_{t-n}) + var(y_t - y_{t-n})}.$$

Engel (1999) reports that the relative price of traded goods accounts for at least 95 percent of the variance of the real exchange rate for different measures of x_t and y_t, and for different horizons and different US exchange rates.[5]

Engel's approach cannot be used directly to investigate the transmission mechanism of real shocks affecting the real exchange rate. In order to determine the channels by which real shocks are transmitted to the real exchange rate, I develop vector autoregressive (VAR) models in first differences and vector error-correction (VECM) models, relating the relative prices and possible real determinants of exchange rates.

The models include four lags of the relative prices of tradables and nontradables, and four real variables. The real variables are chosen to capture the key sources

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[5] Engel (1999) also constructs a decomposition that takes the comovement between x_t and y_t into account. This decomposition gives similar results because comovements of x_t and y_t are small. In addition, Engel uses decompositions that take persistence into account. Since I look at forecast error variance decompositions later in this section, I discuss only those results of Engel that rely on variance decompositions and are comparable to what I calculate.

of commodity and productivity shocks. I use two approaches to identify structural shocks. The first approach uses a Cholesky decomposition. The second approach uses the condition that the only shocks that have a long-run effect on the level of productivity are shocks to productivity.

I use these models to decompose forecast errors variances. This allows me to obtain contributions of real shocks to the forecast error variation of x and y. The forecast errors s periods into the future $\Delta x_{t+s} - \Delta\hat{x}_{t+s|t}$ and $\Delta y_{t+s} - \Delta\hat{y}_{t+s|t}$ are functions of the structural shocks. I need to calculate the mean squared error for $\Delta q = \Delta x + \Delta y$ and decompose this error into contributions from the relative price of traded goods and the relative price of nontraded goods, and ultimately into contributions from the structural shocks. I assume that the forecast errors for x and y are uncorrelated, and estimate the contribution of x according to:

$$\frac{MSE(\Delta\hat{x}_{t+s|t})}{MSE(\Delta\hat{x}_{t+s|t}) + MSE(\Delta\hat{y}_{t+s|t})} \tag{2.4}$$

where $MSE(\Delta\hat{x}_{t+s|t}) = E[(\Delta x_{t+s} - \Delta\hat{x}_{t+s|t})^2]$.

This approach, unlike Engel (1999), provides decompositions conditional on real variables. This allows me to evaluate the importance of the relative prices in the transmission mechanism.

2.3 Data

Engel (1999) discusses four ways to construct the relative prices of traded and nontraded goods using four different types of price indices: (i) consumer prices (CPI), (ii) output prices, (iii) personal consumption deflators (PCD), and (iv) producer price index (PPI). The first measure treats goods as tradable and services as nontradable. Prices for these components are taken from the CPI index. Of course, these components are not perfect measures of traded and nontraded goods. Goods may contain services that are not tradable, while some services may be traded. The second measure is supposed to deal better with the nontradable component since output prices do not contain many services like marketing services included in the CPI data. The third measure uses national income accounts. The price index for personal expenditure on goods is considered as the price index for traded goods, while the price index for personal expenditure on services is treated as the price index for nontraded goods. Finally, the last method treats the overall PPI as an index of traded goods prices, and the overall CPI as an index of nontraded goods. In this case, $x = s + ln(PPI^*) - ln(PPI)$, and $y = ln(CPI^*) - ln(PPI^*) - (ln(CPI) - ln(PPI))$.

There are many problems with this latter approach. Engel (1999) reports at least four serious problems. First, using the aggregate PPI as a measure of traded goods price is crude, since some output is nontraded. Second, measures of traded and nontraded goods in this approach come from different surveys. Third, the aggregate price index is not a weighted average of traded and nontraded goods. Finally, the decomposition assumes that x and y are independent, while this is not true with this type of measure. The relative prices x and y are expected to be negatively correlated since $ln(PPI^*) - ln(PPI)$ appears with a positive sign in x and negative sign in y as apparent from the above formulas. The only advantage is that this approach can be used for a wider range of countries.

I use two out of the four methods in my dissertation: consumer prices and personal consumption deflators. Output prices are not used since the data are not available for some industries at a quarterly frequency. The fourth approach is not used since I work only with Canada-US data, so potential benefits of using this approach for many countries disappear while the disadvantages stay. It should be mentioned that Engel (1999) finds that the results are robust for all four measures of the relative prices.

I introduce two sets of real variables in the models. I want to consider proxies for shocks to terms-of-trade and productivity differentials. The first set is implied by terms-of-trade models that emphasize that exogenous shocks to terms of trade affect the real exchange rate. Exogenous shocks to terms-of-trade are not easily identifiable in general. I use the approach used in Chen and Rogoff (2003) and Amano and van Norden (1995) that identify exogenous shocks to terms of trade as shocks to commodity prices for countries with a high share of primary commodities in their exports, like Canada, Australia, and New Zealand. The second set is related to the Balassa-Samuelson hypothesis that states that shocks to productivity in the traded sector versus the nontraded sector affect the real exchange rate.

As proxies for terms-of-trade shocks, I use the Bank of Canada indexes for energy and non-energy commodity prices denominated in US dollars and adjust them for US inflation measured by the CPI to construct the real price of energy and non-energy commodities. Energy and non-energy commodities are an important share of

Canadian exports. The advantage of including these goods only is that commodity prices are determined in the world market and Canadian producers have no control of them. The prices denominated in US dollars, thus they do not contain the nominal exchange rate and are not subject to nominal exchange rate fluctuations. The prices are adjusted by US CPI which proxies the price index for Canadian imports. This approach to construct proxies for terms-of-trade is used in Chen and Rogoff (2003). The relative Canada-US productivity measures are constructed by dividing output measures by hours-worked. All variables are in logs and at a quarterly frequency. A more detailed description of how series are constructed and the sources of the data can be found in Appendix A. The data range is from 1972:1 to 2000:4. Figure 2.1 presents commodity prices and productivity differentials, while Figure 2.2 plots the relative prices constructed using CPI and PCD data.

2.4 Testing for unit roots and cointegration

First I analyze whether a unit root is present in the series. Following the literature on unit root testing, the data generating process (DGP) for y_t has the following form:

$$y_t = \gamma_0 + \gamma_1 t + u_t, \qquad t = 1, ..., T$$

$$u_t = \alpha u_{t-1} + v_t$$

where v_t is a stationary process. If $\alpha = 1$ this process is equivalent to

$$y_t = \gamma_1 + y_{t-1} + v_t \tag{2.5}$$

while if $|\alpha| < 1$ it reduces to

$$y_t = \gamma_0(1-\alpha) + \gamma_1\alpha + \gamma_1(1-\alpha)t + \alpha y_{t-1} + v_t.$$

Following Elliott et al. (1996) the series are detrended

$$y_t^d = y_t - \hat{\beta}_0 - \hat{\beta}_1 t$$

Figure 2.1: Graph of commodity prices and productivity differentials

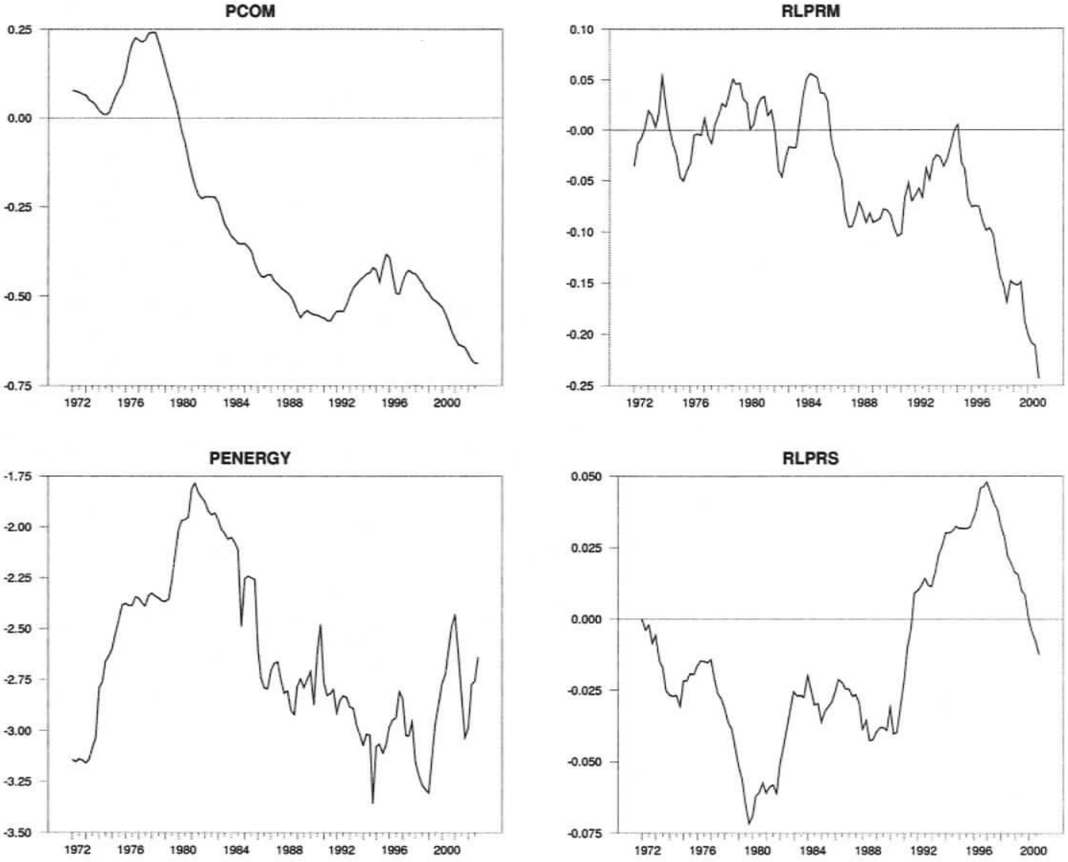

Figure 2.1
PCOM is the log of the real non-energy commodity price index; PENERGY is the log of the real energy commodity price index; RLPRM is the log of labour productivity in manufacturing in Canada versus the US; RLPRS is the log of labour productivity in services in Canada versus the US.

Figure 2.2: Graph of the relative prices

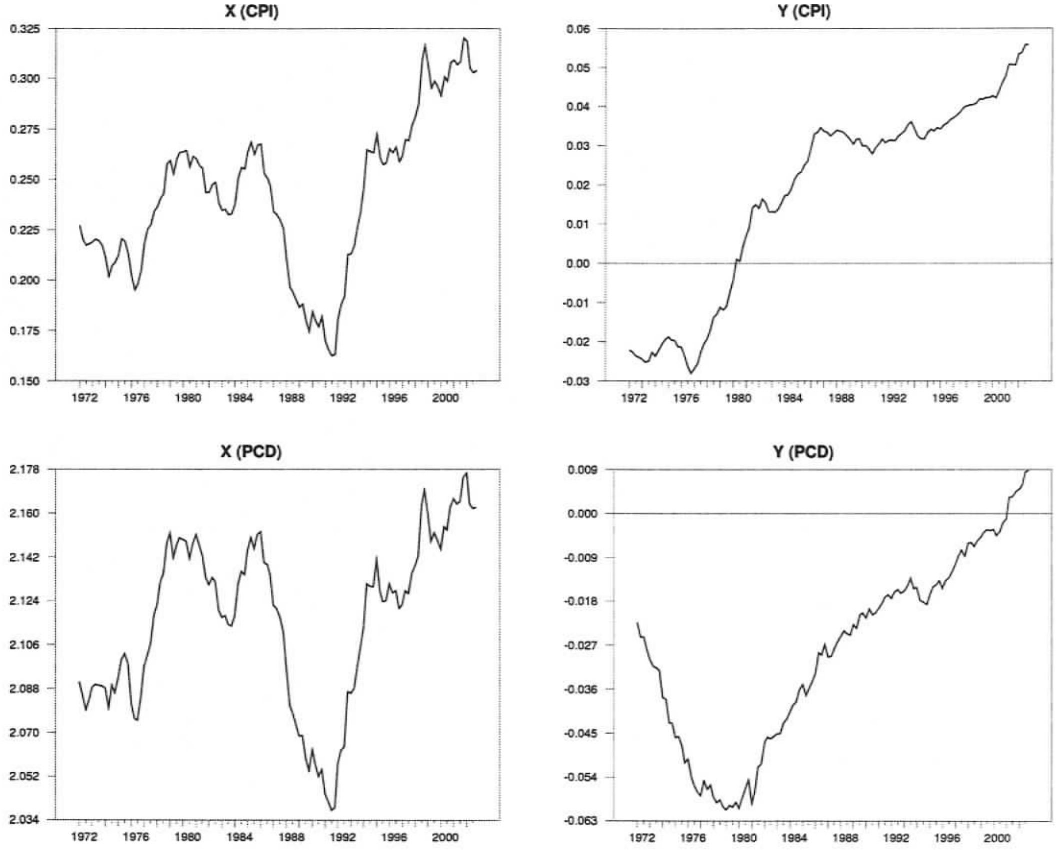

Figure 2.2
X (CPI) and X (PCD) are the log of the relative price of traded goods, as defined in (2.2), constructed using the CPI and PCD data, respectively. Y (CPI) and Y (PCD) are the log of the relative price of nontraded goods, as defined in (2.3), constructed using the CPI and PCD data, respectively

where (β_0, β_1) are obtained by regressing $\tilde{y}_t$ on $\tilde{z}_t$ where

$$\tilde{y}_t = [y_1, (1 - \tilde{\alpha}L)y_2, ..., (1 - \tilde{\alpha}L)y_T]$$

$$\tilde{z}_t = [z_1, (1 - \tilde{\alpha}L)z_2, ..., (1 - \tilde{\alpha}L)z_T]$$

and $z_t = (1, t)'$, $\tilde{\alpha}_t = 1 - 13.5/T$.

The augmented Dickey-Fuller test (Dickey and Fuller, 1979, and Said and Dickey, 1984) is then applied to the detrended data:

$$\Delta y_t^d = a_0 y_{t-1}^d + a_1 \Delta y_{t-1}^d + ... + a_p \Delta y_{t-p}^d + error$$

where the number of lags is chosen according to the Modified Akaike Information Criterion proposed by Ng and Perron (2001). The critical values for the test are given in Elliott et al. (1996). This test is supposed to have better power at a predetermined point than the usual ADF test. Table 2.1(a) reports the results of testing for a unit root in the series. The null hypothesis of a unit root cannot be rejected at the 10% significance level for all series.

I further allow for a possibility of breaks in trends and intercept following Perron and Rodriguez (2003). In this case, the DGP is assumed as:

$$y_t = \mu + \nu t + \delta I(t > T_B) + \theta I(t > T_B)(t - T_B) + u_t, \qquad t = 1, ..., T$$

$$u_t = \alpha u_{t-1} + v_t$$

where I(.) is the indicator function and the same assumptions apply to v_t. If $\alpha = 1$ the process becomes

$$y_t = y_{t-1} + \gamma_1 + \gamma_2 I(t = T_B + 1) + \gamma_3 I(t > T_B) + v_t, \tag{2.6}$$

while under $|\alpha| < 1$ it is equivalent to

$$y_t = \gamma_0 + \gamma_1 t + \gamma_2 I(t > T_B) + \gamma_3 I(t > T_B)(t - T_B) + v_t.$$

Table 2.1(b) reports the results of testing for unit root allowing for a change in level and slope at an unknown time. The break point is chosen so that the absolute value of the t-statistics on the coefficient of the change in slope is maximized according to Perron (1997). The data are GLS detrended following the suggestion by Elliott et al. (1996). The optimal non-centrality parameter for detrending of this type of models is found by simulations in Perron and Rodriguez (2003). The augmented Dickey-Fuller test (Dickey and Fuller, 1979, and Said and Dickey, 1984) is then applied to the detrended data. The number of lags in the augmented regression is chosen according to the Modified Akaike Information Criterion proposed by Ng and Perron (2001). The critical values for the test are given in Perron and Rodriguez (2003). The null hypothesis of a unit root cannot be rejected at the 10% significance level for all series.

A disadvantage of allowing breaks is that their presence cannot be tested for simultaneously with testing for a unit root. They are either assumed to be present as in (2.6) or assumed to be absent as in (2.5). I expect that allowing for breaks in levels in (2.5) is not going to affect further qualitative results, and assume that the individual data are generated according to (2.5).

I analyze whether variables are stationary, I(0), or difference-stationary of order 1, i.e. I(1). The I(1) process corresponds to a model with persistent shocks. It is possible, however, to model persistent shocks with I(d) processes where $0 < d < 1$. Baillie (1996) reviews long memory processes and their applications in econometrics. In what follows, I restrict my analysis to I(1) processes. Fractional integration and cointegration is left for future work.

Since all variables are first-difference stationary, I proceed with system based approaches and single equation methods to test for possible cointegration. First, I apply the Johansen procedure for testing for cointegration. Since the DGP is assumed to be (2.5), a vector autoregressive (VAR) model in levels of the following form is appropriate in this multivariate case:

$$\Phi(L)(Z_t - \mu - \gamma t) = e_t$$

where Z_t is an m-dimensional column of I(1) variables, Φ is a matrix polinomial of order l in the lag operator L, μ and γ are vectors of constants. The VAR model can be expressed in the vector error-correction form (VECM):

$$\Delta Z_t = \Pi Z_{t-1} + \sum_{i=1}^{i=l-1} \Gamma_i \Delta Z_{t-i} + \mu_0 + \mu_1 t + e_t, \tag{2.7}$$

Table 2.1: Unit root tests

	a) No breaks		b) Breaks		
Series	ADF-GLS	k	ADF-GLS	k	T_B
RLPRM	-1.36	1	-2.67	1	1994:3
RLPRS	-1.77	2	-2.20	2	1981:4
RLPR	-1.24	2	-3.02	1	1982:1
y CPI/PCD	-1.88/-1.51	5/7	-1.83/-1.93	1/1	1986:3/1977:1
x CPI/PCD	-1.67/-1.97	4/4	-2.25/-2.42	4/3	1990:4/1990:4
PENERGY	-1.46	1	-2.20	1	1981:2
PCOM	-2.22	4	-1.78	2	1988:4

Augmented Dickey-Fuller test (Dickey and Fuller, 1979, and Said and Dickey, 1984) applied to GLS detrended data following Elliott, Rothenberg, and Stock (1996). a) The model with no breaks. b) The model allows for a change in slope and intercept. The break date (T_B) is chosen so that the absolute value of the t-statistics on the coefficient of the change in slope is maximized according to Perron (1997). The number of lags (k) in both cases is chosen according to the Modified Akaike Information Criterion proposed by Ng and Perron (2001). All variables are in logs. The critical values for the test are given in Elliott et al. (1996) for (a) and in Perron and Rodriguez (2003) for (b). The null hypothesis of a unit root cannot be rejected at the 10% significance level for all series.

Variables: PENERGY is the log of the real price of energy commodities; PCOM is the log of the real price of non-energy commodities; RLPRM is the log of the relative Canada-U.S. labour productivity in manufacturing; RLPRS is the log of the relative Canada-U.S. productivity in services; RLPR=RLPRM-RLPRS; x is the log of the relative price of tradables as defined in (2.2); y is the log of the relative price of nontradables as defined in (2.3). One measure of the relative prices is based on CPI data (CPI), the other on personal consumption deflators (PCD).

where Π and Γ_i are matrices of coefficients, $\mu_0 = -\Pi\mu + (\Gamma + \Pi)\gamma$, and $\mu_1 = -\Pi\gamma$, with $\Gamma = I_m - \sum_{i=1}^{l-1} \Gamma_i$. The hypothesis of cointegration may be stated in the following way $\Pi = \alpha\beta'$ where α and β are respectively (m, r) and (m, r) matrices of full rank, with r being the rank of cointegration, or the number of stationary linear combinations of the elements of Z_t.

It is common in the literature testing the cointegration between real exchange rates and real variables to assume that cointegrating vectors annihilate not only common stochastic but also deterministic trends (Amano and van Norden, 1995, Canzoneri et al., 1999, Chen and Rogoff, 2003, Kakkar, 2003). In other words, even if variables have deterministic trends, these trends do not enter cointegrating vectors. Mathematically, this condition can be formulated by requiring $\Pi\gamma = 0$ in equation (2.7). Kakkar (2003) argues that the Balassa-Samuelson model implies not only stochastic but also deterministic cointegration between the price of nontraded goods relative to traded goods and productivity differentials. I return to the discussion of this question in Chapter 3 after I discuss my model that also implies that deterministic trends do not enter cointegrating vectors. In what follows, I consider cointegrating vectors without deterministic trends.

The lag order for each model is determined by the following procedure. The default number is five lags for a VAR in levels. If the residuals exhibit some autocorrelation of the same order, the number of lags is increased by one up to eight lags until autocorrelation disappears. Details of the residual analysis can be found in Table 2.2. In two cases, I fail to find the appropriate lag order as autocorrelation is present in the system for any lag order considered. One problem arises with respect to productivity differentials RLPRM and RLPRS when PCD data are used to construct the relative price of nontraded goods. The problem can be resolved if instead of two productivity differentials in manufacturing and services, one relative productivity differential in manufacturing versus services is considered. The other case is when PCD data are used to construct the relative price of traded goods.

The results for cointegration are mixed (see Table 2.3). Depending on the statistic used, the Johansen tests find no cointegration, or one or two or even three cointegrating vectors. There is stronger evidence in favour of cointegration for the relative price of nontraded goods. Table 2.4 presents cointegrating vectors estimated by the Johansen method under the restriction that deterministic trends do not enter the cointegrating vector.

Table 2.2: Johansen procedures: Residual analysis

Equation	JB	LM	ARCH	Equation	JB	LM	ARCH
X (CPI)	0.615	0.108	0.481	X(PCD)	0.654	0.040	0.319
PCOM	0.000	0.605	0.832	PCOM	0.000	0.713	0.803
PENERGY	0.000	0.169	0.060	PENERGY	0.000	0.178	0.077
RLPRM	0.851	0.085	0.237	RLPRM	0.796	0.134	0.372
Equation	JB	LM	ARCH	Equation	JB	LM	ARCH
Y(CPI)	0.203	0.218	0.177	Y(PCD)	0.000	0.002	0.401
PCOM	0.000	0.150	0.825	PCOM	0.000	0.193	0.418
PENERGY	0.000	0.290	0.042	PENERGY	0.000	0.256	0.076
RLPRM	0.937	0.182	0.122	RLPRM	0.962	0.002	0.379
RLPRS	0.237	0.197	0.518	RLPRS	0.126	0.046	0.159
Equation	JB	LM	ARCH	Equation	JB	LM	ARCH
Y(CPI)	0.032	0.533	0.319	Y(PCD)	0.000	0.328	0.854
PCOM	0.000	0.296	0.903	PCOM	0.038	0.058	0.696
PENERGY	0.000	0.073	0.033	PENERGY	0.000	0.330	0.230
RLPR	0.768	0.797	0.220	RLPRM	0.933	0.231	0.225

JB: Jarque-Bera normality test (Bera and Jarque, 1981, 1982). LM: Lagrange multiplier test for residual autocorrelation (Breusch, 1978, and Godfrey, 1978). The order of autocorrelation tested corresponds to the lag order in the VAR model. ARCH: Lagrange multiplier test for residual ARCH (Engle, 1982). Asymptotic p-values are reported for each test. Variables: see the description in Table 2.1

Table 2.3: Johansen procedures: Testing for cointegration

X, PCOM, PENERGY, RLPRM

	CPI				PCD			
H_0 :	r=0	r=1	r=2	r=3	r=0	r=1	r=2	r=3
L-max	24.40	19.57	14.84	3.65	24.57	19.42	15.20	3.99
Trace	62.46	38.06	18.49	3.65	63.19	38.61	19.19	3.99

Y, PCOM, PENERGY, RLPRM, RLPRS

	CPI					PCD				
H_0 :	r=0	r=1	r=2	r=3	r=4	r=0	r=1	r=2	r=3	r=4
L-max	45.77*	28.29	16.12	13.45	6.72	50.50*	30.75	16.10	7.23	6.64
Trace	110.35*	64.58*	36.28	20.17	6.72	111.22*	60.72	29.97	13.87	6.64

Y, PCOM, PENERGY, RLPR

	CPI				PCD			
H_0 :	r=0	r=1	r=2	r=3	r=0	r=1	r=2	r=3
L-max	27.11	16.86	12.26	9.02	43.57*	24.56	21.20*	11.12
Trace	65.24*	38.13	21.28	9.02	100.45*	56.88*	32.32*	11.12

Testing for cointegration in VAR with constant and a deterministic trend in the cointegration space using Johansen test (Johansen, 1991). The null hypothesis is of r cointegrating vectors. An asterisk * means significance at the 5% level using the critical values reported in MacKinnon et al. (1999). L-max is the maximum eigenvalue test; Trace is the trace statistic. Depending on the tests statistics or method used to construct the relative prices there is no cointegration or one or two or three cointegrating vectors for X and Y.
Variables: see the description in Table 2.1

Table 2.4: Johansen procedures: Estimated cointegrating vectors

$X - \beta_1 PCOM - \beta_2 PENERGY - \beta_3 RLPRM$

	β_1	β_2	β_3
CPI	0.027	0.045	-0.395
PCD	0.014	0.052	-0.276

$Y - \alpha_1 PCOM - \alpha_2 PENERGY - \alpha_3 RLPRM - \alpha_4 RLPRS$

	α_1	α_2	α_3	α_4
CPI	-0.535	0.161	1.280	0.078
PCD	-0.058	0.007	-0.062	0.284

$Y - \gamma_1 PCOM - \gamma_2 PENERGY - \gamma_3 RLPR$

	γ_1	γ_2	γ_3
CPI	-0.027	-0.010	-0.138
PCD	-0.042	0.007	-0.147

Assuming one cointegrating vector, the cointegrating relationships are estimated using the Johansen method. "CPI" means that x or y are constructed using the CPI data. "PCD" means that x or y are constructed using the PCD data.
Variables: see the description in Table 2.1

The residual analysis, however, reveals some violations of normality such as excess kurtosis (see Table 2.2). The problem of excess kurtosis usually arises for commodity prices. Huang and Yang (1996) report that the Johansen method tends to overreject the null of no cointegration comparing to least squares methods when the errors are not independently normally distributed. I analyzed the eigenvalues of the companion matrix. For the relative price of tradables, the largest eigenvalue exceeds one, indicating an explosive process. This is another sign that the system is misspecified.

I further investigate the possibility of cointegration using single-equation test in Table 2.5. Residual-based tests include ADF (Dickey and Fuller, 1979, and Said and Dickey, 1984), ADF-GLS (Perron and Rodriguez, 2001), and M-test (Stock, 1999, Perron and Rodriguez, 2001). I also use the ECM test of Banerjee et al. (1998). The Table indicates that the tests cannot reject the null hypothesis of no cointegration, implying that the variables may not be cointegrated.

As a sensitivity analysis, and given the well-known low power of the tests, I proceed by estimating cointegrating vectors by DOLS with two leads and lags (Stock and Watson, 1993). The results are presented in Table 2.6. The following cointegrating relationships are estimated for x and y:

$$ECM1 = x - \beta_0 - \beta_1 PCOM - \beta_2 PENERGY - \beta_3 RLPRM$$

$$ECM2 = y - \alpha_0 - \alpha_1 PCOM - \alpha_2 PENERGY - \alpha_3 RLPRM - \alpha_4 RLPRS$$

where $PCOM$ is the log of the real price of non-energy commodities, $PENERGY$ is the log of the real price of energy commodities, $RLPRM$ is the relative labour productivity in Canadian versus US manufacturing, $RLPRS$ is the relative Canada-US productivity in services. The motivation for the first error-correction term is discussed in Chapter 3 and is based on a model that implies that the relative price of traded goods may be cointegrated with real variables. The motivation for the second vector comes from terms-of-trade and Balassa-Samuelson models that imply that the relative price of nontraded goods may be cointegrated with terms-of-trade, proxied by energy and non-energy commodities price indexes, and the relative productivity in the traded versus nontraded sectors.

Since the Balassa-Samuelson hypothesis implies that the relative price of nontraded goods, y, may be cointegrated with the relative productivity in manufacturing relative to services, I also estimate the following cointegrating relationship, which takes relative productivity into account:

$$ECM3 = y - \gamma_0 - \gamma_1 PCOM - \gamma_2 PENERGY - \gamma_3 RLPR$$

where RLPR is the difference between RLPRM and RLPRS.

The prior expectations for the cointegrating vectors are the following. If there is no relationship in the long run among real variables and the relative price of traded goods, as the law of one price implies, all slope coefficients are expected to be insignificant. Table 2.6 shows that the cointegrating vector for x has insignificant, at the 5% significance level, slope coefficients for the two measures of this relative price, consistent with prior expectations of this Chapter. I return to this issue in Chapter 3 after introducing a model explaining the relationship between the relative price of traded goods and real variables, that would imply a cointegrating vector.

The prior expectations for the relative price of nontraded goods are based on Balassa-Samuelson and terms-of-trade models. The Balassa-Samuelson model implies that α_3 and α_4 are expected to be negative and positive respectively, as higher productivity in the tradable sector is expected to appreciate the relative price, while higher productivity in the nontradable sector is expected to depreciate it. This is because productivity shocks in the tradable sector drive wages and the relative price of nontraded goods up. Productivity shocks in the nontradable sector are absorbed by lower prices of nontraded goods, without affecting nominal wages. Positive terms of trade shocks increase income and the demand for nontraded goods. Consequently, the relative price of nontraded goods increases to clear the market. Since terms of trade improvements are expected to appreciate the relative price of nontraded goods, α_1 and α_2 are expected to be negative. Consistent with the above discussion, γ_1, γ_2, and γ_3 are expected to be negative.

The cointegrating vector for y has expected signs in Table 2.6, except for α_2, and the estimated coefficients are significant at the 5% significance level. A positive shock to commodity prices appreciates the relative price as expected. Higher energy prices depreciate the relative price constructed with the CPI data contrary to the prior expectations but in accordance with other studies (Amano and van Norden, 1995, Chen and Rogoff, 2003) that also find a puzzling response with respect to energy commod-

Table 2.5: Testing of cointegrating relationships

	$ECM1$		$ECM2$		$ECM3$	
	CPI	PCD	CPI	PCD	CPI	PCD
ADF (BIC)	-2.46 (3)	-2.62 (3)	-2.66 (1)	-3.27 (0)	-2.42 (1)	-3.40 (0)
ADF (4)	-1.98	-2.19	-2.68	-2.76	-2.36	-2.88
ADF-GLS (4)	-2.97	-3.04	-3.22	-2.81	-3.31	-2.62
$MZ_\alpha - GLS$	-17.25	-17.81	-17.21	-9.23	-18.59	-7.81
ECM	0.19	-0.24	-0.43	-3.27	0.56	-2.75

$ECM1 : x = \beta_0 + \beta_1 PCOM + \beta_2 PENERGY + \beta_3 RLPRM$, $ECM2 : y = \alpha_0 + \alpha_1 PCOM + \alpha_2 PENERGY + \alpha_3 RLPRM + \alpha_4 RLPRS$, and $ECM3 : y = \gamma_0 + \gamma_1 PCOM + \gamma_2 PENERGY + \gamma_3 RLPR$. Residuals from the cointegration regressions estimated by OLS are tested for unit roots using ADF tests with the lag order selected by the BIC criterion (ADF(BIC)), the lag order is given in the parentheses) and with fixed four lags (ADF(4)). The critical values are taken from MacKinnon (1991). ADF-GLS is the ADF test applied to GLS-detrended data following Perron and Rodriguez (2001). MZ_α-GLS is the M-test proposed by Stock (1999) and applied to GLS-detrended data following Perron and Rodriguez (2001). There are four lags in the augmented regression. The critical values are from Perron and Rodriquez (2001). ECM tests for $\beta = 0$ in the following regression $\Delta y_t = \alpha' \Delta x_t + \beta y_{t-1} + \theta' x_{t-1} + \epsilon_t$; t ratio is reported. The critical values and test derivation are from Banerjee et al. (1996). The null hypothesis of no cointegration cannot be rejected at the 10% significance level for all tests.
Variables: see the description in Table 2.1

Table 2.6: Estimation of cointegrating relationships

	ECM1			ECM2			
	β_1	β_2	β_3	α_1	α_2	α_3	α_4
DOLS (CPI)	0.0365	-0.0108	-0.1304	-0.0803	0.0135	-0.0304	0.1987
se	(0.025)	(0.013)	(0.148)	(0.004)	(0.004)	(0.018)	(0.029)
DOLS (PCD)	0.0346	0.0026	-0.0517	-0.0345	-0.0141	-0.0443	0.1495
se	(0.021)	(0.012)	(0.124)	(0.003)	(0.003)	(0.014)	(0.024)

	ECM3		
	γ_1	γ_2	γ_3
DOLS (CPI)	-0.0701	0.0061	-0.0811
se	(0.004)	(0.004)	(0.016)
DOLS (PCD)	-0.0314	-0.0177	-0.0684
se	(0.003)	(0.003)	(0.013)

$ECM1 : x = \beta_0 + \beta_1 PCOM + \beta_2 PENERGY + \beta_3 RLPRM$, $ECM2 : y = \alpha_0 + \alpha_1 PCOM + \alpha_2 PENERGY + \alpha_3 RLPRM + \alpha_4 RLPRS$, and $ECM3 : y = \gamma_0 + \gamma_1 PCOM + \gamma_2 PENERGY + \gamma_3 RLPR$.

DOLS estimates (Stock and Watson, 1993) with two leads and lags and Newey and West (1987) heteroscedasticity and autocorrelation robust standard errors are reported for the long-run cointegrating relationships.

Variables: see the description in Table 2.1

ity prices. An increase in the relative productivity in manufacturing appreciates the relative price, while an increase in the relative productivity in services depreciates it, again, as was expected based on theoretical considerations. It is interesting that the coefficient corresponding to energy commodity prices switches sign again when the PCD data are used. Energy commodity prices tend to depreciate the relative price of nontraded goods when the CPI data are used and to appreciate it when the relative price is constructed with the PCD data. It is assumed in the third cointegrating vector that relative productivities in manufacturing and services have similar effects, in absolute value, on the relative price. Under this restriction, the estimates do not change much qualitatively, compared to the unrestricted vector. Shocks to commodity prices appreciate the relative price, shocks to energy prices depreciate or appreciate the relative price depending on the measure used. Shocks to relative productivity in manufacturing relative to services appreciate the relative price of nontraded goods.

The cointegrating vectors estimated by Johansen method in Table 2.4 are very different from the vectors estimated by DOLS. It is known that the Johansen procedure produces more outliers than other procedures (see Phillips, 1994 and references therein). Since I detect some problems with the Johansen procedure, I rely on single equation tests and estimation for further analysis.

All tests for cointegration used in this section has the null hypothesis of no cointegration. This approach may seem unnatural since as discussed in Chapter 3, cointegration among some variables may follow from theory. In this case, a more natural approach is to use the null hypothesis of cointegration and to reject it if there is enough evidence in the data that the cointegrating relationships do not hold. A variety of tests are developed for the null of cointegration, but their performance is not so well studied as for test with the null of no cointegration (see Gabriel, 2003, for a Monte Carlo study in this direction). It is also not clear how tests with cointegration and no cointegration as the null are suited for confirmatory analysis. Since later I check the sensitivity of my results if cointegration is present, and since tests with the null of cointegration are not so well studied, I do not conduct them in this paper.

2.5 Empirical models

2.5.1 Cholesky decomposition

I use a Cholesky decomposition with the following ordering of the six variables: the real price of energy commodities, real price of non-energy commodities, relative productivity in tradables, relative productivity in nontradables, relative price of tradables, and the relative price of nontradables. The ordering reflects exogeneity of shocks. Shocks to commodity prices are assumed to be the most exogenous: they affect all other variables but are affected only by shocks to themselves. They are followed by productivity shocks. With respect to the relative prices, I order the relative price of traded goods first. Shocks to the relative price of traded goods may affect both relative prices, but shocks to the relative price of nontraded goods cannot affect the relative price of traded goods on impact. An interesting question arises whether the results are specific to this particular ordering. I analyze whether the results change with other possible orderings.

2.5.2 Long-run identifying decomposition

This identification scheme uses the condition developed by Gali (1999) that only productivity shocks have permanent effects on labour productivity. I introduce a new variable for this model: RLPR which is the log of the ratio of the relative productivity in manufacturing to the relative productivity in services between the two countries. Permanent shocks to this variable are permanent productivity changes in manufacturing versus services in one country versus the other. Permanent shocks to this variable reflect the essence of the Balassa-Samuelson model.

The question is whether the scheme proposed by Gali (1999) identifies exactly technology shocks and not something else. As argued by Hall (1988) and Evans (1992), the technology shock should not be correlated with other exogenous shocks. Francis and Ramey (2003) analyze whether technology shocks identified in such a manner are correlated with monetary indicators, oil shock dummies, war dates, and the federal funds rate. As the latter study, which finds no evidence of such correlations, seems to support Gali's approach to identifying productivity shocks, I am reasonably confident of using this approach in the current context.

I further assume that commodity prices are exogenous. Neither productivity changes nor shocks to the relative prices have an impact on commodity prices. This assumption is plausible, since Canada is a small supplier of commodities in the world market and Canada has no impact on the prices of its commodities (see further discussion in Amano and van Norden, 1995, and Chen and Rogoff, 2003). Of course, economic conditions in the United States and the world economy are expected to affect commodity prices. That is, commodity prices may not be exogenous to the relative Canada-US prices, because economic conditions in the United States may affect the relative prices and commodity prices simultaneously. Amano and van Norden (1995) test for exogeneity between commodity prices and the real exchange rate and find that commodity prices are exogenous. Chen and Rogoff (2003) use a broad world commodity price index as an instrument for country specific commodity price indices. This approach is supposed to deal with the endogeneity problem arising from market pricing power of commodity suppliers. The results do not change substantially indicating that Canada, New Zealand, and Australia may be treated as price takers for commodities they export. Another source of bias may arise due to global shocks. Chen and Rogoff (2003) argue that in this case commodity prices should go up while currencies of small open economies should depreciate. Since the estimates indicate that shocks to commodity prices appreciate the exchange rates at least for New Zealand and Australia, the authors rule out concerns about this type of bias. In accordance with these findings, I treat commodity prices as exogenous.

The structural VAR model is the following:

$$A_0 \begin{bmatrix} \Delta RLPR_t \\ \Delta x_t \\ \Delta y_t \end{bmatrix} = \nu + B_0 \begin{bmatrix} \Delta PCOM_t \\ \Delta PENERGY_t \end{bmatrix} + A_1 \begin{bmatrix} \Delta RLPR_{t-1} \\ \Delta x_{t-1} \\ \Delta y_{t-1} \end{bmatrix} +$$

$$+B_1 \begin{bmatrix} \Delta PCOM_{t-1} \\ \Delta PENERGY_{t-1} \end{bmatrix} + \ldots + A_4 \begin{bmatrix} \Delta RLPR_{t-4} \\ \Delta x_{t-4} \\ \Delta y_{t-4} \end{bmatrix} +$$

$$+B_4 \begin{bmatrix} \Delta PCOM_{t-4} \\ \Delta PENERGY_{t-4} \end{bmatrix} + \begin{bmatrix} e_t \\ \epsilon_t \\ \eta_t \end{bmatrix}.$$

The model can be represented as:

$$A(L)\begin{bmatrix}\Delta RLPR_t\\ \Delta x_t\\ \Delta y_t\end{bmatrix}=\nu+B(L)\begin{bmatrix}\Delta PCOM_t\\ \Delta PENERGY_t\end{bmatrix}+\begin{bmatrix}e_t\\ \epsilon_t\\ \eta_t\end{bmatrix},$$

where $A(L)=A_0-A_1L-...-A_4L^4$, $B(L)=B_0+B_1L+...+B_4L^4$, and L is the lag operator.

Let $\Phi(L)=\sum_{i=0}^{\infty}\Phi_iL^i$ be an operator such that

$$\Phi(L)A(L)=I_3.$$

Then

$$\begin{bmatrix}\Delta RLPR_t\\ \Delta x_t\\ \Delta y_t\end{bmatrix}=\Phi(L)\nu+D(L)\begin{bmatrix}\Delta PCOM_t\\ \Delta PENERGY_t\end{bmatrix}+\Phi(L)\begin{bmatrix}e_t\\ \epsilon_t\\ \eta_t\end{bmatrix},$$

where $D(L)=\Phi(L)B(L)$, and $D(L)=\sum_{i=0}^{\infty}D_iL^i$.

The long-run effects from unit changes in the exogenous variables are described by $\sum_{i=1}^{\infty}D_i$, while the long-run effects from unit shocks to endogenous variables are represented by $\sum_{i=1}^{\infty}\Phi_i$. These effects can be equivalently represented by the matrices $D(1)$ and $\Phi(1)$ respectively. Permanent productivity shocks are identified by requiring that they are the only shocks that have a long-run impact on relative productivity. All other shocks have zero accumulated impact in the long-run. This means that the matrix of long-run effects $D(1)$ has zeros in the first row. The matrix $\Phi(1)$ has zeros in the first row except for the first element.

These conditions imply, in the manner of Shapiro and Watson (1988), that for the first equation in the model

$$\Delta RLPR_t=\beta_0+\sum_{j=1}^{4}\beta_{1,j}\Delta RLPR_{t-j}+\sum_{j=0}^{4}\beta_{2,j}\Delta PCOM_{t-j}$$

$$+\sum_{j=0}^{4}\beta_{3,j}\Delta PENERGY_{t-j}+\sum_{j=0}^{4}\beta_{4,j}\Delta x_{t-j}+\sum_{j=0}^{4}\beta_{5,j}\Delta y_{t-j}+\psi_t$$

the sum of all own lags for $PCOM$, $PENERGY$, x, and y are zero, where the reduceform disturbance term ψ_t is the first row element of the $\Phi(L)\begin{bmatrix} e_t \\ \epsilon_t \\ \eta_t \end{bmatrix}$ matrix. That is, $\sum_{j=0}^{4}\beta_{2,j}=0$, $\sum_{j=0}^{4}\beta_{3,j}=0$, $\sum_{j=0}^{4}\beta_{4,j}=0$, and $\sum_{j=0}^{4}\beta_{5,j}=0$. These conditions imply that the equation can be rewritten as

$$\Delta RLPR_t = \beta_0 + \sum_{j=1}^{4}\beta_{1,j}\Delta RLPR_{t-j} + \sum_{j=0}^{3}\alpha_{2,j}\Delta^2 PCOM_{t-j}$$

$$+\sum_{j=0}^{3}\alpha_{3,j}\Delta^2 PENERGY_{t-j} + \sum_{j=0}^{3}\alpha_{4,j}\Delta^2 x_{t-j} + \sum_{j=0}^{3}\alpha_{5,j}\Delta^2 y_{t-j} + \psi_t.$$

Since some of the RHS variables are correlated with ψ_t, namely $\Delta^2 x_t$ and $\Delta^2 y_t$, this equation is estimated by instrumental variables using lags one to four of $\Delta RLPR_t$, Δx_t, and Δy_t and lags zero to four of $\Delta PCOM_t$, and $\Delta PENERGY_t$.

The equations for x_t and y_t are reduced form equations since I do not identify structural shocks for x and y. Since the residual term does not correlate with the right-hand side variables, the equations are estimated by usual OLS.

2.5.3 Error-correction model

Models in 2.1-2.2 are in first-differences. They are misspecified if some of the variables are cointegrated. I fail to find cointegration among the variables using single-equation methods, as discussed in Section 2.4. The system-based approach, the Johansen procedure, indicates the presence of one or more cointegrating vectors for the relative price of nontraded goods. The disagreement between the single equation tests and system-based tests is not surprising. Gregory et al. (2004) report that for the null of no cointegration the correlation of p-values from a single-equation residual-based test and a system-based test is very low even when the sample size is large. The results of the Johansen procedure supporting cointegration may be due to violations of normality. Other studies, by Canzoneri at al. (1999) and Kakkar (2003), using different data and tests report cointegration among the price of nontraded goods in terms of traded goods and productivity differentials for some countries. Therefore, it is crucial to check the sensitivity of my results to the assumption that the relative price of nontraded goods is cointegrated with commodity prices and the relative productivity.

The cointegrated vector is estimated using DOLS with two leads and lags (Stock and Watson, 1993) in Table 2.6. I reproduce the estimated error-correction term for convenience here:

$$\begin{array}{llllllll} ecm = y & -0.009 & +0.070 & PCOM & -0.006 & PENERGY & +0.081 & RLPR \\ & (0.009) & (0.005) & & (0.004) & & (0.016) & \end{array}$$

when the CPI data are used and

$$\begin{array}{llllllll} ecm = y & +0.088 & +0.031 & PCOM & +0.018 & PENERGY & +0.068 & RLPR \\ & (0.006) & (0.003) & & (0.003) & & (0.013) & \end{array}$$

for the PCD data with standard errors in the parentheses.

The estimated coefficients are significant at the 5% significance level, except for energy commodities in the first cointegrating vector when the CPI data are used. The cointegrating vectors imply that positive shocks to non-energy commodity prices appreciate the relative price of nontraded goods. This is consistent with theoretical considerations since terms-of-trade improvements for Canada are supposed to increase the relative demand for nontraded goods and consequently drive their relative price up. Productivity improvements in the tradable sector appreciate the relative price of nontraded goods. This is consistent with the Balassa-Samuelson hypothesis. As was discussed before, shocks to energy commodities have a different impact on the relative price depending on the measure used. In the case of the CPI data, the impact is positive, although insignificant. In the case of the PCD data, the impact is negative meaning that a positive shock to energy commodities appreciates the relative price. This is the response one would expect given that Canada exports energy commodities. However, previous studies by Amano and van Norden (1995) and Chen and Rogoff (2003) found that shocks to energy prices depreciate the Canada-US real exchange rate. It is interesting that in both cases CPI indexes were used to construct real exchange rates. Thus, their surprising finding that shocks to energy prices depreciate the Canada-US real exchange may not hold if GDP deflators are used instead.

The structural shocks are identified in the manner similar to 2.5.2. That is, productivity shocks are identified as the only shocks that have a long-run impact on labour productivity. Shocks to commodity prices are assumed to be exogenous. Structural shocks to the relative price of traded and nontraded goods are not identified individually, since only their aggregate impact is analyzed. The relative productivity variable, commodity prices, and the relative price of nontraded goods all share a common stochastic trend. At the same time, commodity prices and the relative price of nontraded goods do not affect the relative productivity in the long-run. Therefore, the relative productivity variable is weakly exogenous. Since commodity prices are exogenous, a disequilibrium in the long-run relationship among the variables has to be corrected only through the relative price of nontraded goods. In other words, the error-correction term enters only the equation for the relative price of nontraded goods.

2.6 Forecast error variance decompositions

2.6.1 Cholesky decomposition

Table 2.7(a) reports mean square errors of 20-period ahead forecasts for x and y.[6] By using (2.4), I find that the structural shocks propagating through the relative price of traded goods account for 96% of the mean square error at this horizon for the real exchange rate. This result that x accounts for at least 96% holds at any horizon up to s=20, and, in addition, x accounts for at least 92% at horizons up to s=20 if a VAR in levels is used. The 96% figure is consistent with Engel's (1999) unconditional variance decomposition finding that the relative price of traded goods account for at least 95% of volatility in the real exchange rate. I find that, conditional on the real variables, the structural shocks identified in the VAR model propagate through the relative price of traded goods to the real exchange rate.

Table 2.7(b-c) shows the Forecast Error Variance Decompositions obtained from the model. Table 2.7(b) contains the unweighted contributions. If the Balassa-Samuelson model and terms-of-trade models are right, in assuming that real shocks propagate only through the relative price of nontaded goods, we should see zero contributions of real shocks to x, and high contributions to y. However, both predictions are questioned in the Table. First, the contributions for x are not zero at a five-year horizon and account for about 26% of the forecast variance of x. Second, the effects of real shocks on x and y are roughly the same. Real shocks identified in the model

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[6] Table 2.7(a) also provides justification for dropping the covariance term in (2.4). Formally, MSE($x + y$)=MSE(x)+MSE(y)+2 MSE(x,y). The last term, the covariance of forecast errors, is not zero since forecast errors are functions of structural shocks. However, as can be seen from the Table, the MSE(x,y) is significantly lower than MSE(x) or MSE(y).

account for about 39% of the forecast variance of y. There is some support for terms-of-trade models since shocks to energy and non-energy commodity prices account for roughly 26%. The Balassa-Samuelson hypothesis does not come through at all, as the driving force of the story, shocks to productivity in the tradable sector account for roughly 5% of the forecast error variance decomposition.

Table 2.7(c) uses the fact that the MSE for x contributes 96% to the MSE of q to weight the contributions from the structural shocks. Table 2.7(c) shows that real shocks affect the real exchange rate almost entirely through tradables. The total contribution of real shocks to the real exchange rate through the relative price of traded goods is around 25% while through the relative price of nontraded goods is minor at 1.6%. The Balassa-Samuelson and terms-of-trade stories get even weaker when we consider the real exchange rate, rather then the relative price of nontraded goods.

Engel (1999) finds that the relative prices of traded x and nontraded goods y are independent random walks. I assume that the forecast errors for Δx and Δy are uncorrelated. One may argue that if both relative prices are affected by real factors, the relative prices cannot be independent. Since I control for real shocks, I can address this issue. Table 2.7(b) shows that the relative price of tradables is driven by shocks to itself at the horizon considered. Since the relative price of tradables x is more volatile than the relative price of nontradables y, and is driven by shocks to itself, the correlation between these two variables may be low even if they are both affected by real shocks. Second, one may argue that if movements in the nominal exchange rate pass through to prices, the relative prices of tradables and nontradables cannot be independent. Table 2.7(b) shows that indeed there is some pass-through from x to y. But since y is not so volatile as x, this pass-through does not contribute a lot to the comovement of the two relative prices.

It is interesting whether the results are robust to other measures of x and y. Table 2.8 presents weighted and unweighted contributions when the PCD data are used. The overall story stays the same. Real shocks are equally important for the two relative prices. Since the relative price of nontraded goods does not matter much for the real exchange rate, real shocks propagate, to the extent they do, almost entirely through the relative price of traded goods.

The finding that real shocks propagate through the relative price of traded goods may not contradict theoretical considerations after all. Indeed, real shocks may affect

Table 2.7: Forecast error variance decompositions with Cholesky identifying restrictions: CPI data

(a) Mean square errors of 20-period ahead forecasts

	x	y
x	5.591×10^{-5}	0.007×10^{-5}
y	0.007×10^{-5}	0.225×10^{-5}

(b) Unweighted contributions

	PENERGY	PCOM	RLPRM	RLPRS	x	y
x	0.068	0.078	0.071	0.047	0.683	0.053
	(0.035, 0.201)	(0.034, 0.219)	(0.029, 0.196)	(0.019, 0.173)	(0.395, 0.689)	(0.019, 0.155)
y	0.074	0.186	0.052	0.079	0.117	0.492
	(0.035, 0.213)	(0.061, 0.318)	(0.021, 0.194)	(0.023, 0.236)	(0.043, 0.252)	(0.266, 0.565)

(c) Weighted contributions of structural shocks to the real exchange rate

	PENERGY	PCOM	RLPRM	RLPRS	x	y
by x	0.065	0.074	0.068	0.045	0.656	0.051
	(0.034, 0.193)	(0.033, 0.210)	(0.028, 0.188)	(0.018, 0.166)	(0.379, 0.661)	(0.018, 0.149)
by y	0.003	0.007	0.002	0.003	0.005	0.020
	(0.001, 0.009)	(0.002, 0.013)	(0.001, 0.008)	(0.001, 0.009)	(0.002, 0.010)	(0.011, 0.023)

A VAR in first differences with the Cholesky ordering (PENERGY, PCOM, RLPRM, RLPRS, x, and y) is used to calculate FEVDs 20 quarters ahead. (a) Mean square errors for 20-period ahead forecasts for x and y. (b) Decompositions for x and y. (c) Decompositions for q, given that x contributes 96% of FEVD of q. 95% confidence intervals, constructed by 999 bootstrap replications of residuals keeping the same time across equations, are given in the parentheses.

Variables: See the description in Table 2.1. The CPI data are used to construct x and y.

Table 2.8: Forecast error variance decompositions with Cholesky identifying restrictions: PCD data

(a) Unweighted contributions

	PENERGY	PCOM	RLPRM	RLPRS	x	y
x	0.051	0.060	0.072	0.046	0.719	0.052
	(0.028,	(0.026,	(0.034,	(0.020,	(0.417,	(0.017,
	0.193)	0.193)	0.203)	0.176)	0.725)	0.348)
y	0.010	0.104	0.087	0.050	0.055	0.605
	(0.046,	(0.030,	(0.042,	(0.028,	(0.032,	(0.348,
	0.219)	0.226)	0.219)	0.177)	0.169)	0.615)

(b) Weighted contributions of structural shocks to the real exchange rate

	PENERGY	PCOM	RLPRM	RLPRS	x	y
by x	0.049	0.057	0.069	0.043	0.683	0.049
	(0.027,	(0.025,	(0.032,	(0.019,	(0.396,	(0.016,
	0.184)	0.183)	0.193)	0.167)	0.689)	0.143)
by y	0.005	0.005	0.004	0.002	0.003	0.030
	(0.002,	(0.001,	(0.002,	(0.001,	(0.001,	(0.017,
	0.011)	0.011)	0.011)	0.009)	0.008)	0.031)

A VAR in first differences with the Cholesky ordering (PENERGY, PCOM, RLPRM, RLPRS, x, and y) is used to calculate FEVDs 20 quarters ahead. (a) Mean square errors for 20-period ahead forecasts for x and y. (b) Decompositions for x and y. (c) Decompositions for q, given that x contributes 95% of FEVD of q. 95% confidence intervals based on 999 nonparametric bootstrap replications or residuals with the same time across equations are given in the parentheses.

Variables: PENERGY is the log of the real price of energy commodities; PCOM is the log of the real price of non-energy commodities; RLPRM is the log of the relative Canada-U.S. labour productivity in manufacturing; RLPRS is the log of the relative Canada-U.S. productivity in services; x is the log of the relative price of tradables as defined in (2.2); y is the log of the relative price of nontradables as defined in (2.3). The PCD data are used to construct x and y.

the nominal exchange rate. Further, prices may be sticky in the short-run. There are other possible explanations why the law of one price may not hold for the relative price of traded goods in the short-run. Even if goods arbitrage arises, it usually takes some time before trade in goods may equilibrate relative prices and remove arbitrage opportunities. The question is how long it takes for prices and the nominal exchange rate to adjust to the law of one price equilibrium. In the theoretical literature it is usually assumed that price stickiness longer that one year is unrealistic. Rogoff (1996) reviews studies estimating half-lives with which deviations from PPP die out and favours estimates in the range from three to five years. One would expect that at a five year horizon deviations from the law of one price should die out and, therefore, the relative price of nontraded goods should be the dominant factor in explaining the real exchange rate at this horizon. I find that real shocks propagate entirely through the relative price of traded goods at the horizons up to five years. This suggests that slow adjustment in prices and the nominal exchange rate can not be responsible for high contribution of real shocks to the relative price of traded goods at such horizon.

Another test of the slow adjustment story can be done by considering contributions of shocks at different horizons. Theoretical considerations based on the law of one price for traded goods imply that arbitrage opportunities should be gradually removed and the relative price of traded goods should matter less and less, while the relative price of nontraded goods should gain in importance. To investigate this possibility, I calculate joint contributions of real shocks to the real exchange rate through the two relative prices at different horizons in Table 2.9.

The story that emerges from Table 2.9 is the opposite to what one would expect based on the deviations from the law of one price argument. Contributions of real shocks through the relative price of traded goods do not decline, but rather gain in importance at longer horizons. There is no way to explain these results as the outcome of a slow adjustment process. First, the contribution of real shocks through the relative price of traded goods should be low at a five-year horizon while I find that it is high. Second, the contributions of real shocks should decline over time, while they actually increase. I return to the discussion of this result in Chapter 3 where I analyze possible theoretical explanations of the importance of traded goods.

The proposed Cholesky decomposition is based on the assumption that some shocks are more "exogenous" than the others. Of course, there is some degree of arbitrariness in such ordering. I investigate whether the result that real shocks prop-

Table 2.9: **Forecast error variance decompositions at different horizons for Cholesky decomposition**

	CPI		PCD	
Horizon	by x	by y	by x	by y
1	0.047	0.007	0.062	0.013
5	0.187	0.015	0.170	0.017
10	0.246	0.015	0.209	0.017
20	0.257	0.015	0.218	0.018

Contribution of real shocks to the real exchange rate through the relative price of traded (x) and nontraded goods (y) constructed using the CPI and PCD data at different horizons.

agate through the relative price of traded goods holds for other possible orderings.[7] In all cases, I maintain the assumption that real shocks are at the top and the relative prices are at the bottom of the orderings. This assumption implies that real shocks affect the relative price but relative prices do not affect real shocks contemporaneously. I divide all variables in three groups: COMM for commodity prices, PROD for relative productivity differentials, and PRIC for the relative prices. I consider the following orderings: (COMM, PROD, PRIC) and (PROD, COMM, PRIC). I change the order of the variables within each block. In total, there are 16 possible combinations following this rule. For each combination, I calculate the joint impact of real variables on the real exchange rate through the relative price of traded and nontraded goods. While individual contributions change for each ordering, their joint impact stays the same for all 16 orderings. Real shocks contribute 25.7% and 21.8% to the real exchange rate variability at the horizon s=20 through the relative price of traded goods with the CPI data and the PCD data respectively. Real shocks propagating through the relative price of nontraded goods contribute 1.5% and 1.8% respectively

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[7] Faust (1998) advocates to check robustness of results for different identifying assumptions.

at the same horizon.

2.6.2 Long-run identifying decomposition

Table 2.10 shows contributions of shocks using the long-run identifying restriction. The productivity shock is equally important in explaining the variance of the relative prices of traded and nontraded goods and accounts for roughly 8-9% of the variance decompositions when the CPI data are used and 10-12% when the PCD data are used at the horizon s=20. These numbers are roughly similar to the ones obtained using the Cholesky identifying restriction that resulted in approximately 12-13% contributions from productivity shocks. Thus, the results with respect to the productivity shocks do not change dramatically for the two identifying restrictions.

Shocks to commodity prices play a more important role in this long-run decomposition. Shocks to non-energy commodity prices account for 38% of the variance of x and 20% of the variance of y with the CPI data and 33% and 10% with the PCD data. These higher contributions could be due to the condition imposed in this identifying restriction that commodity shocks are exogenous. Finally, since structural shocks to x and y are not identified, their contributions are presented together.

Using formula (2.4), I obtain the contribution of structural shocks propagating through x to the real exchange rate to be around 97.5%. This is similar to the contribution obtained using the Cholesky decomposition. Table 2.10(b) uses this number to weight contributions of the structural shocks propagating through x and y to the real exchange rate. The same story emerges with this decomposition. Real shocks identified in the model propagate mainly through the relative price of traded goods. The contribution of real shocks through x is even higher with this decomposition. Permanent shocks to productivity and exogenous shocks to commodity prices propagating through x account for approximately 49% with the CPI data and 46% with the PCD data of the variance decomposition of q.

Table 2.11 also shows that contributions of real shocks through the relative price of traded goods increase, while contributions through the relative price of nontraded goods decrease. After one period, real shocks propagating through x account for 11-14% of the real exchange rate variance decomposition. This contribution gradually grows to 44-48% at a five-year horizon. The contribution of real shocks through the relative price of nontraded goods slightly declines. As was discussed in the previous

Table 2.10: Forecast error variance decompositions: Long run identifying restrictions

(a) Unweighted contributions

	CPI				PCD			
	RLPR	PCOM	PENERGY	x & y	PRPR	PCOM	PENERGY	x & y
x	0.087	0.384	0.023	0.506	0.101	0.329	0.026	0.544
y	0.082	0.204	0.100	0.614	0.122	0.096	0.132	0.650

(b) Weighted contributions to the real exchange rate

	CPI				PCD			
	RLPR	PCOM	PENERGY	x & y	RLPR	PCOM	PENERGY	x & y
by x	0.085	0.374	0.022	0.494	0.097	0.317	0.025	0.525
by y	0.002	0.005	0.002	0.015	0.004	0.004	0.005	0.024

A VAR in first differences with the long run identifying restriction used to calculate FEVDs 20 quarters ahead. (a) Decompositions for x and y. (b) Decompositions for q, given that x contributes 97.5% of FEVD of q.

Variables: PENERGY is the log of the real price of energy commodities; PCOM is the log of the real price of non-energy commodities; RLPR is the log of the relative Canada-U.S. labour productivity in manufacturing versus productivity in services; x is the log of the relative price of tradables as defined in (2.2); y is the log of the relative price of nontradables as defined in (2.3).

Table 2.11: Forecast error variance decompositions at different horizons for long-run identifying restrictions

	CPI		PCD	
Horizon	by x	by y	by x	by y
1	0.107	0.011	0.143	0.015
5	0.419	0.010	0.402	0.013
10	0.434	0.010	0.436	0.013
20	0.481	0.009	0.439	0.013

Contribution of real shocks to the real exchange rate through the relative price of traded (x) and nontraded goods (y) constructed using the CPI and PCD data at different horizons.

sub-section, this is not the pattern one would expect based on theoretical considerations, which have the importance of x in the transmission mechanism declining.

2.6.3 Error-correction model

The results of the model are presented in Table 2.12. Overall they are similar to the results of the previous sub-section. The imposed cointegrated vector does not change the variance decompositions dramatically. Productivity shocks and shocks to commodity prices propagate almost exclusively through the relative price of traded goods.

The story also does not change with respect to FEVDs at different horizons. Table 2.13 shows the usual pattern for the importance of shocks. Real shocks propagating through the relative price of traded goods become more important as the horizon increases, while real shocks propagating through the relative price of nontraded goods decline in their importance. The error-correction term makes the transmission mechanism through the relative price of nontraded goods marginally more important, but

Table 2.12: Forecast error variance decompositions: Error-correction model

(a) Unweighted contributions

	CPI				PCD			
	RLPR	PCOM	PENERGY	x & y	RLPR	PCOM	PENERGY	x & y
x	0.083	0.386	0.021	0.510	0.095	0.330	0.026	0.549
y	0.083	0.261	0.096	0.560	0.135	0.116	0.147	0.602

(b) Weighted contributions to the real exchange rate

	CPI				PCD			
	RLPR	PCOM	PENERGY	x & y	RLPR	PCOM	PENERGY	x & y
by x	0.081	0.375	0.021	0.496	0.091	0.316	0.025	0.526
by y	0.002	0.007	0.003	0.015	0.006	0.005	0.006	0.025

A VECM with the long run identifying restriction used to calculate FEVDs 20 quarters ahead. (a) Decompositions for x and y. (b) Decompositions for q, given that x contributes 97.25% of FEVD of q.

Variables: PENERGY is the log of the real price of energy commodities; PCOM is the log of the real price of non-energy commodities; RLPR is the log of the relative Canada-U.S. labour productivity in manufacturing versus productivity in services; x is the log of the relative price of tradables as defined in (2.2); y is the log of the relative price of nontradables as defined in (2.3).

Table 2.13: Forecast error variance decompositions at different horizons for the EC model

	CPI		PCD	
Horizon	by x	by y	by x	by y
1	0.107	0.016	0.143	0.018
5	0.418	0.012	0.401	0.016
10	0.469	0.012	0.431	0.016
20	0.477	0.012	0.433	0.016

Contribution of real shocks to the real exchange rate through the relative price of traded (x) and nontraded goods (y) constructed using the CPI and PCD data at different horizons.

still not enough to considerably outweigh real shocks propagating by x. Contributions of real shocks through y increase from 9% to 12% using the CPI data and from 13% to 16% using the PCD data when the error-correction terms are added.

2.7 Conclusions

A striking result that emerges from the analysis of this chapter is that real shocks propagate almost entirely through the relative price of traded goods. This result is surprising in the light of theoretical considerations that assign no role to the relative price of traded goods in the transmission of real shocks. The relative price of traded goods may play a role in the transmission mechanism in the short-run if real variables affect the nominal exchange rate. In this case temporary deviations from the law of one price for traded goods should arise, but goods arbitrage should eliminate these deviations at longer horizons. Therefore, even if the relative price of traded goods is important in the short-run, its importance should decline as the horizon widens. Another striking result of my analysis is that the contributions of real shocks through the relative price of traded goods do not decline, while the contributions through the relative price of nontraded goods do not increase at longer horizons.

I use three models and find that the results are robust to different identifying strategies. The first model uses a Cholesky decomposition with real variables ordered on the top, i.e. shocks to real variables affect the relative prices simultaneously, but shocks to the relative prices do not affect real variables. Different possible orderings discussed in the text all give the same cumulative effects for the importance of the relative prices in the transmission mechanism. The second model uses the long-run identifying condition that the only shock that has a long-run impact on relative labour productivity is a technology shock. Commodity prices are treated as exogenous in this model, and shocks to the relative prices are not identified individually. Finally, the third model extends the second model by allowing the relative price of nontraded goods to be cointegrated with real variables.

From my point of view, the second approach that uses the long-run identifying restriction and assumes that commodity prices are exogenous is the most preferable in the current context. First, this is the most common approach in the literature to identify technology shocks (for example, see Gali, 1999, Francis and Ramey, 2003, and Altig et al., 2002). Second, the residual analysis reveals that equations for commodity prices show some violations of normality. Johansen (1992) shows that conditioning on 'problem' variables may improve inference in the rest of the system. The second approach uses commodity prices as exogenous. Third, shocks to the relative prices are not identified individually. This is an advantage because a reasonable identification scheme is not an easy task given that both relative prices contain prices of traded goods. Finally, a Cholesky decomposition may pick nominal shocks that affect labour productivity. It is known that labour productivity is pro-cyclical. The long-run identifying restriction may avoid this problem as nominal shocks are not supposed to affect labour productivity in the long run.

However, this identification scheme is subject to the critique by Faust and Leeper (1997) that long-run effects are imprecisely estimated in finite samples, and this imprecision is transferred by the long-run identifying scheme to the estimates of other parameters. Faust and Leeper (1997) propose to use short-run (finite-sample) restrictions to check the robustness of results. I use the Cholesky ordering and find similar qualitative results.

The model of the second approach is misspecified, and consequently the results are not valid, if some of the variables are cointegrated. Even though I failed to find cointegration among the variables, I analyse whether the results are robust to possible cointegration in the third approach. The imposed cointegration among the relative price of nontraded goods and the real variables does not change FEVDs considerably.

The analysis of this chapter reveals that real shocks propagate almost entirely through the relative price of traded goods, and that this relative price becomes more important as the horizon increases. This finding is at odds with theoretical considerations. In Chapter 3 of my dissertation I attempt to fill the gap between theory and empirical evidence by developing a stylized model that assigns a role to the relative price of traded goods in the transmission mechanism.

Chapter 3

An extension of the Balassa-Samuelson model with a role for traded goods in the transmission mechanism

3.1 Introduction

The previous chapter highlights a gap between postulates of the theoretical literature and empirical evidence. On the one hand, the theoretical literature generated by the seminal work of Balassa (1964) and Samuelson (1964) on productivity shocks has almost exclusively postulated that real shocks affect the real exchange rate through nontraded goods.[1] On the other hand, Engel (1999) finds that movements in the relative price of nontraded goods account for almost none of the movement of US real exchange rates. Rather, he finds that the other component of the real exchange rate, the relative price of traded goods, accounts for at least 95% of the volatility of the real exchange rate.

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[1] Nontraded goods play an exclusive role in the transmission mechanism because traded goods are assumed to be homogenous across countries and the law of one price pins down the relative price of traded goods at 1. In Section 2.2 the literature is reviewed and the log of the real exchange rate q is decomposed $q = x + y$, where x is the log of the relative price of traded goods and y is the log of the relative price of nontraded goods. With homogenous traded goods, purchasing power parity requires that $x = 0$ so that the real exchange rate is entirely explained by variations in the relative price of nontraded goods, $q = y$.

Engel's (1999) work has strong implications for the importance of real shocks. Real shocks can only account for a maximum of 5% of real exchange rate volatility if they only influence the relative price of nontraded goods (as maintained in the Balassa-Samuelson model). On the other hand, if real shocks are important for the real exchange rate, they must propagate through the relative price of traded goods. Chapter 2 tests these implications explicitly with Canada-US data and finds that productivity shocks and shocks to commodity prices affect the Canada-US real exchange rate almost entirely through the relative price of traded goods.

Another surprising finding of Chapter 2 is that the contribution of real shocks through the relative price of traded goods does not decline over time. This contradicts theoretical considerations that assume that real shocks cause short-term deviations from the law of one price parity that are eliminated by goods arbitrage at longer horizons. These empirical findings call for explicit modeling of the transmission mechanism which allows real variables to propagate through traded goods. This transmission mechanism is precluded in the existing Balassa-Samuelson model since prices of traded goods are pinned down by the law of one price. In this Chapter, I develop a minimal extension of the Balassa-Samuelson model which generates the transmission mechanism through traded goods.

First, I split the tradable sector of a small open economy into commodity producing and manufacturing sectors. This allows me to study shocks to commodity prices (terms-of-trade shocks) and productivity shocks in one framework. Resources are assumed to be homogeneous across countries, and the small open economy producing them has no pricing power; considerations relevant for resource exporting countries like Canada, Australia, or New Zealand. These considerations determine the wage rate in the resource producing sector. As in the Balassa-Samuelson model, labour is mobile so that shocks that affect wages in one sector are transmitted through wage adjustments to the other sectors. Unlike the Balassa-Samuelson model, it is commodity price shocks, rather than productivity shocks, that affect wages fully.

Second, I assume that manufacturing goods are heterogeneous. Manufacturing goods produced at home and abroad are not perfect substitutes. The composite traded good consists of commodities, home manufacturing good, and foreign manufacturing good. The model allows for the law of one price to hold for each individual traded good; i.e. commodities, the home good, and the foreign good each trade at the same price in both the home country and abroad.

Third, I assume that consumers have a home bias in preferences toward domestically produced manufacturing goods. The relative price of traded goods (bundle of commodities and manufacturing goods) deviates from one only if there is a home bias towards domestically produced manufacturing goods. The assumption of the home bias is crucial for the model to generate the transmission mechanism through traded goods. This assumption is used in other models such as Warnock (2003), Benigno and Thoenissen (2003), and MacDonald and Ricci (2002).

I assume that home bias is given exogenously. It is possible to model home bias endogenously, for example, by considering transportation costs as done in the literature. The focus of my paper is to analyze whether home bias would be enough to generate a transmission mechanism through the relative price of traded goods and explain why this relative price does not decline in importance as the horizon widens. If such a simplified model is successful in explaining these empirical findings, further efforts can be devoted to refinements of the existing model. If the model is not successful, further research should be directed to other possible approaches to break the law of one price for traded goods.

The model predicts that productivity shocks in manufacturing depreciate the relative price of tradables. The mechanism behind this effect is the following. Productivity improvements allow producers to lower prices given that wages are not affected. Home bias ensures that the relative price of tradables depreciates. This prediction is similar to Benigno and Thoenissen (2003) and MacDonald and Ricci (2002). The former model is based on the "new open economy macroeconomics" model of Obstfeld and Rogoff (2000), while the latter is based on the "new" trade theory approach of Helpman and Krugman (1985). The model of this paper is based on the classical Balassa-Samuelson model (e.g. Obstfeld and Rogoff, 1996, Ch.4). The model shows, in a parsimonious way, that the prediction that productivity shocks in manufacturing depreciate the relative price of tradables depends on the assumption of the home bias.

The model predicts that shocks to commodity prices appreciate the relative price of tradables. They drive wages up. Producers of manufacturing goods increase prices to compensate for higher wages. Home bias ensures that the relative price of tradables appreciates. The predictions of the model with respect to the relative price of nontraded goods are similar to classical models.

The model is tested by analyzing impulse response functions based on dynamic single-equation frameworks. I find that the relative price of tradables depreciates in response to both productivity and commodity shocks. The latter response contradicts the model. Impulse response functions for the relative price of nontraded goods support the importance of commodity prices for this relative price implied by the model.

This is not the only paper that allows real shocks to propagate through traded goods. Any model that allows traded goods to play a role in the transmission mechanism needs to break the law of one price. There are several approaches discussed in the literature. Bergin (2003) uses translog preferences that allow producers to set different prices at home and abroad in response to productivity shocks. Sticky prices (local currency pricing) are assumed in Benigno and Thoenissen (2003), with respect to productivity shocks, and in Engel (2004) with respect to commodity shocks. In this paper, the law of one price holds for each traded good, but does not hold for the composite traded good. It is well known that empirically the law of one price does not hold even at the disaggregated level (see Rogoff, 1996). This fact may cast doubt on the model of this paper. However, I argue below that the fact that the law of one price does not hold may not imply that the law of one price does not hold in the relative form with respect to real shocks.

I focus on real shocks in my model. While prices may be sticky with respect to nominal shocks, they may not be sticky with respect to real shocks. Roberts et al. (1994) find empirically that prices at the industry level adjust rapidly to nominal cost innovations, while Clark (1999), using the same data, finds that prices are very sluggish with respect to monetary policy shocks. Commodities are inputs in the production of manufactures. Consequently, commodity and productivity shocks affect the nominal cost. The evidence presented in Roberts et al. (1994) suggests that these types of shocks pass quickly to nominal prices. Therefore, flexible prices may be a desirable feature of a model explaining the transmission mechanism of real shocks. The model of this paper shows how real shocks can propagate through traded goods without assuming local currency pricing.

The contributions of this Chapter to the literature are the following. First, this Chapter explores one possible direction to explain the empirical findings of Chapter 2. The direction is based on home bias that is introduced in an otherwise standard model (i.e. along the lines of Obstfeld and Rogoff, 1996). Second, the Chapter explores the predictions of a set of the models with a role for traded goods in the transmission mechanism. Finally, these predictions, along with predictions of my model, are tested directly by considering impulse responses of the relative prices with respect to real shocks. This allows me to contrast the different models and make recommendations for further research.

The Chapter proceeds as follows. Section 3.2 provides a brief review of the recent literature. Section 3.3 develops a model that can be used to analyze how shocks to commodity prices and productivity may affect the relative price of tradables. Section 3.4 tests the predictions of this model and other papers. Section 3.5 concludes.

3.2 A review of the recent literature

There are only a handful of papers in the literature that do not *a priori* assume the law of one price holds for traded goods and instead have differentiated traded goods. Key features and results of these papers are summarized in Table 3.1.

Fitzgerald (2003) reconsiders the Balassa-Samuelson hypothesis with differentiated goods. Imperfect substitutability of goods implies that as productivity increases the supply of traded varieties increases and the downward sloping demand curve implies that the relative price of output falls. Consequently, wages increase by less than in the classical model. The Balassa-Samuelson effect weakens. The model assumes constant elasticity of demand, and thus implies that the relative price of tradables is stationary.[2] This model cannot explain movements in the relative price of traded goods.

Benigno and Thoenissen (2003) and MacDonald and Ricci (2002) show how the relative price of tradables may be affected by shocks to productivity under constant elasticity of substitution preferences. If households have a home bias toward domestically produced goods, the relative price of tradables may be affected in the long-run. This can be illustrated by continuing the decomposition in (2.2) by further dividing traded goods into home-produced manufacturing and foreign-produced manufacturing goods according to:

$$p_T = \beta p_H + (1-\beta) p_F$$

$$p_T^* = \beta^* p_H^* + (1-\beta^*) p_F^*$$

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[2] Obstfeld and Rogoff (2000) show that given constant elasticity of demand preferences for differentiated goods firms set prices at home and abroad so that the law of one price holds in relative form.

Table 3.1: Outline of recent studies modeling the impact of productivity shocks on the relative price of traded goods (x)

Study	Home bias	Preferences	Prices	Response of x	Integration and cointegration
Fitzgerald	No	CES	flexible	not affected	x is I(0)
Benigno and Thoenissen	Yes	CES	sticky	depreciation	cointegration
MacDonald and Ricci	Yes	CES	flexible	depreciation	cointegration
Bergin	No	translog	flexible	appreciation	

Studies: Fitzgerald (2003), Benigno and Thoenissen (2003), MacDonald and Ricci (2002), and Bergin (2003). Home bias means a preference toward domestically produced manufacturing goods. Preferences are over consumption goods. Prices can be flexible or sticky (local currency pricing). x is I(0) means that x is stationary, while cointegration indicates that x may be cointegrated with real variables if all are nonstationary.

where p_H and p_F are the logs of home-produced and foreign-produced manufacturing goods sold at home. Superscript * indicates that the parameters and prices are for the foreign country.

Assuming that foreign and domestic agents have different tastes towards home-produced traded goods, i.e., $\beta \neq \beta^*$, x can be further decomposed into:

$$x = \underbrace{\beta^*(s + p_H^* - p_H) + (1 - \beta^*)(s + p_F^* - p_F)}_{\text{Market segmentation}} + \underbrace{(\beta - \beta^*)(p_F - p_H)}_{\text{Home bias}}.$$

If the law of one price holds for each of the home and foreign goods, the market segmentation part is zero. The relative price of traded goods is not zero, though, if $\beta \neq \beta^*$. Under this assumption, a higher productivity in tradables in the home country would result in lower prices of home-produced tradables, p_H falls, and if $\beta > \beta^*$, the relative price of tradables depreciates, x increases. The testable prediction from this analysis is that the relative price of tradables depreciates in response to higher productivity in tradables. Another testable prediction is that if the relative price of tradables and $p_F - p_H$ are nonstationary, and the market segmentation part is stationary since the law of one price holds, then x may be cointegrated with factors affecting $p_F - p_H$.

The above studies all assume the CES preferences. Bergin (2003) considers translog preferences. In this case, firms charge different prices at home and abroad unless unit costs of production are the same in both countries. A positive shock to productivity in the tradable sector causes the real exchange rate to appreciate, and pricing to market accounts for half of the appreciation in the exchange rate. Both x_t and y_t appreciate by the same amount. The mechanism behind the appreciation of y_t is the same as offered by Balassa and Samuelson. Higher productivity in the tradable sector will drive wages and the cost of producing nontradables up. The relative price of nontradables increases in response. The intuition behind the appreciation of x_t is the following. Firms price traded goods at home in response to the costs of production of traded goods at home and abroad, and nontraded goods at home. Firms price traded goods abroad in response to the costs of production of traded goods at home and abroad, and nontraded goods abroad. Since the cost of production of nontraded goods increases at home, firms will charge a lower price for traded goods sold abroad than for traded goods sold at home ($p_H^* - p_H$ is negative). Foreign firms also respond to the cost and charge a higher price in the home market ($p_F^* - p_F$ is negative). The relative price of tradables appreciates.

Table 3.1 lists predictions of the above studies that can be tested. Constant elasticity of substitution preferences imply that the relative price of tradables is stationary unless there is a home bias. If there exists a home bias and x is nonstationary, then x has to be cointegrated with real variables. The home bias and CES preferences imply that the relative price of tradables depreciates in response to higher productivity in the tradable sector. Translog preferences imply that the relative price of tradables appreciates by the same amount as the relative price of nontradables. I will test these predictions in Section 3.4.

The above models only consider productivity shocks. I am also interested in how commodity prices affect the real exchange rate through the relative price of tradables.[3] Shocks to commodity prices may be particularly important for countries with a high share of commodities in exports like Canada, New Zealand, and Australia. Since these small open economies do not influence the price of commodities in the world markets, exogenous shocks to commodity prices may have effects on wages similar to that of productivity shocks. I consider both productivity and commodity price shocks in the rest of the Chapter.

3.3 Model

This section develops a simple model which allows tradables, as well as nontradables, to be channels through which shocks to real variables can impact the real exchange rate. The model differs in three respects from the basic small-open economy Balassa-Samuelson model (e.g. Obstfeld and Rogoff, 1996, Ch.4). First, a commodity producing sector is included in the model. Second, it is primary commodities, rather than manufacturing goods, that are homogenous across countries. Commodities usually have similar characteristics across countries, while many manufacturing products are differentiated. Therefore, this is a more reasonable assumption. Third, like Benigno and Thoenissen (2003) and MacDonald and Ricci (2002), I include a home bias; home consumers like their home produced manufacturing good more than foreign consumers. The home bias is necessary to ensure that real variables affect

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[3] Chen and Rogoff (2003) analyze how shocks to commodity prices affect the real exchange rate through nontradables.

the relative price of traded goods in this model. The home bias is usually present in the data. In particular, I find the home bias in the Canada-US data (see details in Appendix A).

There are two countries: home and foreign. All goods are produced according to constant returns to scale. There are tradable goods (denoted with a subscript T) and nontradable goods. Tradable goods produced in the home country are comprised of primary commodities (C) and home manufacturing good (H). The two types of traded goods and one type of nontraded goods are produced according to constant-returns production functions,

$$Y_C = A_C F(K_C, L_C),\ Y_H = A_H F(K_H, L_H),\ Y_N = A_N F(K_N, L_N),$$

where subscripts C, H, N denote the commodity producing sector, home manufacturing sector, and nontradable sector respectively; K is capital, L is labour, and A is total factor productivity. The foreign country produces only one type of traded good, foreign manufacturing good (F), and one type of nontraded good (N*) according to the following production functions: $Y_F^* = A_F^* F(K_F^*, L_F^*)$ and $Y_N^* = A_N^* F(K_N^*, L_N^*)$, respectively.

All three traded goods (primary commodities, home manufacturing good, and foreign manufacturing good) are consumed in the two countries. The home country is a small-open economy that has no pricing power over homogeneous primary commodities. The price of commodities is set in the world market.

Labour is freely mobile within the country, but immobile internationally. This ensures that wages are equal across the sectors within the country. Capital is assumed to be perfectly mobile internationally. The total supply of labour is fixed: L=$L_C + L_H + L_N$. All markets, input and output, are assumed to be perfectly competitive. With constant returns to scale, production functions can be expressed as $y_i = A_i f(k_i)$ where $y_i = Y_i/L_i$ and $k_i = K_i/L_i$, the capital-labour ratio, for each sector, $i = C, H$, and N, respectively.

I use the price of foreign manufacturing goods as a numeraire: P_F for the home country and P_F^* for the foreign country. All other prices are measured relative to the price of foreign manufacturing goods. The real interest rate r and the real wage w are measured in terms of foreign manufacturing goods. The real interest rate is assumed constant.

Firms are assumed to be competitive and in the domestic sector maximize present-value profits measured in foreign manufacturing goods

$$\sum_{s=t}^{\infty}\left(\frac{1}{1+r}\right)^{s-t}[\mathcal{P}_{i,s}A_{i,s}F(K_{i,s},L_{i,s})-wL_{i,s}-\Delta K_{i,s+1}]$$

for each sector, $i = C,\ H$, and N. First-order conditions with respect to capital and labour in per capita form imply:

$$\mathcal{P}_iA_if'(k_i)=r,\ \mathcal{P}_iA_i[f(k_i)-f'(k_i)k_i]=w \ \text{ for } i=C,N,H.$$

With constant returns to scale and competitive markets, payments to factors of production exhaust output:

$$\mathcal{P}_iA_if(k_i)=w+rk_i;\ \ \text{for } i=C,N,H,$$

and profits are zero when markets are competitive. Taking the log of the above equations and differentiating, keeping r constant, gives:

$$\frac{d\mathcal{P}_i}{\mathcal{P}_i}+\frac{dA_i}{A_i}+\frac{f'(k_i)dk_i}{f(k_i)}=\frac{dw}{w+rk_i}+\frac{rdk_i}{w+rk_i}.$$

Using the first order condition $\mathcal{P}_iA_if'(k_i)=r$ to substitute $\frac{r}{\mathcal{P}_iA_i}$ for $f'(k_i)$, and using the zero-profit condition $\mathcal{P}_iA_if(k_i)=w+rk_i$ to substitute $\mathcal{P}_iA_if(k_i)$ for $w+rk_i$, the last equation reduces to

$$\frac{d\mathcal{P}_i}{\mathcal{P}_i}+\frac{dA_i}{A_i}=\frac{w}{\mathcal{P}_iA_if(k_i)}\frac{dw}{w},$$

that can be rewritten for each sector in the following form:

$$\tilde{\mathcal{P}}_C+\tilde{A}_C=\mu_{LC}\tilde{w},$$

$$\tilde{\mathcal{P}}_N+\tilde{A}_N=\mu_{LN}\tilde{w},$$

$$\tilde{\mathcal{P}}_H+\tilde{A}_H=\mu_{LH}\tilde{w},$$

where $\mu_{LC} = \frac{w}{\mathcal{P}_C A_C f(k_C)}$, $\mu_{LN} = \frac{w}{\mathcal{P}_N A_N f(k_N)}$, and $\mu_{LH} = \frac{w}{\mathcal{P}_H A_H f(k_H)}$ are constant labour's shares of income in commodity producing, nontradable and home manufacturing sectors respectively. A "tilde" above a variable denotes logarithmic derivative, $\tilde{z} = dlog(z) = dz/z$ for any nonnegative variable z.

Since commodity prices and productivity are exogenous, the first condition reveals that the wage is determined solely in the resource producing industry:

$$\tilde{w} = \frac{1}{\mu_{LC}}(\tilde{\mathcal{P}}_C + \tilde{A}_C).$$

In the model wages are determined solely in the commodity-producing sector. This result obtains because of the assumption of constant returns to scale in the resource sector and the assumption that the country is a price taker with respect to resource prices.

Substituting the wage $\tilde{w}$ into the other equations gives:

$$\tilde{\mathcal{P}}_N = \frac{\mu_{LN}}{\mu_{LC}}(\tilde{\mathcal{P}}_C + \tilde{A}_C) - \tilde{A}_N, \tag{3.1}$$

$$\tilde{\mathcal{P}}_H = \frac{\mu_{LH}}{\mu_{LC}}(\tilde{\mathcal{P}}_C + \tilde{A}_C) - \tilde{A}_H. \tag{3.2}$$

Since generally the commodity producing sector is the least labour-intensive (μ_{LC}), while the nontradable sector is the most labour-intensive (μ_{LN}), these equations show that shocks to commodity prices are magnified in their impact on other prices ($\mu_{LN} > \mu_{LH} > \mu_{LC}$). Since labour is mobile within the country, wages have to equalize across the sectors. Producers in nontradable and manufacturing sectors will have to change prices to reflect changes in costs.

The impact of commodity prices (and commodity productivity) in this model is similar to the impact of productivity in the tradable sector in the Balassa-Samuelson framework. The Balassa-Samuelson model assumes that traded goods are homogeneous and the law of one price holds for them. Exogenous productivity improvements in the production of these goods are completely absorbed by wages, since the prices of tradables are fixed by the law of one price. Producers of nontradables have to increase prices of their products to compensate for higher wages.

The representative consumer maximizes a life-time utility function of the following form:

$$U_t = \sum_{s=t}^{\infty} \beta^{s-t} u(C_s)$$

subject to the constraint that the present value of the consumption expenditure is equal to the sum of financial and human wealth:

$$\sum_{s=t}^{\infty} \left(\frac{1}{1+r}\right)^{s-t} \mathcal{P}_s C_s = (1+r)Q_t + \sum_{s=t}^{\infty} \left(\frac{1}{1+r}\right)^{s-t} (w_s L_s - G_s),$$

where $\mathcal{P}$ denotes the aggregate price level, G denotes government expenditure, which is assumed equal to tax payments, Q denotes individual's financial wealth on date s.[4] The solution to this problem gives optimal consumption. Given the total consumption level, demands for the four individual goods are given by intratemporal maximization.

I assume the following Cobb-Douglas preferences of traded and nontraded goods:

$$C = \frac{C_T^{1-\alpha} C_N^{\alpha}}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}},$$

and for tradables:

$$C_T = \frac{C_C^{\gamma} C_H^{\beta} C_F^{1-\gamma-\beta}}{\gamma^{\gamma}\beta^{\beta}(1-\gamma-\beta)^{1-\gamma-\beta}}.$$

The representative agent each period maximizes the utility function

$$C = \frac{1}{(1-\alpha)^{1-\alpha}} \left(\frac{C_C^{\gamma} C_H^{\beta} C_F^{1-\gamma-\beta}}{\gamma^{\gamma}\beta^{\beta}(1-\gamma-\beta)^{1-\gamma-\beta}}\right)^{1-\alpha} \frac{C_N^{\alpha}}{\alpha^{\alpha}} \tag{3.3}$$

subject to the budget constraint $Z = \mathcal{P}_C C_C + \mathcal{P}_H C_H + C_F + \mathcal{P}_N C_N$. The first order conditions for the maximization problem are:

$$\frac{\gamma(1-\alpha)C_C^{\gamma(1-\alpha)-1}}{(1-\alpha)^{1-\alpha}} \left(\frac{C_H^{\beta} C_F^{1-\gamma-\beta}}{\gamma^{\gamma}\beta^{\beta}(1-\gamma-\beta)^{1-\gamma-\beta}}\right)^{1-\alpha} \frac{C_N^{\alpha}}{\alpha^{\alpha}} - \lambda \mathcal{P}_C = 0,$$

$$\frac{\beta(1-\alpha)C_H^{\beta(1-\alpha)-1}}{(1-\alpha)^{1-\alpha}} \left(\frac{C_C^{\gamma} C_F^{1-\gamma-\beta}}{\gamma^{\gamma}\beta^{\beta}(1-\gamma-\beta)^{1-\gamma-\beta}}\right)^{1-\alpha} \frac{C_N^{\alpha}}{\alpha^{\alpha}} - \lambda \mathcal{P}_H = 0,$$

$$\frac{(1-\gamma-\beta)(1-\alpha)C_F^{(1-\gamma-\beta)(1-\alpha)-1}}{(1-\alpha)^{1-\alpha}} \left(\frac{C_C^{\gamma} C_H^{\beta}}{\gamma^{\gamma}\beta^{\beta}(1-\gamma-\beta)^{1-\gamma-\beta}}\right)^{1-\alpha} \frac{C_N^{\alpha}}{\alpha^{\alpha}} - \lambda = 0,$$

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[4] The treatment of the consumer's problem follows Obstfeld and Rogoff (1996, Section 4.4) with the only difference that I assume a Cobb-Douglas specification rather than a CES.

$$\frac{1}{(1-\alpha)^{1-\alpha}}\left(\frac{C_C^{\gamma}C_H^{\beta}C_F^{1-\gamma-\beta}}{\gamma^{\gamma}\beta^{\beta}(1-\gamma-\beta)^{1-\gamma-\beta}}\right)^{1-\alpha}\frac{\alpha C_N^{\alpha-1}}{\alpha^{\alpha}}-\lambda\mathcal{P}_N=0,$$

where λ is the Lagrange multiplier. These conditions can be rewritten as:

$$\mathcal{P}_H C_H = \beta \mathcal{P}_C C_C/\gamma,$$

$$C_F = (1-\gamma-\beta)\mathcal{P}_C C_C/\gamma,$$

$$\mathcal{P}_N C_N = \frac{\alpha \mathcal{P}_C C_C}{\gamma(1-\alpha)},$$

and after substituting in the budget constraint one obtains:

$$C_C = \frac{Z\gamma(1-\alpha)}{\mathcal{P}_C}.$$

Similarly, $C_H = \frac{\beta(1-\alpha)Z}{\mathcal{P}_H}$, $C_F = (1-\gamma-\beta)(1-\alpha)Z$, and $C_N = \frac{\alpha Z}{\mathcal{P}_N}$.

Substituting the solution back to the utility function in (3.3), one can find $\mathcal{P}$ as the minimum expenditure function such that C=1. This gives:

$$\mathcal{P} = \mathcal{P}_T^{1-\alpha}\mathcal{P}_N^{\alpha};\ \mathcal{P}_T = \mathcal{P}_C^{\gamma}\mathcal{P}_H^{\beta}.$$

Foreign preferences are assumed to be the same $\alpha = \alpha^*$, $\gamma = \gamma^*$, except $\beta^* < \beta$. This implies that agents have the same preferences for primary commodities and nontradables, but prefer home-produced manufacturing goods. That is,

$$\mathcal{P}^* = \mathcal{P}_T^{*\,1-\alpha}\mathcal{P}_N^{*\,\alpha};\ \mathcal{P}_T^* = \mathcal{P}_C^{*\,\gamma}\mathcal{P}_H^{*\beta^*}.$$

At this point, it useful to go back to nominal prices since this is how the decomposition of the real exchange rate that follows is usually done in the literature. The prices of traded goods are:

$$P_T = P_C^{\gamma}P_H^{\beta}P_F^{1-\gamma-\beta};\ P_T^* = P_C^{*\,\gamma}P_H^{*\beta^*}P_F^{*\,1-\gamma-\beta^*}.$$

The log of the real exchange rate, $Q = SP^*/P$, is $q = s + p^* - p$. Using the formulas for P and P^*, one obtains

$$q = s + (1-\alpha)p_T^* + \alpha p_N^* - (1-\alpha)p_T - \alpha p_N =$$

$$s + p_T^* - p_T + \alpha(p_N^* - p_T^* - (p_N - p_T)),$$

which is the familiar decomposition of Section 2.2 implying $q = x + y$. In this case the logarithm of the relative price of tradables in the long run is

$$x = s + p_T^* - p_T =$$

$$\gamma(s + p_C^* - p_C) + \beta^*(s + p_H^* - p_H) + (1 - \gamma - \beta^*)(s + p_F^* - p_F) - (\beta - \beta^*)(p_H - p_F). \quad (3.4)$$

The three first terms in (3.4) are zero if the law of one price holds for each individual good.[5] Since the law of one price holds when preferences have constant elasticity of demand, equation (3.4) simplifies to

$$x = -(\beta - \beta^*)(p_H - p_F). \quad (3.5)$$

The relative price of nontradables is

$$y = \alpha[p_N^* - p_T^* - (p_N - p_T)]. \quad (3.6)$$

It is difficult to analyze (3.6) directly by using prices of foreign and domestic goods, because these prices are endogenous and proper identification may not be achievable. This point is illustrated by Obstfeld and Rogoff (2000) for the terms of trade. If producer prices are fixed and exchange rate pass-through is perfect, both terms of trade and real exchange rates move one-to-one. If prices are fixed in local currency, the correlation would be perfectly negative. If there is a mix of both pricing mechanisms and given that the exchange pass-through is not perfect, the identification of terms-of-trade shocks may be impossible. The same argument applies here to $p_H - p_F$, the relative price of domestic manufacturing goods in terms of foreign manufacturing goods: a mix of both pricing mechanisms and imperfect exchange-rate pass-through makes the identification of shocks to $p_H - p_F$ impossible. Exogenous productivity measures and commodity prices are preferable in such a situation.

If prices $p_H - p_F$, p_N^*, p_T^*, p_N, p_T, x and y have stochastic and deterministic trends, equations (3.5) and (3.6) indicate that the cointegrating vectors imply both stochastic and deterministic cointegration. Consider the relative price of traded goods

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[5] The relative price of traded goods, X, is different from terms-of-trade, which is the relative price of imports in terms of exports. In this model, terms-of-trade is the relative price of foreign manufacturing good in terms of trade weighted prices of commodities and home manufacturing good.

and equation (3.5), for example. Suppose the relative price $p_H - p_F$ is characterized by the following process:

$$p_H - p_F = \mu_0 + \mu_1 t + u_t; \quad u_t = u_{t-1} + \epsilon_t,$$

where ϵ_t is stationary. The relative price of traded goods is affected by real variables that are described by the following process:

$$x = \nu_0 + \nu_1 t + e_t; \quad e_t = e_{t-1} + \xi_t,$$

where ξ_t is stationary. Equation (3.5) implies stochastic, $u_t - \gamma' e_t = I(0)$, and deterministic, $\mu_1 = \gamma' \nu_1$, cointegration.

I use (3.1) and (3.2) to model changes in p_N and p_H. I ignore changes in the productivity in the resource producing sector, i.e. I drop $\tilde{A}_C$ from (3.1) and (3.2). This is a reasonable assumption as commodity prices are expected to be more volatile, due to changes in the world demand, than productivity changes in the resource producing sector.[6] I assume that the price of foreign manufacturing goods depends on foreign productivity only, a_F^*. The price of foreign nontradable goods depends on the productivity in the nontradable sector. Consequently, the relative price of nontraded goods depends on a_N^* and a_F^*: $\tilde{p}_N^* = -\tilde{a}_N^* + \tilde{a}_F^*$.

The relative price of tradables in (3.5), given (3.2) and the assumption about the price of foreign goods, can be written as:

$$\tilde{x} = (\beta - \beta^*)(\tilde{a}_H - \tilde{a}_F^* - \frac{\mu_{LH}}{\mu_{LC}} \tilde{P}_C). \tag{3.7}$$

This equation describes the transmission mechanism of commodity prices and productivity shocks to tradables. I discuss below how shocks to productivity and commodity prices propagate.

The relative price of nontradables in (3.6) can be rewritten using (3.1), (3.2) and the assumption on foreign nontradable goods:

$$\tilde{y} = \alpha(\tilde{a}_N - \tilde{a}_N^* - \frac{\mu_{LN}}{\mu_{LC}} \tilde{P}_C - (\beta - \beta^*)(\tilde{a}_H - \tilde{a}_F^* - \frac{\mu_{LH}}{\mu_{LC}} \tilde{P}_C)). \tag{3.8}$$

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[6] As a robustness check, I augmented non-energy commodity prices by labour productivity in the Canadian forestry and mining industries. This did not change any results qualitatively. For further analysis, I only consider commodity prices.

This equation describes the transmission mechanism for the relative price of nontraded goods. I discuss below how shocks to productivity and commodity prices propagate.

It is possible to calibrate the equations describing the transmission mechanism. The home bias $\beta - \beta^*$ is estimated in Appendix A for Canada-US to be around 0.27. The values of labour's shares of income for Canada are taken from Macklem (1995): $\mu_{LC} = 0.44$, $\mu_{LH} = 0.64$, and $\mu_{LN} = 0.72$. A share of nontraded goods, α, is estimated in Appendix A to be 0.44 approximately, using the CPI data, and 0.52, using the PCD data. Table 3.2 shows the responses of x and y to one standard deviation shocks in the real variables. Commodity prices play an important role for both relative prices in this model. One standard deviation shock (0.28%) to non-energy commodity prices (PCOM) appreciates the relative price of traded goods x by roughly 0.11% and the relative price of nontraded goods y by 0.15%. Productivity shocks (0.06%) in manufacturing, RLPRM, depreciate the relative price of traded goods by 0.018% and appreciate the relative price of nontraded goods by 0.008%, thus depreciating the real exchange rate. In comparison, the calibrated responses in Benigno and Thoenissen (2003) for Euro-UK data also show that the real exchange rate depreciates in response to productivity shocks in the tradable sector. Productivity improvements (0.03%) in the nontradable sector, RLPRS, depreciate y by 0.013%.

Table 3.2 shows that shocks to commodity prices are the most important. This is because the resource-producing sector is the least labour intensive sector where wages are determined. Table 3.2 also reveals that this model cannot account for the fact that real variables affect the real exchange rate almost entirely through x as found empirically in Chapter 2. This is also consistent with Engel (1999), who finds that different weights used to aggregate prices do not change the main prediction; x almost entirely accounts for the persistence and volatility of real exchange rates.

The predictions of my model are quite different than Chen and Rogoff (2003), who modify the Balassa-Samuelson model to include shocks to commodity prices. In their model, productivity shocks operate as in the classical Balassa-Samuelson model. They drive wages and the price of nontradables up, and the relative price of nontradables y appreciates. In contrast, in my model, manufacturing productivity shocks drive prices of tradables down and, if there is a home bias, the relative price of tradables depreciates while the relative price of nontradables appreciates. In Chen and Rogoff (2003), shocks to commodity prices appreciate the relative price of nontradables y, and affect the real exchange rate through y. In my model, shocks to commodity prices

Table 3.2: Calibrated responses of the relative prices of traded and nontraded goods to real shocks

	PCOM	RLPRM	RLPRS
x	- 0.109	0.018	0
y	- 0.152	- 0.008	0.013

Calibrated responses of the relative prices of traded and nontraded goods to one standard deviation shocks in the real variables based on equations (3.7) and (3.8).
Variables: PCOM is the log of the real price of non-energy commodities; RLPRM is the log of the relative Canada-US labour productivity in manufacturing; RLPRS is the log of the relative Canada-US productivity in services; x is the log of the relative price of tradables as defined in (2.2); y is the log of the relative price of nontradables as defined in (2.3).

appreciate not only the relative price of nontradables y but also the relative price of tradables x.

It is useful to summarize the predictions of the model that can be tested.

Prediction 1: x is nonstationary.

This prediction follows from (3.7) and (3.8). It requires the following assumptions:

1. $p_H - p_F$ is nonstationary,
2. The home bias exists, i.e. $\beta \neq \beta^*$,
3. The law of one price holds for each individual good.

This prediction is also implied by models in Benigno and Thoenissen (2003) and MacDonald and Ricci (2002) since these studies also make assumptions 2 and 3.

Prediction 2: x is cointegrated with $a_H - a_F^*$ and P_C.

Equations (3.4), (3.5), and (3.6) explain this prediction. If the law of one price holds for each individual good the first three terms in (3.4) are stationary. If x and $p_H - p_F$ are nonstationary, they have to be cointegrated, given that the home bias exists. The model implies that $p_H - p_F$ is explained by $a_H - a_F^*$ and P_C. Therefore, x has to be cointegrated with $a_H - a_F^*$ and P_C, if all three variables are nonstationary. This prediction requires the same three assumptions listed above. Consequently, it is also implied by the models in Benigno and Thoenissen (2003) and MacDonald and Ricci (2002).

Prediction 3: A positive shock to $a_H - a_F^*$ increases x, i.e. depreciates the relative price of tradables.

This prediction follows from (3.7). The intuition is the following. Higher relative productivity in the tradable sector allows domestic producers to decrease prices of manufacturing goods so that $p_H - p_F$ decreases. Home bias ensures that the relative price of tradables depreciates.[7] This prediction is consistent with models in Benigno

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[7] An interesting test of this model would be a comparison with the Balassa-Samuelson model. In particular, which channel is more important: higher productivity in manufacturing resulting in

and Thoenissen (2003) and MacDonald and Ricci (2002). Bergin's (2003) model predicts an appreciation in this case.

Prediction 4: A positive shock to P_C decreases x, i.e. appreciates the relative price of traded goods.

This prediction follows from (3.7). Higher commodity prices drive wages in Canada up in all sectors.[8] Producers of manufacturing goods increase prices of their products to compensate for higher wages. Since there is a home bias in consumption of manufacturing goods, this increase appreciates x.

Prediction 5: Shocks to real variables affect y according to

$$y = g(\underbrace{p_C}_{-}, \underbrace{a_H - a_F^*}_{-}, \underbrace{a_N - a_N^*}_{+}).$$

The impact of commodity prices (p_C) on y can be described as follows. Higher commodity prices increase wages in the country. Producers of nontradables and manufacturing goods increase the prices of their products in response. Since the nontradable sector is more labour intensive than manufacturing and since the home bias $\beta - \beta^*$ is not large, the price of nontradables increases by more than the price of tradables in Table 3.2.

Higher relative productivity in manufacturing decreases prices of manufacturing products. Home bias ensures that domestic prices of tradables decrease by more than foreign prices. Consequently, the relative price of nontradables y appreciates. Higher relative productivity in nontradables negatively affects prices of nontradables at home relative to prices abroad. Consequently, the relative price of nontraded goods depreciates.

The predictions of the model for the relative price of nontraded goods are sim-

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higher wages, or higher productivity resulting in lower prices. The first channel will reinforce the Balassa-Samuelson model, while the second channel will give some support to my considerations. Edge et al. (2003) analyze the responses of wages and prices to technology shocks using aggregate data and find that prices fall immediately in response while nominal wages are very sluggish, thus somewhat supporting the considerations in this paper. I plan to analyze sectoral technology shocks in future work.

[8] Wages in the United States are not affected since the United Sates does not produce commodities.

ilar to classical studies. However, the mechanics is different for manufacturing. In the Balassa-Samuelson model, productivity shocks in the manufacturing sector drive wages up causing the relative price of nontradables to appreciate. Here, productivity shocks drive prices of manufacturing goods down causing the relative price of nontradables to appreciate.

The next section analyzes the predictions of the model of this section empirically. To allow for the possibility that energy and non-energy commodity prices have different impacts on the real exchange rate empirically, I use two commodity price indexes for P_C in the empirical part of the Chapter.[9]

3.4 Empirical results

This section uses the same data as in Chapter 2. Consequently, the details of testing for unit roots and cointegration can be found there. In this part, I briefly overview some of the test results that are relevant for the predictions. Tests for unit roots reveal that the null hypothesis of a unit root cannot be rejected at the 10% significance level for all series. For the relative price of traded goods this supports Prediction 1. Home bias (or failure of the law of one price) and nonstationarity of $p_H - p_F$ ensures that x is nonstationary.

Single-equation tests for cointegration cannot reject the null hypothesis of no cointegration, implying that the variables may not be cointegrated. Therefore, there is no support for Prediction 2. The variables may not be cointegrated if the law of one price does not hold for traded goods. It is known that the law of one price does not hold well empirically even at the very disaggregated level (see Rogoff, 1996). In this case, the first three terms in (3.4) do not have to be stationary, and therefore x does not have to be cointegrated with $p_H - p_F$.

The Johansen tests find some evidence for cointegration especially for the relative price of nontraded goods. The residual analysis, however, reveals some violations of normality such as excess kurtosis. Huang and Yang (1996) report that the Johansen method tends to overreject the null of no cointegration, compared to single equations methods, when the errors are not independent normal. Therefore, the evidence

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[9] Amano and van Norden (1995) and Chen and Rogoff (2003) report, in their empirical studies, that non-energy and energy commodities have different impacts on the real Canada-US exchange rate.

coming from the Johansen tests may be due to the violation of the normality.

It is interesting to compare my results for cointegration with other studies. Canzoneri et al. (1999) and Kakkar (2003) test for possible cointegration between $p_N - p_T$ and $a_H - a_N$ for a panel of countries. The former study uses labour productivity as a measure of productivity, while the latter study relies on labour-share-adjusted total factor productivity. In the first case, it is found that the analyzed variables are cointegrated for Canada and the United States using the ADF test (but not for Canada using Phillips-Perron tests). The second paper find cointegration for Canada and somewhat mixed results for the United States using canonical cointegration regressions with the null of cointegration.

These results should not be viewed as in contradiction to my results. First, I test for cointegration between y and real variables, not between $p_N - p_T$ and $a_H - a_N$ for each country. The component y is the relative relative price, i.e. $p_N^* - p_T^*$ relative to $p_N - p_T$. Cointegration of $p_N - P_T$ and $a_H - a_N$ will imply cointegration among y, $a_H - a_F^*$ and $a_N - a_N^*$ only if cointegrating vectors are the same for two countries. Indeed, if $p_N - p_T - \eta(a_H - a_N) = I(0)$ and $p_N^* - p_T^* - \eta^*(a_F^* - a_N^*) = I(0)$ then

$$y = \alpha^*(p_N^* - p_T^*) - \alpha(p_N - p_T) =$$

$$\alpha^* I(0) + \alpha^*\eta(a_H - a_N) - \alpha I(0) - \alpha\eta^*(a_F^* - a_N^*).$$

Only if $\alpha^*\eta = \alpha\eta^*$, y has to be cointegrated with $a_H - a_F^*$ and $a_N - a_N^*$. Second, I add commodity prices to the cointegration space. Third, we use different data sources. Canzoneri et al. (1999) and Kakkar (2003) use the OECD International Sectoral Database, while I rely on national statistical agencies. Finally, we use different tests. For example, Kakar (2003) cannot reject the null of cointegration, while I cannot reject the null of no cointegration. Both results can be due to low power of the tests.

3.4.1 Dynamic models and impulse response analysis

In order to test Predictions 3 to 5, I analyze the dynamic relationship among the variables using single-equation models conditional on exogenous real variables. Conditioning on exogenous variables is advocated by Johansen (1992) and Pesaran et al. (2000) among others. The residual analysis of Section 2.4 reveals that equations for commodity prices exhibit some 'problematic' features, such as violations of normality. The equation for the productivity differential in some cases shows signs of serial correlation. Johansen (1992) indicates that conditioning on exogenous variables that exhibit problematic features makes it likely that the rest of the system will be better behaved statistically. Since I treat commodity prices and productivity differentials as exogenous with respect to the relative prices, it may be advantageous to conduct an analysis conditioning on these variables. Pesaran et al. (2000) recommend an approach in which a subset of variables, if justified, is treated as structurally exogenous, paving the way for a more efficient multivariate analysis. The models analyzed include models in first differences and single-equation error-correction models imposing the cointegrated vectors estimated by DOLS.

A starting point of this analysis is models in first differences since the single-equation tests of Section 2.4 failed to find cointegration. The model for the relative price of tradables (x) includes four lags of the explanatory variables:

$$\Delta x(t) = \alpha_0 + \sum_{j=1}^{4} \alpha_j \Delta x(t-j) + \sum_{j=0}^{4} \iota_j \Delta RLPRM(t-j)$$

$$+ \sum_{j=0}^{4} \gamma_j \Delta PENERGY(t-j) + \sum_{j=0}^{4} \delta_j \Delta PCOM(t-j) + \epsilon(t),$$

where RLPRM is relative Canada-US productivity in manufacturing, PENERGY and PCOM are real energy and non-energy commodity prices.

Figure 3.1 shows the impulse responses of x to one standard deviation shocks to the explanatory variables. Prediction 3 is that this relative price needs to depreciate with respect to positive productivity shocks. The response of x with respect to a productivity shock confirms the prediction; the relative price of tradable goods depreciates. A one-standard deviation (0.06%) shock to productivity in manufacturing causes the relative price of traded goods to depreciate by 0.01% in the long-run. This response is also consistent with calibrated simulations of Benigno and Thoenissen (2003) for the UK-euro relative price of tradables. MacDonald and Ricci (2002) report that the impact of productivity in tradables on the real exchange rate is negative as soon as the impact of wages in tradables is controlled for in a panel dynamic OLS estimation of nine bilateral US dollar real exchange rates. The impulse responses presented here complement these studies and explicitly demonstrate that the relative price of traded goods depreciates in response to higher productivity in tradables.

Bergin's (2003) prediction that x appreciates in response to productivity shocks in manufacturing is rejected for my data.

Prediction 4 is that x appreciates with respect to positive shocks to commodity prices. The response of the relative price of traded goods to a positive shock to non-energy commodity prices, shown in Figure 3.1, contradicts Prediction 4. The response shows that the relative price of tradables depreciates. A one-standard deviation shock (0.28%) causes the relative price to depreciate by 0.03% at the five-year horizon. This response is puzzling. To get further insights, I decompose x into the nominal exchange rate s and the ratio of prices $p_T^* - p_T$. Figure 3.3 shows that the nominal exchange rate appreciates on impact as expected. The ratio of prices increases significantly after two quarters. US manufacturing producers increase prices by more than Canadian producers in response to higher commodity prices. This result needs further assessment and investigation. The theoretical model assumes that production sides are similar in the two countries, and the only asymmetry is that Canada produces primary commodities while the US does not. Thus, commodity shocks have an impact on wages in Canada but not in the United States. This impact on wages affects all prices in the economy and through the home bias the relative price of tradables. One possible explanation to the puzzling response is that production structures are different in the two countries with respect to commodities as inputs. Due to this possible asymmetry, US producers may have to increase prices by more than Canadian producers.

The model for the relative price of nontradables is:

$$\Delta y(t) = \beta_0 + \sum_{j=1}^{4} \beta_j \Delta y(t-j) + \sum_{j=0}^{4} \kappa_j \Delta RLPRM(t-j) + \sum_{j=0}^{4} \eta_j \Delta PENERGY(t-j)$$

$$+ \sum_{j=0}^{4} \theta_j \Delta PCOM(t-j) + \sum_{j=0}^{4} \vartheta_j \Delta RLPRS(t-j) + \varepsilon(t),$$

where RLPRS is the relative productivity in nontradables.

Figure 3.2 shows impulse response functions for y with respect to one standard deviation shocks to the explanatory variables. Note that the responses are insignificant for all variables except non-energy commodity prices. The fact that commodity prices are more important for the relative price of nontraded goods corresponds to the calibration of the theoretical model presented in Table 3.2. The impulse response

Figure 3.1: Impulse response functions of the relative price of traded goods to real shocks

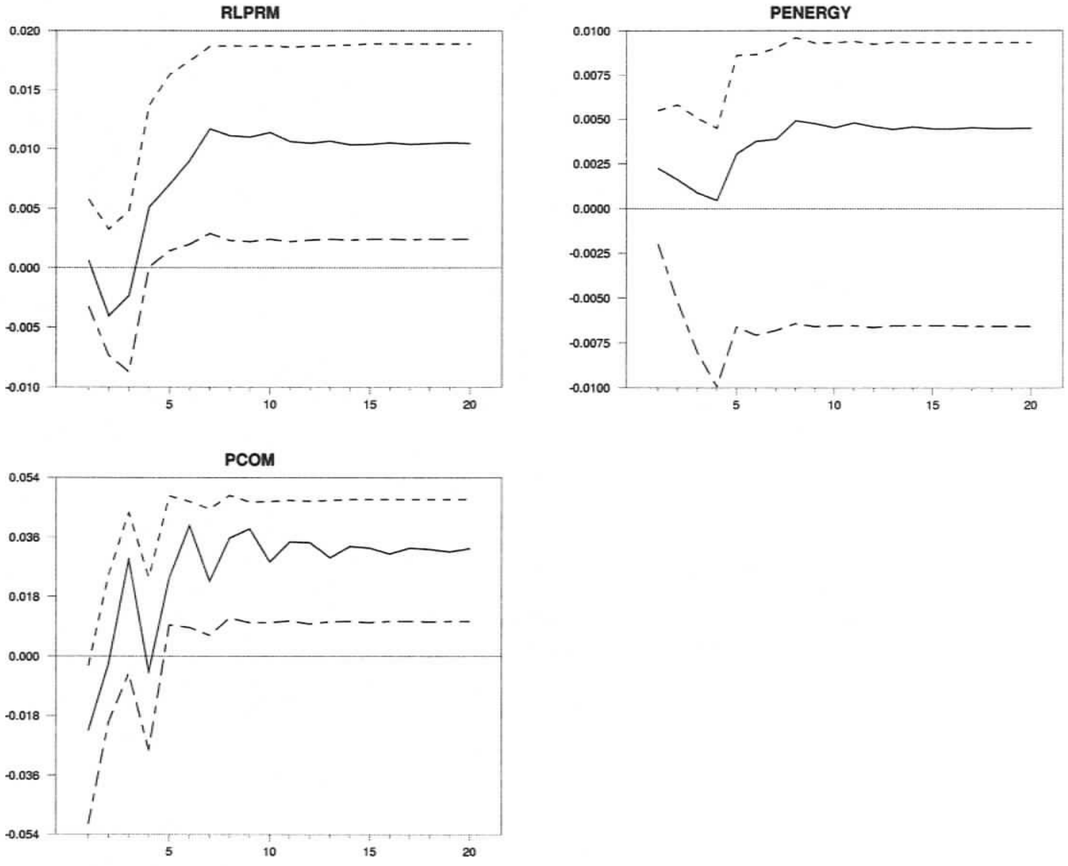

Figure 3.1

Models in first differences. Dynamic response of the relative price of traded goods to one standard deviation shocks to explanatory variables. 90% confidence intervals are based on 999 nonparametric bootstrap simulations with replacement. The relative prices are constructed using the CPI data. Variables are described in Table 2.1

Figure 3.2: Impulse response functions of the relative price of nontraded goods to real shocks

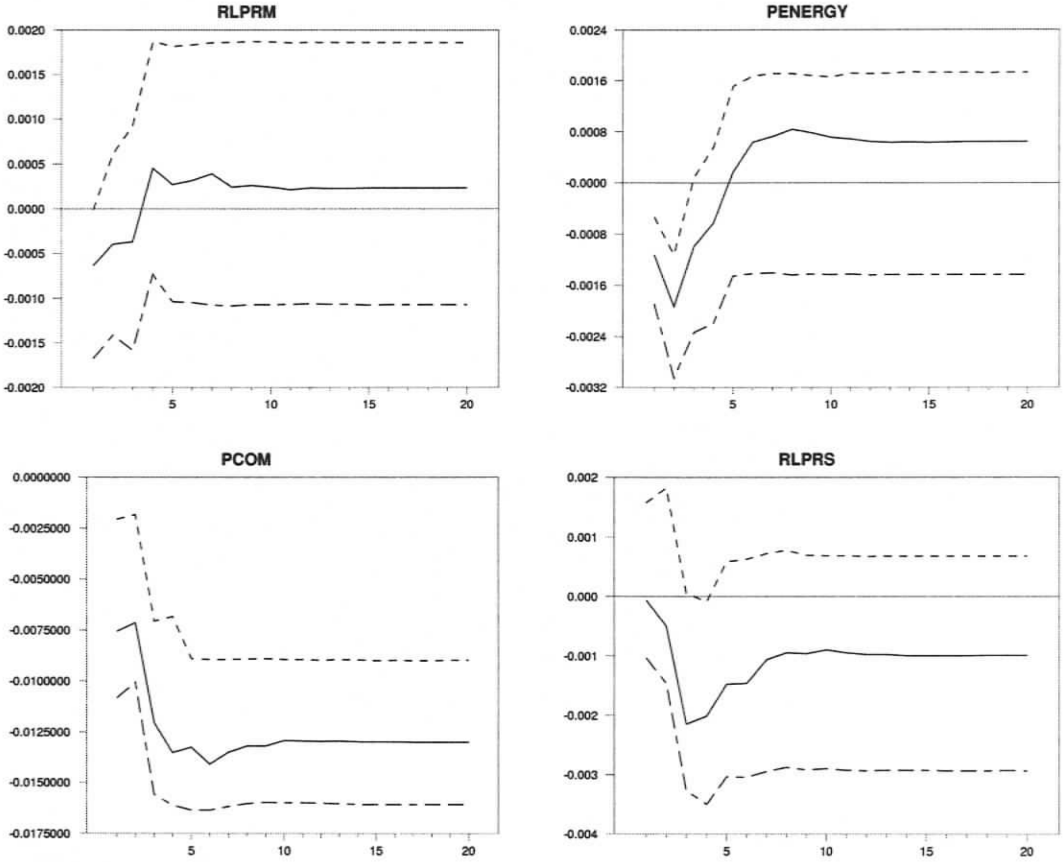

Figure 3.2
Models in first differences. Dynamic response of the relative price of nontraded goods to one standard deviation shocks to explanatory variables. 90% confidence intervals are based on 999 nonparametric bootstrap simulations with replacement. The relative prices are constructed using the CPI data. Variables are described in Table 2.1

Figure 3.3: Impulse responses of the price ratio and the nominal exchange rate

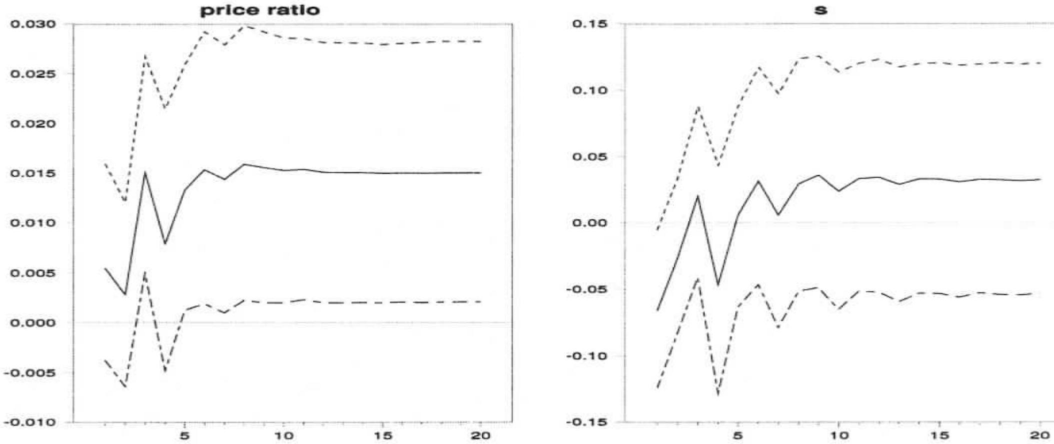

Figure 3.3
Dynamic response of the log price ratio of traded goods $(p_T^* - p_T)$ and the log nominal exchange rate s to an one standard deviation shock in commodity prices. 90% confidence intervals are based on 999 parametric bootstrap simulations assuming normal disturbances. The CPI data are used to construct the price ratio.

functions of this section support the importance of commodity prices for y.

I investigate whether the responses obtained with the CPI data stay the same when the PCD data are used. Figures 3.4 and 3.5 show responses of the relative prices to the same real shocks, but the relative prices are constructed using personal consumption deflators. Figure 3.4 shows no change in the qualitative responses of the relative price of traded goods. Figure 3.5, however, shows that responses change. All responses are now of the right sign, while two responses to productivity shocks are still insignificant. The relative price of nontraded goods appreciates in response to shocks to non-energy and energy commodity prices. Again, the response of the relative price with respect to energy shocks depends on the measure used to construct the relative price. The relative price based on the CPI data depreciates in response to energy shocks, while the price based on the PCD data appreciates. These different responses may be due to different concepts used to derive CPI and consumption deflator price indices. The main difference between these indices is that the CPI assigns fixed weights to prices of different goods, while the consumption deflators assign changing weights. The CPI may overstate changes in the cost of living with respect to energy shocks because consumers may switch to cheaper goods and/or more energy efficient goods.

The models developed above are misspecified if cointegration is present among the variables. Even though I have not found strong evidence against no cointegration in the previous sub-section, I pursue a possibility that these failures are due to the low power of the tests and I estimate single-equation error-correction models for each relative price.

For the relative price of tradables:

$$\Delta x(t) = \alpha +_0 + \sum_{j=1}^{4} \alpha_j \Delta x(t-j) + \sum_{j=0}^{4} \xi_j \Delta RLPRM(t-j)$$

$$+ \sum_{j=0}^{4} \gamma_j \Delta PENERGY(t-j) + \sum_{j=0}^{4} \delta_j \Delta PCOM(t-j) + \lambda ECM_1(t-1) + \epsilon(t),$$

and for the relative price of nontradables:

$$\Delta y(t) = \beta_0 + \sum_{j=1}^{4} \beta_j \Delta y(t-j) + \sum_{j=0}^{4} \kappa_j \Delta RLPRM(t-j) + \sum_{j=0}^{4} \eta_j \Delta PENERGY(t-j)$$

$$+ \sum_{j=0}^{4} \theta_j \Delta PCOM(t-j) + \sum_{j=0}^{4} \vartheta_j \Delta RLPRS(t-j) + \mu ECM_2(t-1) + \varepsilon(t),$$

where ECM_1 and ECM_2 are error correction vectors estimated by DOLS and reported in Table 2.6.

The responses for the relative price of tradables (x) to a permanent shock to explanatory variables suggest that they may be nonstationary. This may be a consequence that the imposed cointegrating vector is nonstationary. Thus, not only do the tests of the previous sub-section fail to find cointegration, but also estimation assuming one cointegrating vector reveals that cointegration is unlikely in this case. This failure to find cointegration may be due to the failure of the law of one price for traded goods. It also may be due to mis-specification of the model.

The responses of the relative price of nontradables (y) to permanent shocks are in accordance with theoretical considerations. They reflect the imposed cointegrating vectors at a five-year horizon.

Figure 3.4: Impulse response functions of the relative price of traded goods to real shocks using PCD data

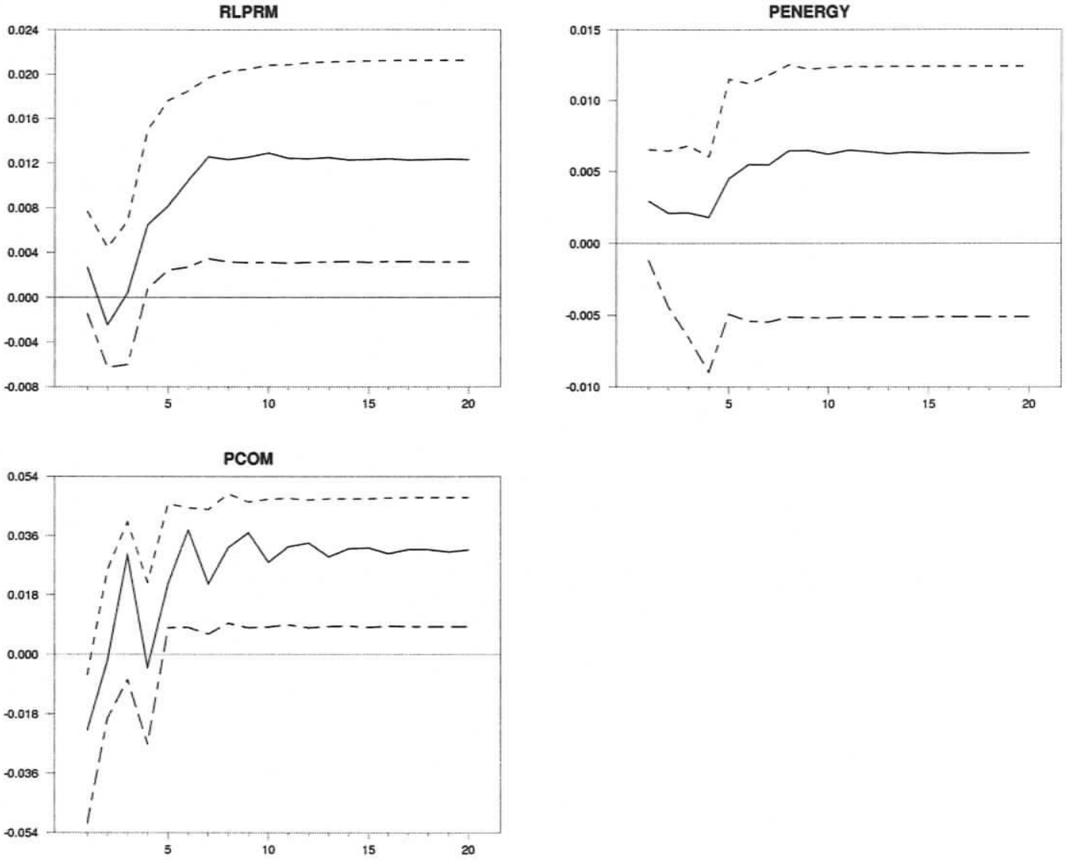

Figure 3.4
Models in first differences. Dynamic response of the relative price of traded goods to one standard deviation shocks to explanatory variables. 90% confidence intervals are based on 999 nonparametric bootstrap simulations with replacement. The PCD data are used to construct the relative prices.
Variables: described in Table 2.1

Figure 3.5: Impulse response functions of the relative price of nontraded goods to real shocks using PCD data

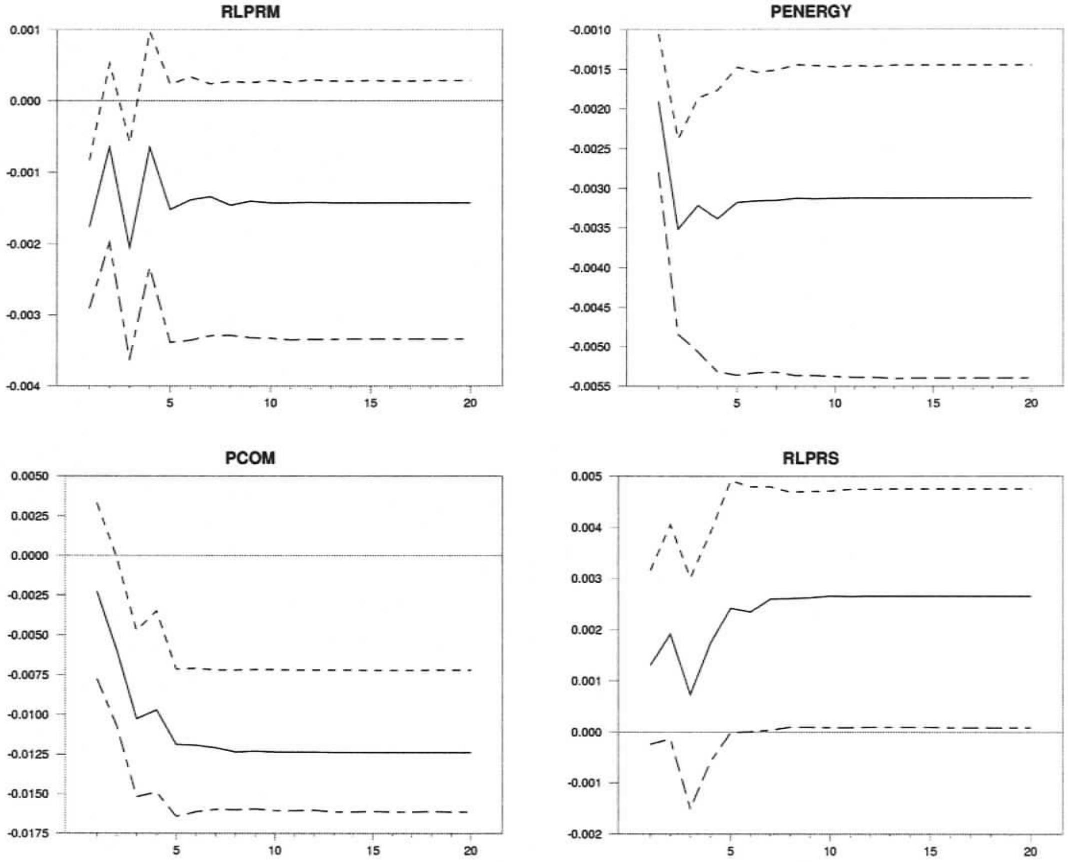

Figure 3.5

Models in first differences. Dynamic response of the relative price of nontraded goods to one standard deviation shocks to explanatory variables. 90% confidence intervals are based on 999 nonparametric bootstrap simulations with replacement. The PCD data are used to construct the relative prices.

Variables: described in Table 2.1

3.4.2 Tests for stability of coefficients

I explore the possibility that there is a structural break in the relationship among the variables. Table 3.3 reports the results of the test that all of the coefficients including the constant and coefficients on lagged dependent variables may have changed. All tests show that there is not enough evidence to argue that the parameters changed significantly in the sample for the relative price of traded goods (x). There is some evidence that the parameters could change for the relative price of nontradables (y) with the estimated breakpoint in 1980:2. I re-estimate the model for the two subsamples. The responses for the second subsample are similar to those for the whole sample. The responses for the first subsample are somewhat erratic due to the fact that there are 30 observations and 25 parameters to be estimated. These responses are not presented here due to this small sample problem.

I further analyze the possibility that there is a structural break in parameters corresponding to lags of one explanatory variable at a time, while all other parameters are assumed fixed. Table 3.4 indicates that there is some evidence that the relationship between lags of the non-energy commodity prices variable and the relative price of nontradables changed around the first quarter of 1980. I re-estimate the model for the relative price of nontraded goods in first differences allowing for a structural change in coefficients corresponding to lags of non-energy commodity prices before and after the first quarter of 1980. The impulse responses do not change qualitatively. The signs of responses stay the same.

Testing the error-correction models for possible structural breaks in the coefficients similar to the testing done for the model in first differences reveals a break in the short-run dynamics around the same date. Re-estimated impulse responses allowing for a structural break in the short-run dynamics do not change much.

3.5 Conclusions

The empirical results of Engel (1999) and Chapter 2 seriously undermine the foundation of the Balassa-Samuelson model. This paper examines whether the existing paradigm approach can be straightforwardly modified in a way that is consistent with the data. In particular, this paper develops and tests a generalization of the basic Balassa-Samuelson that incorporates a role for traded goods in the transmission

Table 3.3: Test for stability of all coefficients

	Test Statistics	Asymptotic P-value	Bootstrap P-value	Hetero-corrected P-value
Dependent variable x				
SupF	24.477	0.770	0.814	0.817
ExpF	9.626	0.766	0.842	0.841
AveF	14.458	0.896	0.892	0.902
Dependent variable y				
SupF	57.032	0.005	0.037	0.099
ExpF	25.354	0.004	0.034	0.096
AveF	30.263	0.156	0.212	0.065
Estimated breakpoint	1980Q3			

SupF test is due to Andrews (1993). Andrews and Ploberger (1994) suggest AvgF and ExpF tests. All tests search for a break within [0.25T, 0.75T] range where T is the sample size. The asymptotic p-values calculated as in Hansen (1997), bootstrap homoscedastic and heteroscedastic p-values as in Hansen (2000). I am grateful to Bruce Hansen for making his program publicly available at http://www.ssc.wisc.edu/~bhansen

Table 3.4: Test for stability of coefficients corresponding to a lagged explanatory variable

Model in first differences

	Own lags	RLPRM	PCOM	PENERGY	RLPRS
Dependent variable x					
SupF	3.21	8.23	7.99	4.31	
Break	1987:1	1987:1	1986:1	1991:2	
Dependent variable y					
SupF	5.36	13.99	15.33*	10.01	10.55
Break	1980:1	1986:4	1980:1	1983:2	1980:2

Single-equation error-correction model

	Own lags	RLPRM	PCOM	PENERGY	RLPRS
Dependent variable x					
SupF	2.92	8.04	8.03	5.09	
Break	1987:1	1987:1	1986:1	1991:2	
Dependent variable y					
SupF	5.64	12.78	16.77**	8.99	11.34
Break	1980:1	1986:4	1980:1	1983:1	1980:2

SupF test is due to Andrews (1993). I search for a break within [0.3T, 0.7T] range where T is the sample size, and use asymptotic critical values from Andrews (1993). Asterisks * and ** denote statistically significant at the 10% and 5% levels respectively.
Variables: see the description in Table 2.1.

mechanism.

The generalized model is both a natural and parsimonious extension of the Balassa-Samuelson model. It allows consideration of terms-of-trade and productivity shocks in a unified framework. The extension is parsimonious since it maintains the law of one price for each traded good. However, the model does not have the law of one price for the composite traded good. This is necessary to allow traded goods to act as a channel in the transmission mechanism. There are several approaches to break the law of one price (local currency pricing, transportation costs, translog preferences, home bias). The paper uses the home bias approach which is arguable the most straightforward approach to incorporate in the Balassa-Samuelson model.

The model has several predictions that are tested in the paper. If the home bias is not present, and the law of one price holds, then the relative price of tradables is stationary. Since I find that x is nonstationary, there is some evidence that the law of one price does not hold and/or that the home bias is present. The home bias and the law of one price imply that the relative price of tradables may be cointegrated with explanatory variables. I, however, fail to find cointegration using single equation techniques. System approaches, like the Johansen method, find some evidence of cointegration but the residual analysis reveals violations of some assumptions that could make the results biased. The failure to support cointegration may be due to known poor finite sample properties of the tests, rather than due to absence of cointegration itself. The failure to find cointegration for the relative price of tradables may be because the law of one price does not hold empirically (see Rogoff, 1996).

The model allows real variables to affect the relative price of traded goods and predicts that productivity shocks should depreciate this relative price, while shocks to commodity prices should appreciate it. The empirical analysis supports the first prediction, but rejects the second prediction. The latter response is puzzling and further empirical assessment is necessary to clarify the issue.

The model is successful in providing a role for traded goods in the transmission mechanism, but it does not deliver an exclusive role to traded goods. Both the relative price of traded goods and the relative price of nontraded goods are equally important in the transmission mechanism. This suggests that other possible channels to break the law of one price are worth considering before rejecting the presumption that real shocks are important determinants of the real exchange rate.

Chapter 4

The real exchange rate and Canada-US relative labour productivity in manufacturing

4.1 Introduction

Labour productivity in Canada has fallen relative to that in the United States since the 1980s, with the relative decline being particularly large in the manufacturing sector. Canadian relative productivity in manufacturing has fallen by approximately 25 per cent since the mid-1980s, with much of this decline occurring since 1993 (for a review of recent trends in productivity, see Crawford, 2002). At the same time, there have been two episodes of significant Canadian dollar depreciation, first between 1976-1986 and second between 1991-2002. Some economists have argued that the depreciation of the Canadian dollar has been a contributing factor to the decline in relative productivity. Figure 4.1 presents indices of relative Canada-US labour productivity in manufacturing and the real exchange rate between the two countries, depicting their comovement over the period from 1961-2000.

One possible channel through which an exchange rate depreciation can affect labour productivity in Canadian manufacturing is known as the factor-cost hypothesis. It states that a real exchange rate depreciation makes imported capital goods expensive relative to labour causing domestic producers to adopt more labour intensive technologies in response to the higher relative price of capital. Labour intensive

Figure 4.1: Canada-US real exchange rate vs relative labour productivity

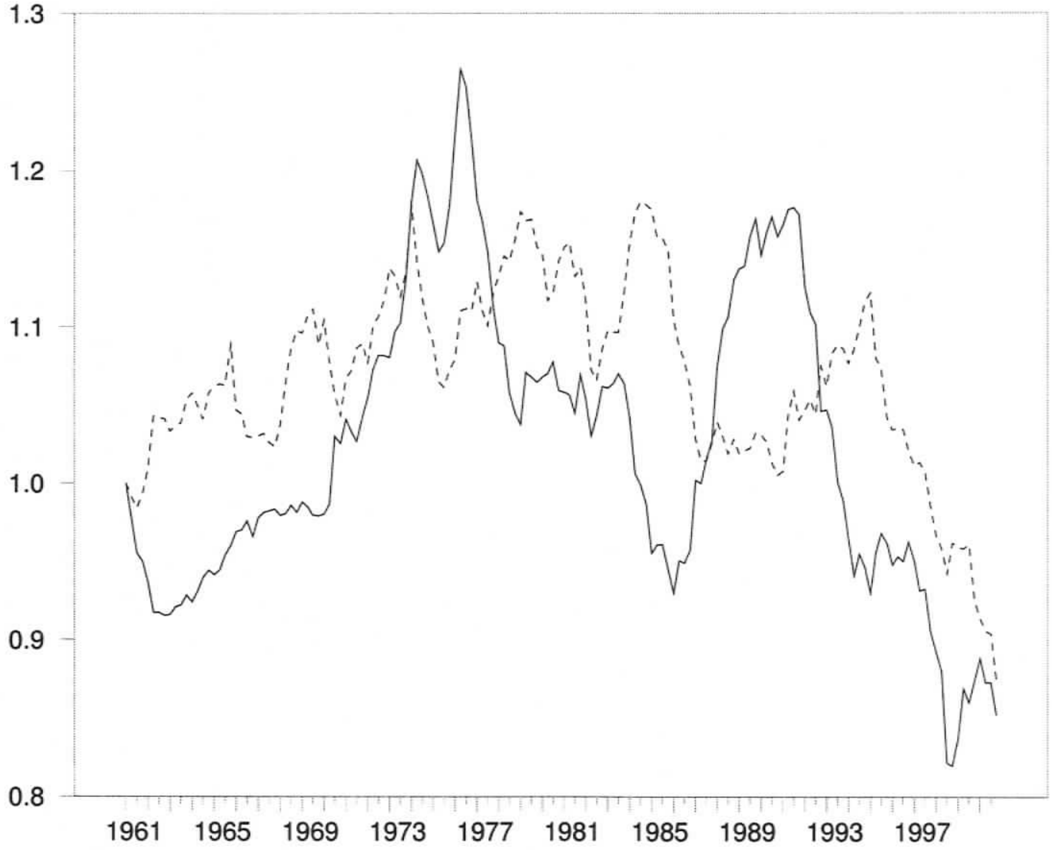

Figure 4.1

Real Canada-US exchange rate based on GDP deflators and relative Canada-US labour productivity in manufacturing. Both series are set to one in 1961.

— Real Canada-US exchange rate

- - Relative labour productivity in manufacturing (Canada/US) technologies in turn would make labour less productive. Since 70% of machinery and equipment is imported to Canada, this hypothesis is especially relevant for Canada. The real exchange rate depreciation during the periods 1976-1986 and 1991-2002 may have made capital relatively more expensive than labour, and firms may have substituted labour for capital. Both the capital-labour ratio and labour productivity could fall as a result of the real exchange rate depreciation. Lafrance and Schembri (2000), Harris (2001), and Bernstein et al. (2002) consider this channel as a possible contributing factor in explaining the gap.

The purpose of this Chapter is to investigate whether the depreciation of the Canadian dollar has contributed to lower relative labour productivity in the manufacturing sector through its impact on the capital-labour ratio. There has been no rigorous empirical analysis of this hypothesis to our knowledge. Dupuis and Tessier (2000) analyze possible Granger causality links between the Canada-US exchange rate and relative productivity in manufacturing in a multivariate framework. However, their model does not include the relative capital-labour ratio and thus cannot be used to test the factor-cost hypothesis directly. We contribute to the literature by introducing the relative capital-labour ratio into a VECM which allows us to test this hypothesis explicitly and to determine the contribution of the depreciation of the Canadian dollar in explaining the Canada-US productivity gap.

Specifically, we first develop a VECM that includes the real exchange rate, the relative Canada-US capital-labour ratio, the Canada-US labour productivity ratio and other conditioning variables. We then examine impulse response functions to test the factor-cost hypothesis and analyze how a shock to the real exchange rate propagates, the timing and the magnitude of the impact on the relative capital-labour ratio and labour productivity. Finally, we use forecast error variance decompositions to evaluate the importance of shocks to the real exchange rate in explaining the forecast error variance of the capital-labour ratio and labour productivity.

To foreshadow the results of our analysis, we find some support for the factor-cost hypothesis. Impulse response functions show that the capital-labour ratio and labour productivity increase in response to a real exchange rate appreciation, thus supporting the factor-cost hypothesis. However, forecast error variance decompositions reveal that shocks to the real exchange rate contribute only around 10% of the forecast error variance of the capital-labour ratio and the relative labour productivity at a five-year horizon. Shocks to the capital-labour ratio and relative labour productivity are far more important in explaining movements in relative labour productivity. Therefore, the factor-cost hypothesis, through the depreciation of the Canadian dollar, cannot be a driving force of the Canada-US productivity gap in manufacturing.

The organization of this Chapter is as follows. In Section 4.2 we discuss other factors that can affect the relationship between the real exchange rate and productivity that we need to take into consideration in order to test the hypothesis properly. Section 4.3 discusses the data construction and formulates a VECM model based on theoretical considerations and empirical testing. In Section 4.4 we use the developed model to construct impulse response functions and forecast error variance decompositions that are used to test the factor cost hypothesis and its importance. Section 4.5 concludes.

4.2 Literature review

To conduct this analysis properly, we need to consider other forces at work that can affect the relationship between the real exchange rate and productivity. In particular, one force that can reverse the causation between the real exchange rate and relative productivity is the Balassa-Samuelson hypothesis. This states that differences in productivity growth in the tradeables versus nontradeables sector between two countries causes movements in the bilateral real exchange rate. This hypothesis implies that higher relative productivity in the home country would cause its real exchange rate to appreciate.[1] Thus, there is a two-way relationship between the real exchange rate and productivity growth. The factor-cost hypothesis states that a real exchange rate depreciation causes labour productivity to fall, while the Balassa-Samuelson hypothesis arrives at the opposite conclusion and states that it is in fact a decline in relative productivity growth that causes the real exchange rate to depreciate.[2]

Another possible explanation might be that the movements in the exchange rate and productivity may simply reflect factors that affect both the exchange rate and

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[1] The empirical evidence on the Balassa-Samuelson hypothesis is based mainly on cointegration studies. See Alexius and Nilsson (2000), Alquist and Chinn (2002), Chinn and Johnston (1996), Chinn(2000), Strauss (1996).

[2] The BS hypothesis states that differences in productivity growth in the tradable versus nontradable sector between countries causes movements in the bilateral exchange rate. It is often assumed that productivity growth in the nontradable sectors is equal across countries. Therefore, the difference in productivity growth in the tradable versus nontradable sectors between countries can be proxied as the difference in productivity growth between countries' tradable sectors.

labour productivity. Lafrance and Schembri (2000) argue that cyclical movements in aggregate demand and changes in fiscal policy can influence both the exchange rate and productivity simultaneously. Higher aggregate demand for Canadian goods is expected to lead to an exchange rate appreciation and to increased labour productivity. Since labour and capital cannot adjust immediately, labour productivity rises (falls) during an expansion (contraction). A real exchange rate appreciation is associated with higher productivity in this example, but this does not imply causation in any direction as both the exchange rate and productivity are caused by higher demand. Consequently, while testing the factor-cost hypothesis, we need to take the Balassa-Samuelson hypothesis and cyclical movements into account.

It should be stressed that some of the gap in manufacturing labour productivity between Canada and the United States can be attributed to different contributions of information technology. A detailed analysis by Sharpe (1999) reveals that the gap between the Canada-US rate of productivity growth in manufacturing is concentrated mainly in two industries: industrial machinery and equipment, and electronic and other electrical equipment. These two industries include information and communication technology (ICT) industries. Information technology plays an important role in the American growth resurgence during the last decade according to Jorgenson (2001), among others. Oliner and Sichel (2000) and Stiroh (2001) suggest that ICT use and ICT production were major contributing factors in the recent growth of US labour productivity. In contrast, Armstrong et al. (2002) and Khan and Santos (2002) found the use and production of ICT had less of an effect on labour productivity in Canada.

We are interested in determining how exchange rate movements contribute to the Canada-US productivity gap in manufacturing. If some of the gap is primarily due to a smaller share of ICT production in Canada and due to the mix of ICT goods produced in Canada, and these factors are presumably not affected by the real exchange rate, then we should remove ICT producing industries from our analysis. Unfortunately, we cannot do this over the same sample because aggregate hours worked data for the US electronic and other electrical equipment industry are not available prior to 1988 at monthly or quarterly frequencies. Prior to 1988, the sample size for this industry was not large enough for the index of aggregate weekly hours to be published. The fact that these two industries are included in our analysis could bias upward the contribution of the real exchange rate to the labour productivity gap. We find, however, that even with these two industries included the contribution of the real exchange rate is very small.

4.3 Model and data

This section discusses what variables are included into our analysis and the reasons for their inclusion. We then test for nonstationarity and cointegration. Finally, we discuss how impulse response functions and forecast error variance decompositions can be used to test the factor-cost hypothesis.

4.3.1 Variables

The following variables are included in the analysis. Canadian variables include: real GDP, GDP deflator, yield spread, the real exchange rate calculated using GDP deflators, relative Canada-US labour productivity, and relative Canada-US capital-labour ratio in manufacturing. In addition to the variables of interest (real exchange rate, relative Canada-US productivity and capital-labour ratio in manufacturing), the model includes Canadian and US GDP and GDP deflators so that cyclical movements can be identified. The real price of oil and the real non-energy commodity price index are included since they are considered important determinants of the real exchange rate (see Amano and van Norden, 1995). The Canadian yield spread and the US Federal Funds Rate are included to identify monetary policy impacts. We try to identify all of these factors since they have an impact on the exchange rate and/or the capital-labour ratio and labour productivity.[3] Consequently, we need to isolate their influence in order to test the factor-cost hypothesis properly. Table 4.1 explains variable names used in the rest of the chapter. Figures 4.2 to 4.4 plot the variables.

There are several reasons why we work with the capital-labour ratio and labour productivity in relative terms. First, this allows us to focus on asymmetric shocks to capital and labour between the two countries. Any symmetric shocks, like the post-1973 productivity slowdown, will not have an impact since we consider both variables in relative terms. Second, the capital-labour ratio and labour productivity enter the hypotheses of interest in relative terms. Specifically, it is relative productivity

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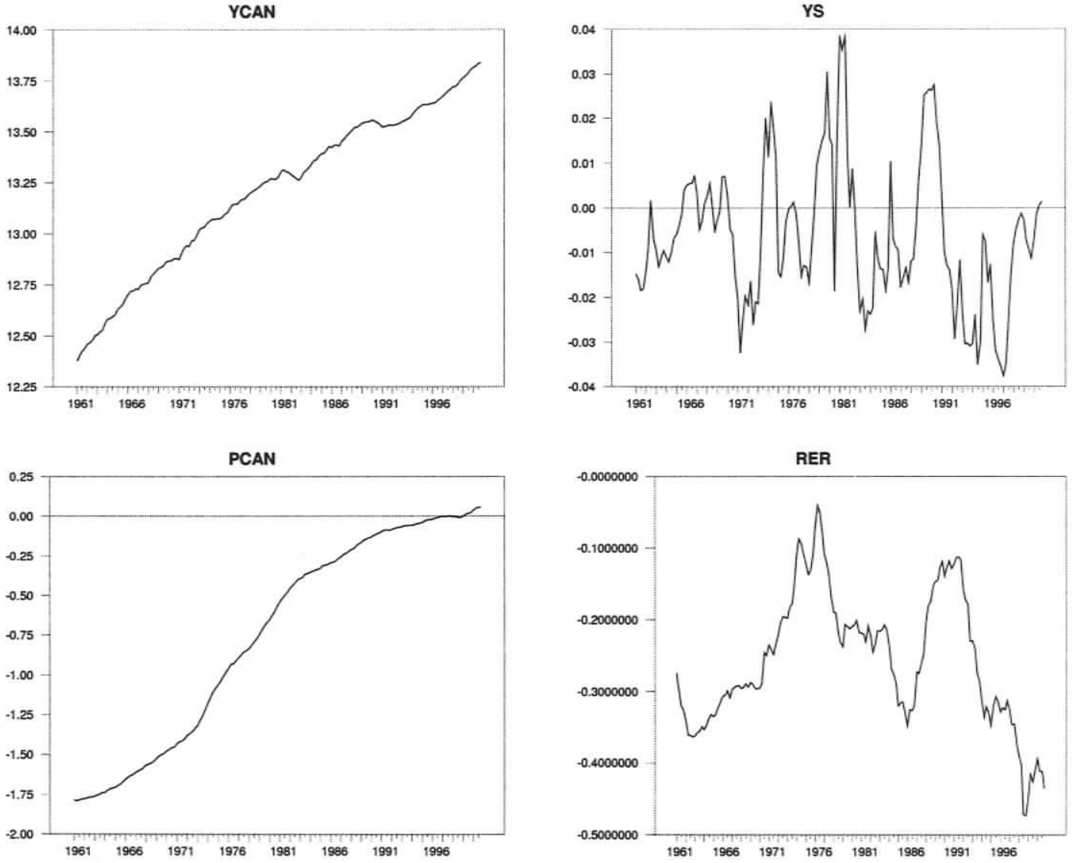
[3] Other factors that might affect the Canada-US productivity gap are discussed in Bernstein et al. (2002) and Crawford (2002).

Table 4.1: Variable names

Variable	**Description**
RER	log real Canada-US exchange rate
YCAN	log real Canadian GDP
RLPR	relative Canada-US productivity in manufacturing RLPR=$(YCAN - L) - (YUS - L^*)$, where L and L^* are labour inputs in Canada and US respectively
PCAN	log Canadian GDP deflator
PCOM	real non-energy commodity price index
POIl	real price of oil
YS	yield spread
KL	relative Canada-US capital-labour ratio $KL = (K - L) - (K^* - L^*)$, where K and K^* are stocks of capital in Canada and US respectively
YUS	log real US GDP
PUS	log US GDP deflator
RFFR	real Federal Funds Rate

Figure 4.2: Canadian variables


YCAN

YS

PCAN

RER

Figure 4.2
YCAN is the log real Canadian GDP, PCAN is the log Canadian GDP deflator, YS is the yield spread, and RER is the log real Canada-US exchange rate

Figure 4.3: Commodity prices and relative productivity and capital-labour ratio

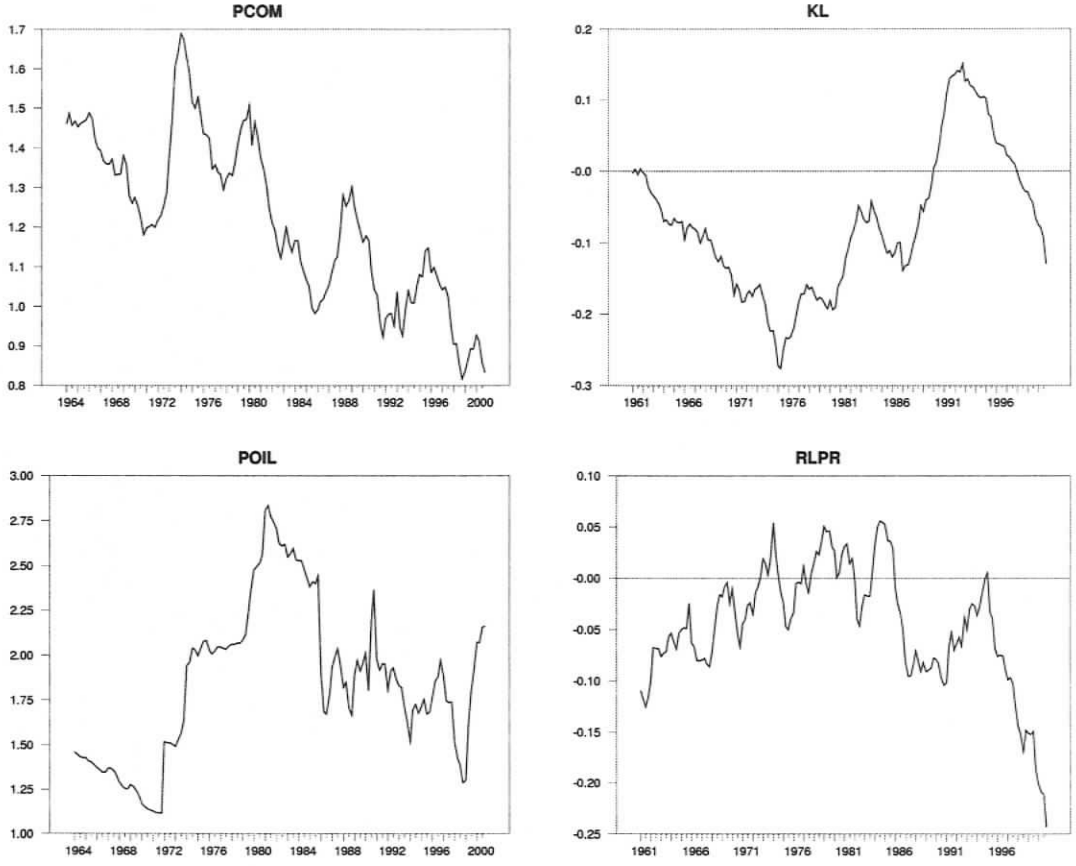


Figure 4.3
KL is the log of Canada-US capital-labour ratio in manufacturing, RLPR is the log of the relative productivity in Canadian versus US manufacturing, PCOM is the log real price of non-energy commodities in US dollars, POIL is the log real price of energy commodities in US dollars

Figure 4.4: US variables

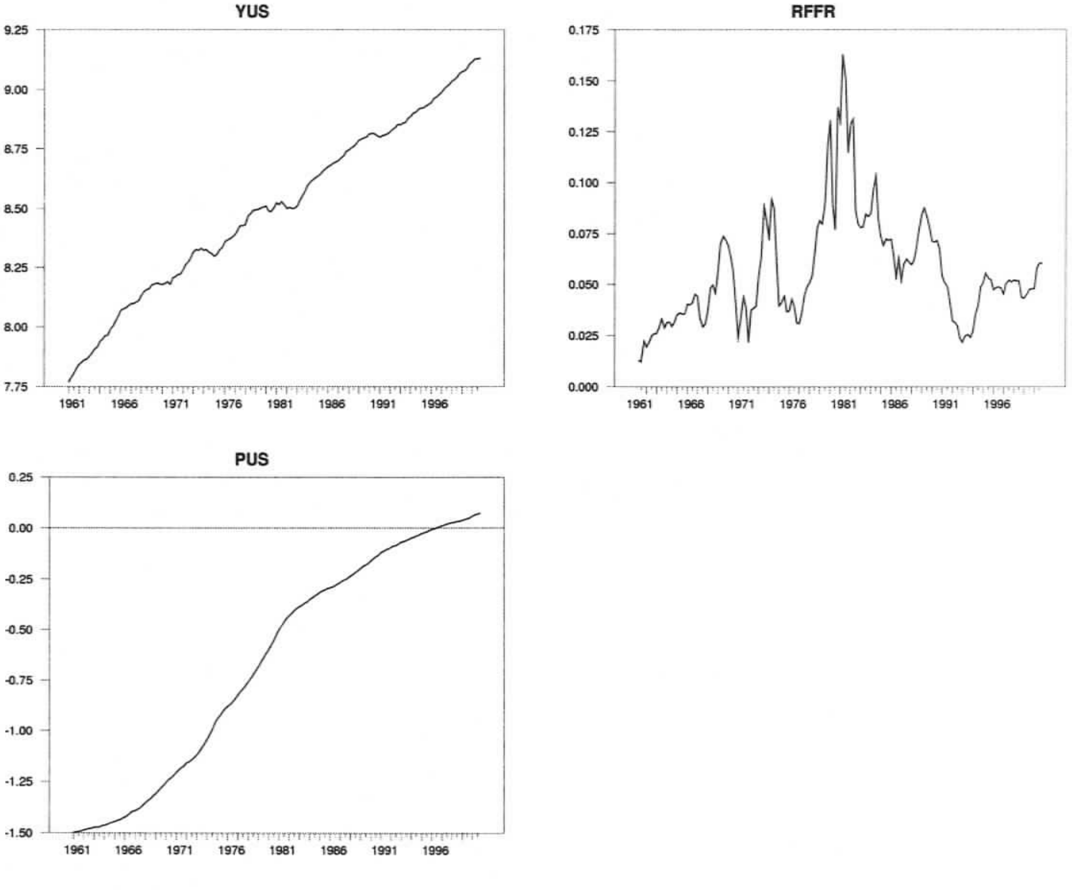


Figure 4.4
YUS is the log real US GDP, PUS is the log US GDP deflator, RFFR is the US Federal Funds Rate.

that affects the real exchange rate in the Balassa-Samuelson hypothesis and it is the relative (Canada-US) factor-cost ratio that is affected by the exchange rate in the factor-cost hypothesis. Since the factor-cost hypothesis states that the capital-labour ratio and labour productivity are affected by the exchange rate, through its impact on relative factor-costs, we extend the main model by including relative factor-costs.

We treat the relative Canada-US capital-labour ratio and labour productivity differentials in manufacturing as Canadian variables. We also assume that US variables are weakly exogenous. Thus, treating the differentials as endogenous will allow the US variables to influence them, while at the same time, the differentials will not affect the US variables, a plausible assumption.

Appendix B describes the construction of the data. The relative capital-labour ratios and relative productivity were constructed for the purpose of this study, since official data were not available at a quarterly frequency.

4.3.2 Tests for unit roots and cointegration

We test the series for unit roots allowing for a change in level and slope at an unknown time and without such breaks. The break point is chosen so that the absolute value of the t-statistics on the coefficient of the change in slope is maximized according to Perron (1997). The data is GLS detrended following the suggestion by Elliott et al. (1996). The optimal non-centrality parameter for detrending of this type of models is found by simulations in Perron and Rodriguez (2003). The augmented Dickey-Fuller test (Dickey and Fuller, 1979, and Said and Dickey, 1984) is then applied to the detrended data. The number of lags in the augmented regression is chosen according to the Modified Akaike Information Criterion proposed by Ng and Perron (2001). The critical values for the test are given in Perron and Rodriguez (2003) when breaks are allowed and in Elliott et al. (1996) with no breaks. The results are reported in Table 4.2. The null hypothesis of a unit root cannot be rejected at the 10% significance level for all variables, except for the Canadian yield spread at the 1% level. It is interesting that a unit root in the yield spread is not rejected if breaks are not allowed. I expect that breaks in a drift for a random walk process would not play an important role in further analysis. Consequently, breaks are not modeled in the rest of the Chapter. In this case, the yield spread is better approximated by a first-difference stationary process.

Table 4.2: Unit root tests

			a) Breaks				b) No breaks				
Variable	k	Tb	ADF		C.V.		k	ADF		C.V.	
				1%	5%	10%			1%	5%	10%
RER	1	1989:2	-2.251	-4.74	-4.14	-3.84	4	-1.544	-3.58	-3.03	-2.74
YCAN	1	1974:2	-2.432	-4.74	-4.14	-3.84	1	-0.652	-3.58	-3.03	-2.74
RLPR	1	1979:2	-2.877	-4.74	-4.14	-3.84	1	-0.866	-3.58	-3.03	-2.74
PCAN	3	1988:2	-2.172	-4.74	-4.14	-3.84	3	-1.482	-3.58	-3.03	-2.74
PCOM	1	1974:4	-2.701	-4.74	-4.14	-3.84	1	-2.591	-3.58	-3.03	-2.74
POIL	2	1981:2	-2.364	-4.74	-4.14	-3.84	2	-1.661	-3.58	-3.03	-2.74
YS	4	1967:2	-4.842	-4.74	-4.14	-3.84	8	-0.129	-3.58	-3.03	-2.74
KL	3	1975:2	-1.515	-4.74	-4.14	-3.84	3	-1.454	-3.58	-3.03	-2.74
YUS	1	1969:3	-3.080	-4.74	-4.14	-3.84	2	-1.653	-3.58	-3.03	-2.74
PUS	2	1988:2	-1.985	-4.74	-4.14	-3.84	3	-1.893	-3.58	-3.03	-2.74
RFFR	2	1980:3	-2.534	-4.74	-4.14	-3.84	7	-1.941	-3.58	-3.03	-2.74

ADF denotes the Augmented Dickey-Fuller test statistic (Dickey and Fuller, 1979, and Said and Dickey, 1984) applied to GLS detrended data following Elliott, Rothenberg, and Stock (1996). a) The model allows for a change in slope and intercept. The break date (Tb) is chosen so that the absolute value of the t-statistics on the coefficient of the change in slope is maximized according to Perron (1997). b) No breaks are allowed. The number of lags (k) in the augmented regression in both cases is chosen according to the Modified Akaike Information Criterion proposed by Ng and Perron (2001). The critical values for the test are given in Elliott et al. (1996) for (b) and in Perron and Rodriguez (2003) for (a) for T=100. The critical values (C.V.) are reported for the 1%, 5%, and 10% significance levels. The null hypothesis of a unit root cannot be rejected at the 10% significance level for all series, except ys, which is significant at the 1% significance level when breaks are allowed. Notation: RER is the real Canada-US exchange rate, YCAN is real Canadian GDP, PCAN is Canadian GDP deflator, PCOM is real non-energy commodity price index, POIL is the real price of oil, YS is Canadian yield spread, KL is relative Canada-US capital-labour ratio index, RLPR is relative Canada-US labour productivity in manufacturing index, YUS is real US GDP, PUS is US GDP deflator, RFFR is real Federal Funds Rate

Given nonstationary data, we analyze for possible cointegration among the variables. We assume that the US variables are weakly exogenous for the long-run parameters (i.e. the US variables are allowed to be cointegrated with the Canadian variables but possible cointegration vectors do not enter the US equations). Under such circumstances, Johansen (1992) shows that the analysis of long-run parameters can be conducted conditionally on weakly exogenous variables.

$$\Delta y_t = \Gamma_0 \Delta x_t + \Gamma_1 \Delta z_{t-1} + ... + \Gamma_4 \Delta z_{t-4} + \alpha\beta' z_{t-1} + \mu + \epsilon_t,$$

where y is a vector of Canadian variables, x is a vector of US variables, and z combines all variables. A fixed number of four lags is considered. A higher number of lags is not considered due to the loss of degrees of freedom in the 11-variable model. A lower number of lags is not considered since the data have quarterly frequency. The constant is allowed in and outside of cointegration relationships. The sample is from 1965q2 to 2000q4. Table 4.3 reports the results of testing for the cointegration rank (Johansen and Juselius, 1990).

The results of the tests for the cointegration rank are ambiguous. Both tests accept the hypothesis that there is no cointegration among variables. At the same time, the trace test rejects the hypothesis of one cointegrating vector, but cannot reject the hypothesis of two cointegrating vectors. Given the ambiguity of the results, further analysis will be conducted assuming two cointegrating vectors, as there is empirical evidence that the exchange rate is cointegrated with productivity differentials and terms-of-trade. Begum (2000) finds that real exchange rates are cointegrated with productivity differentials for Group Seven countries, while Amano and van Norden (1995) find a long run relationship between energy and non-energy terms of trade and the real Canada-US exchange rate.

4.3.3 Cointegrating vectors

The Balassa-Samuelson hypothesis implies that the real exchange rate is cointegrated with the total-factor productivity differential. As commodities represent a high share of Canadian exports, terms-of-trade shocks can be proxied by commodity price indices. We impose two cointegrating vectors: one is the cointegration of the real

Table 4.3: Johansen's test for cointegration rank

	H_0: Number of Cointegrating Vectors					
	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$
Trace Statistic	292.32	218.92	148.05	96.16	53.73	20.34
p-value	0.148	0.027	0.194	0.249	0.240	0.759
$H_A : r = 6$						
L-max Statistic	73.40	70.87	51.85	42.47	33.38	20.34
p-value	0.639	0.183	0.682	0.636	0.577	0.759
$H_A : r + 1$						

The number of variables in the statistical model is 11 but only 6 variables are treated as endogenous. The lag length in the VECM is four. A constant term is allowed for in the cointegration relationship and outside the cointegration space. $r = 0$ means no cointegrating vectors, $r = 1$ means one cointegrating vectors and so on. $r = 6$ corresponds to the case where all of the variables are stationary. Marginal significance levels (p-values) are based on 999 bootstrap nonparametric replications of residuals with replacement keeping the same time across equations.

exchange rate with relative total-factor productivity.[4] Since relative total-factor productivity is relative labour productivity minus the share of capital times relative capital-labour ratio, we include both the relative capital-labour ratio and relative labour productivity in the cointegrating vector.[5] The other cointegrating vector is the cointegration of the real exchange rate with the non-energy commodity price index and the price of oil.[6] These two cointegrating vectors can be written in the following form:

$$\beta = (H_1\varphi_1, H_2\varphi_2),$$

where H_1 and H_2 are 11×3 matrices:

$$H_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

---

[4] We impose the vectors rather than rely on statistical tools to find them for three reasons. First, in a large system (in our case of 11 variables: 6 endogenous and 5 weakly exogenous) Johansen's statistical tools are known to have size distortions and low power. Second, if some variables were correctly found to be cointegrated in a smaller system, they will still have to be cointegrated in a larger system. Third, an identification problem exists with more than one cointegrating vector because any linear combination of the cointegrating relationships are stationary. We impose two vectors since Table 4.3 provides some support for the rank of cointegration being two.

[5] Assuming a Cobb-Douglas production function.

[6] Such division was found appropriate for Canada by Amano and van Norden (1995). They report that energy and non-energy term of trade shocks have different effects on the Canadian dollar.

and

$$H_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

while φ_1 and φ_2 are 3×1 matrices of unknown parameters. The following ordering of variables is assumed: RER, YCAN, PCAN, PCOM, POIL, YS, KL, RLPR, YUS, PUS, RFFR. The imposed restrictions on the two cointegrating vectors are not rejected at the 10% significance level (the p-value based on nonparametric bootstrap replications is 12.5%). The test statistic is developed in Johansen and Juselius (1992).

The estimated relationships are presented below, with the asymptotic standard errors in parentheses.

$$\begin{array}{llllll} ECV1 = X- & 1.112 & RLPR+ & 1.510 & KL \\ & (0.50) & & (0.46) & \\ ECV2 = X- & 0.292 & PCOM+ & 0.118 & POIL \\ & (0.12) & & (0.03) & \end{array}$$

The signs of the estimated cointegrating relationships are in accordance with other studies. Specifically, relative Canada-US labour productivity has a positive impact on the exchange rate (stronger Canadian dollar), while the capital-labour ratio has a negative impact, implying that higher relative total-factor productivity causes the exchange rate to appreciate in accordance with the Balassa-Samuelson hypothesis. Specifically, higher non-energy commodity prices cause the exchange rate to appreciate, while the price of oil has a negative impact in accordance with previous results by Amano and van Norden (1995). Figure 4.5 plots the two cointegrated vectors.

Figure 4.5: The two cointegrating vectors

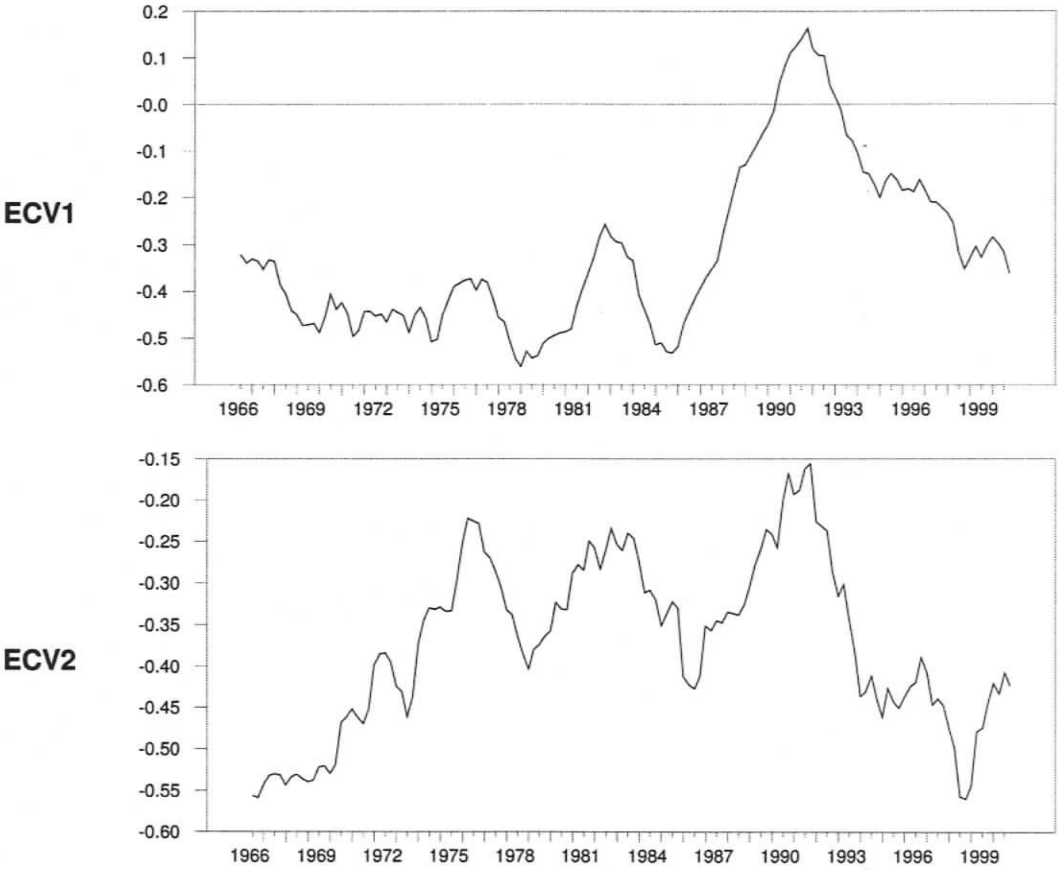


Figure 4.5
The two cointegrating vectors: ECV1=X-1.112 RLPR + 1.510 KL, and ECV2=X - 0.292 PCOM + 0.118 POIL. The vectors are not centered around zero since a constant is allowed for in and outside the cointegration space.

4.3.4 The full system

For the purposes of the impulse response analysis, we need to formulate the full system.

$$\Delta Z_t = \mu + A_1 \Delta Z_{t-1} + ... + A_4 \Delta Z_{t-4} + \alpha \beta' Z_{t-1} + \epsilon_t.$$

The following restrictions are imposed. First, we assume that Canadian variables have no impact on US variables (block-exogeneity).

$$A_j = \begin{bmatrix} A_{xx}^j & 0 \\ A_{xy}^j & A_{yy}^j \end{bmatrix},$$

for any $j = 1, ..., 4$.

As we mentioned in the previous section, US variables are also assumed to be weakly exogenous (i.e. $a_{ij} = 0$ for any i that represents a US variable). Finally, we impose the cointegrating relationships, outlined in the previous section, on β. The system is then estimated by FIML method, taking account of the block exogeneity restrictions (see Hamilton, 1994, pp. 311-313).

4.3.5 Motivation for impulse response functions and forecast error variance decompositions

Impulse response functions allow us to consider the propagation of shocks in the system. They can be used to test the factor-cost hypothesis directly. The hypothesis implies that a positive shock (appreciation) to the real exchange rate is supposed to increase the relative capital-labour ratio and the relative labour productivity. If, for example, relative labour productivity increases while the capital-labour ratio does not, we would be able to say that the real exchange rate affects relative labour productivity but it is not because of the increased capital-labour ratio. Thus, the factor-cost hypothesis would be rejected and further research could pay more attention to other factors. Impulse response functions can also be used to see when shocks have a maximum effect and how long it takes before variables are affected.

Impulse response functions are constructed by the method of Koop et al. (1996) and Pesaran and Shin (1998), so called generalized impulse response functions. We use generalized IRFs mainly for two reasons. First, two variables in our set are related to each other: the relative capital-labour ratio and labour productivity. Even at the structural level, these variables are linked through the production function. Therefore, even structural shocks to these two variables need not be orthogonal. Orthogonalization in such cases can create difficulties in interpreting shocks. Generalized IRFs, on the other hand, do not require shocks to be orthogonalized, which is a desirable property in our case. Second, identifying restrictions are not developed in the literature for systems that include the capital-labour ratio and productivity differentials. Rather than trying to develop such restrictions we opt for not imposing any identifying restrictions at all. This creates another problem; without imposing identifying restrictions, it may be difficult to interpret responses to highly correlated shocks. The interpretation of shocks is also different for generalized IRFs. Generalized IRFs assume that one element of the model's innovations is shocked and that the effects of other shocks are integrated out using an assumed distribution (i.e. a multivariate normal). Consequently, when we say "shock to xxx variable" we mean that the equation for that variable was shocked and the effects of shocks to other equations were integrated out (see Koop et al., 1996, and Pesaran and Shin, 1998).

Impulse response functions do not, however, answer the question of the importance of specific shocks. For this purpose, we use the generalized Forecast Error Variance Decompositions (FEVDs). The decompositions show the contribution of specific shocks to the forecast error variance of the variables. These contributions can be used to assess the importance of shocks. As with impulse response functions, we also constructed generalized FEVDs. Note that the sum of the contributions from all innovations in generalized FEVDs is generally not restricted to one. This is because the covariances between the original (non-orthogonalized) shocks are not zero. The next section presents the results of our analysis.

4.4 Estimation results

4.4.1 Impulse response functions for variables of interest

In this sub-section, using generalized impulse response functions, we find that, in response to a real exchange rate appreciation, the capital-labour ratio and relative labour productivity increase in accordance with the factor-cost hypothesis. However, we also find that the response of relative labour productivity to an exchange rate shock is insignificant, suggesting that the evidence in favour of the factor-cost hypothesis is weak. This conclusion is supported by an extension of the model which includes relative factor-costs.

Sub-section 4.4.3 presents the full set of generalized impulse response functions. First, we use them to assess whether the model correctly describes the effect of key shocks. Shocks to monetary policy in Canada and the United States affect output and price levels in accordance with basic theory. However, there are some puzzling responses: the real exchange rate depreciates initially in response to a monetary contraction and a positive shock to the price of oil causes US output to increase and price to fall. It is noteworthy to mention that these puzzling responses are statistically insignificant.

We can now proceed with the analysis of the shocks of interest in detail: the appreciation of the real exchange rate and positive shocks to the capital-labour ratio and relative productivity. These shocks and responses are presented in Figure 4.6. An appreciation of the exchange rate increases the capital-labour ratio and relative labour productivity in the Canadian manufacturing sector in accordance with the factor-cost hypothesis. In response to a one standard deviation shock in the exchange rate equation, the capital-labour ratio gradually rises by 1% after five quarters and remains at this level. Relative labour-productivity gradually increases by approximately 0.75% over a five-year horizon. However, the response of relative labour productivity is insignificant, suggesting there is some uncertainty in the transmission mechanism from the real exchange rate to labour productivity, through the capital-labour ratio.[7] These responses are consistent with the factor-cost hypothesis. As the real exchange rate appreciates imported capital should become relatively cheaper and, as a result, Canadian manufacturing firms should gradually replace by substitution more capital-intensive technologies. Capital intensive technologies imply that the capital-labour ratio and labour productivity increase. We conclude from these responses that the factor-cost hypothesis is supported for Canada. Real exchange rate fluctuations affect the capital-labour ratio and labour productivity in Canada. This effect cannot be considered as statistically strong as the response of the relative productivity is

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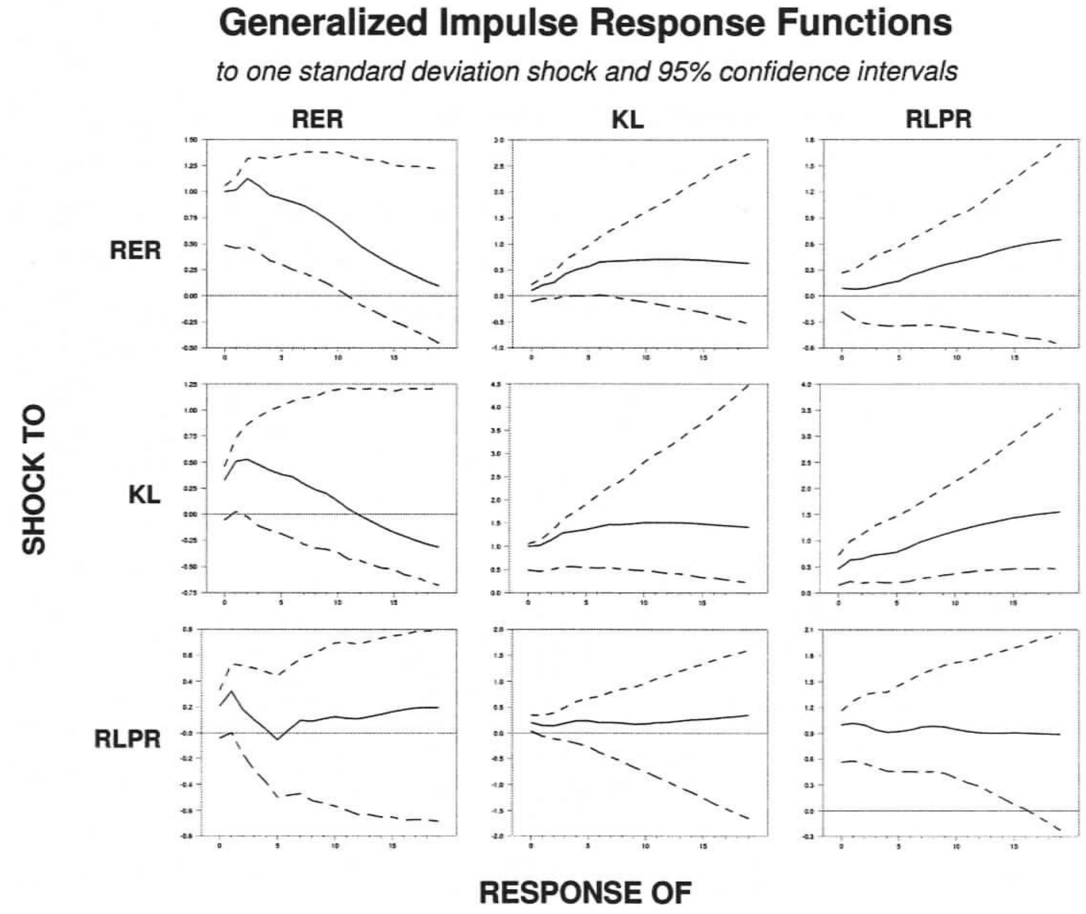
[7] To investigate the impact of the exchange rate on the capital-labour ratio, through its impact on relative factor-costs, we extend the main model by including the relative factor costs in our specification. Our main conclusions are supported by the extended model. In short, relative factor costs (capital/labour) decline in response to an exchange rate appreciation, thus supporting the factor-cost hypothesis.

Figure 4.6: Responses of relative capital-labour ratio (KL), relative productivity (RLPR), and real exchange rate (RER) to some shocks



insignificant at the 5% significance level.

A positive shock to the capital-labour ratio and relative productivity causes the real exchange rate to appreciate on impact by approximately 0.35%. It is noteworthy to mention that the shock to the capital-labour ratio should not affect the exchange rate in the long run. Lower marginal product of capital in the tradeables sector should cause capital and labour reallocation until marginal products are equalized across the sectors. The graph shows that the response of the relative capital-labour ratio is persistent, suggesting that reallocations of capital and labour may not be frictionless. Nevertheless, the response of the real exchange rate is insignificant, supporting that shocks to the relative capital-labour ratio does not affect the real exchange rate in the long run.

The response of the real exchange rate to a positive labour productivity shock is also statistically insignificant; however, it is still economically meaningful. According to the Balassa-Samuelson hypothesis the real exchange rate appreciates in response to higher productivity in manufacturing. The responses of output and the price level presented in Section 4.4.3 provide additional support. While the statistical evidence in favour of the hypothesis is not particularly strong, the economic evidence, based upon the responses of the key variables (exchange rate, output, price level), is appealing.

4.4.2 Generalized forecast error variance decompositions

In this section, using forecast error variance decompositions, we find that shocks to the exchange rate are not important factors in explaining movements of the capital-labour ratio and relative productivity. Rather, shocks to the capital-labour ratio and relative labour productivity are more important in explaining the widening of the Canada-US productivity gap.

Table 4.4 presents the contributions of all variables to the forecast error variances of the relative capital-labour ratio (KL), labour productivity (RLPR) and the real exchange rate (RER). We find that innovations in the exchange rate have an impact on the relative capital-labour ratio and relative labour productivity in accordance with the factor-cost hypothesis. However, they contribute only about 13% and 10% to the variation of the capital-labour ratio and relative labour productivity respectively at 20 quarters.[8] Therefore, the factor-cost hypothesis, while empirically supported in our paper, cannot be a driving force of lagging productivity growth in Canada.

Two major contributing factors are shocks to the relative capital-labour ratio (29%) and relative labour productivity (40% of FEVD after 20 quarters). The high contribution of relative labour productivity can be given two interpretations. One is that shocks to relative labour productivity can be interpreted as supply shocks and may be linked to Jorgenson's (2001) story about the resurgence of the American economy since 1995 and the importance of information technology. Bernstein et al. (2002) decompose the Canada-US productivity gap in manufacturing into the contribution of high-tech manufacturing industries and non-tech industries over the 1994-2000 period and conclude that 71 percent of the widening gap can be attributed to differences in the size of high-tech sectors (5% of the widening gap) and higher

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[8] Note that the sum of all contributions is 138%, so the contribution of the exchange rate is 10% out of 138%. Generalized forecast error variance decompositions are not normalized to 100%.

Table 4.4: Generalized forecast error variance decompositions

Variance of innovation in	Quarters	RLPR	KL	RER
YCAN	1	0.07	0.01	0.00
	20	0.07	0.01	0.04
PCAN	1	0.03	0.08	0.11
	20	0.02	0.01	0.05
RER	1	0.00	0.01	0.93
	20	0.10	0.13	0.31
YS	1	0.01	0.01	0.05
	20	0.02	0.00	0.01
RLPR	1	0.94	0.13	0.03
	20	0.40	0.03	0.01
KL	1	0.16	0.96	0.03
	20	0.29	0.52	0.05
YUS	1	0.12	0.02	0.01
	20	0.24	0.03	0.00
PUS	1	0.03	0.05	0.05
	20	0.07	0.10	0.18
PCOM	1	0.00	0.01	0.01
	20	0.12	0.02	0.29
RFFR	1	0.02	0.08	0.15
	20	0.04	0.01	0.03
POIL	1	0.01	0.00	0.01
	20	0.01	0.04	0.18
SUM	20	1.38	0.90	1.15

Generalized forecast error variance decompositions for the relative labour productivity, relative capital-labour ratio, and the real Canada-US exchange rate. The sum of contributions is not restricted to one.

productivity performance of US high-tech industries (66%). Our model, estimated over the 1965-2000 period, has a contribution of productivity shocks of 40 percent, roughly consistent with the above story. The other interpretation is that some variables, which are thought to be important determinants of labour productivity, are not included in the model. Therefore, the high contribution of relative labour productivity may be explained by the lower explanatory power of the other variables included in the model.

The capital-labour ratio contributes 30 per cent to the variance decomposition of relative labour productivity. The contribution of the capital-labour ratio is consistent with Bernstein et al. (2002), who found that 30% of the widening gap is accounted for by Canada-US capital intensity over the 1994-2000 period. This leaves unexplained what is driving changes in the capital-labour ratio. Clearly, it is not the real exchange rate.

Our model, due to its rich structure, can be used to analyse other shocks that are not the primary focus of our analysis, but can, nevertheless, shed additional light on the Canada-US productivity differential in the manufacturing sector. Refer to Table 4.4. Exogenous shocks originating outside Canada (shocks to US aggregate demand, commodity prices, US price level, price of oil, and Federal Funds Rate) account for 48% of the variance decomposition for relative productivity and, thus, account for a significant amount of variation in productivity. However, unexpected US aggregate demand shocks and shocks to commodity prices do not affect the relative Canada-US capital-labour ratio, suggesting that they have an impact on the relative total factor productivity. The impact of an aggregate demand shock may be pro-cyclical, as labour productivity is known to rise in expansions and fall in recessions.

At a five-year horizon, innovations in commodity prices (PCOM and POIL) account for 47% of the variation in the Canada-US exchange rate. Shocks to commodity prices are asymmetric for Canada and the US, as Canada is a net exporter of commodities while the US is the largest net importer of raw materials. Therefore, changes in commodity prices have to be reflected in the bilateral exchange rate between the two countries. Chen and Rogoff (2003), however, report that the relationship between non-energy commodity prices and the real exchange rate is not robust to detrending for Canada.

Shocks to the capital-labour ratio account for 52% of the variation in the capital-labour ratio at a five-year horizon. When we include the relative factor-costs into the analysis, the contribution of shocks to the capital-labour ratio falls to 28% of the variation. At the same time, the shocks to the relative factor-costs account for 58% of the variation of the relative factor-costs at the same horizon. Thus, the inclusion of the relative factor-costs into the model shifts the high contribution of its own shocks from the capital-labour ratio to the relative factor-costs. Therefore, the capital-labour ratio is explained by shocks to factor-costs, but what is driving factor-costs is still unexplained.

4.4.3 Full set of impulse responses

This sub-section contains the full set of the impulse response functions along with a discussion of some responses that are not addressed in the previous sub-section.

First, we analyze how exchange rate fluctuations and shocks to relative labour productivity affect output and prices. The former analysis is related to exchange rate pass-through literature that analyzes how exchange rate fluctuations are passed to prices. The latter analysis is desirable since we find that the response of the real exchange rate to productivity shocks is statistically insignificant. Therefore, we focus on other predictions from the Balassa-Samuelson model, in particular, how productivity shocks affect output and prices.

Figure 4.9 shows that an exchange rate appreciation contracts the level of output. The price level falls after 10 quarters suggesting the presence of exchange rate pass-through effects. These responses are consistent with theoretical predictions of how exchange rate fluctuations affect economic activity. An appreciation makes domestic exports relatively more expensive in the foreign market, consequently lowering the output. An appreciation makes imported goods relatively cheaper driving the aggregate prices down. The responses, however, are statistically insignificant at the 5% significance level.

We find that a positive shock to relative productivity appreciates the real exchange rate, but the effect is not statistically significant in Section 4.4.1. In this sub-section, we analyze how this shock affects output and prices. The Balassa-Samuelson hypothesis assumes that PPP holds for traded goods. Higher relative productivity does not have any affect on prices in the traded good sector, because domestic traded goods prices are tied to foreign prices. As a result of a positive shock to relative labour productivity, wages in the traded goods sector must rise. Competitive labour markets will ensure that wages increase in the non-traded sector as well. Producers of non-traded goods will raise prices to cover higher wages. As a result, the total price level and the relative price of non-traded to traded goods increase, and the real exchange rate appreciates. The prediction of the model is that output and aggregate price level increase in response to positive productivity shocks. The impulse response functions in Figure 4.9 show that aggregate output and price level increase, and the real exchange rate appreciates in response to a positive shock to relative labour productivity in accordance with the hypothesis. This provides additional support for the Balassa-Samuelson hypothesis.

We analyze shocks to the capital-labour ration in Section 4.4.1. We find that shocks are surprisingly persistent. In accordance with theory, their impact on the real exchange rate is insignificant in the long run. In this sub-section, we can consider the response of output to this shock. A positive shock to the ratio is supposed to increase output in the tradable sector. The response of the aggregate output to an increased capital intensity in Canadian manufacturing (shock to KL) presented in Figure 4.9 is puzzling. Output falls in response to this shock. A possible solution to the puzzle may lie in the fact that we do not explicitly control for other sectors in our model. Marginal product of capital falls while marginal product of labour rises in the capital-intensive manufacturing sector causing capital to move out to other sectors and labour to move in. It is possible that such a reallocation of resources is contractionary for the aggregate economy.

US shocks

Two shocks are of interest in this section: an aggregate demand shock (shock to YUS) and shocks to commodity prices. The first shock is of interest since it is supposed to affect commodity prices and the real exchange rate at the same time. I discuss whether commodity prices can be treated as truly exogenous in Chapter 2. One reason while they may not be treated as exogenous is because they are affected by US shocks simultaneously with the real exchange rate. I address this issue here.

Figure 4.14 shows that an aggregate demand shock increases commodity prices. This response is expected as higher economic activity in the US implies higher demand for commodities and consequently higher commodity prices in the world market. At the same time, the real Canada-US exchange rate depreciates on impact. That is higher commodity prices due to booming US economy are associated with a depreciation of the real Canada-US exchange rate. This result may be an artifact of small sample, as the response of the real exchange rate is insignificant. Figure 4.13 shows the response of the real exchange rate to a positive shock to non-energy commodity prices. This time the response is significant and the real exchange rate appreciates. We may conclude that the response of the real exchange rate is different in response to positive commodity shocks when these shocks are caused by increased economic activity in the US and when they are caused by other reasons.

We consider a shock to the price of oil since this shock does not propagate adequately; the output level increases while the price level falls as can be seen from Figure 4.15. This is exactly the opposite of the expected response. As the US is a consumer of oil, a higher price of oil should act as an adverse aggregate supply shock. Note, however, that responses of output and prices are insignificant. There are several reasons why modeling the price of oil may be difficult. Hamilton (1983) argues that, over the period 1948-1972, oil prices were exogenous with respect to the US economy. In our sample, from 1965 to 2000, the price of oil was treated as endogenous. Before 1980 there were very few cases of falling oil prices, while after that there were big price decreases. Several supply shocks such as the oil shock in 1973 due to an embargo by the Arab members of OPEC, the shock in 1978 due to the Iranian revolution, the onset of war between Iran and Iraq in 1980, and Iraq's invasion into Kuwait in 1990 indicate that the price of oil cannot be modelled purely as an endogenous variable. Hamilton (2000), among others, argues that the impact of the price of oil on economic activity should be modelled nonlinearly. Adequately modelling the price of oil dynamics in our VECM model is an issue for future projects. Note that the transmission of monetary policy is modelled adequately. An unexpected shock to the interest rate reduces the levels of output and prices. Commodity prices fall in response to lower demand for commodities.

4.5 Conclusions

Canadian labour productivity in manufacturing is currently lagging behind that of the US, with a gap that has widened extensively since 1993. In this Chapter we analyse the plausibility of one explanation, the factor-cost hypothesis. Since a real exchange rate depreciation makes imported capital relatively more expensive than labour, the real depreciation of the Canadian dollar may contribute to lower labour productivity in manufacturing by causing manufacturing firms to invest less in capital

Figure 4.7: Responses of Canadian variables to Canadian shocks

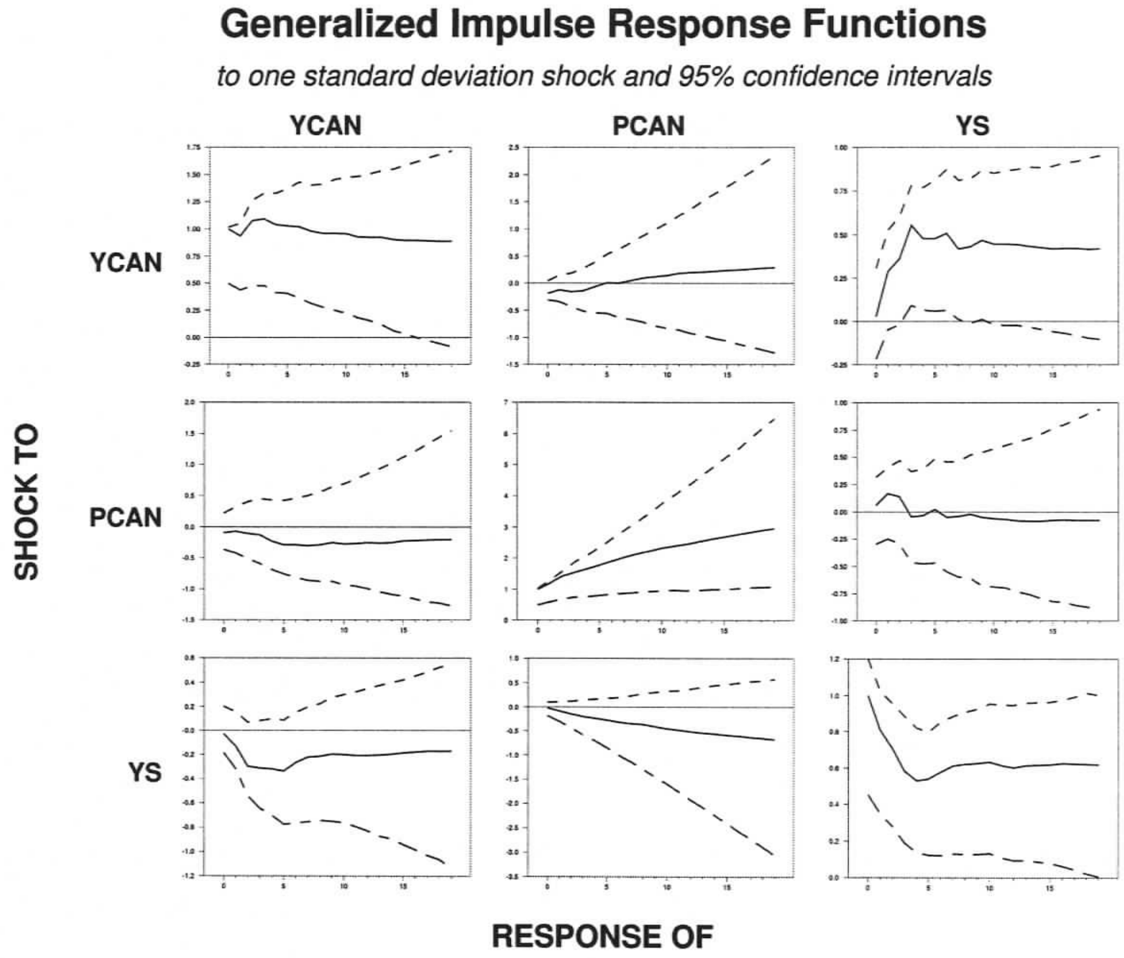

Figure 4.7

Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.8: Responses of Canadian variables to Canadian shocks

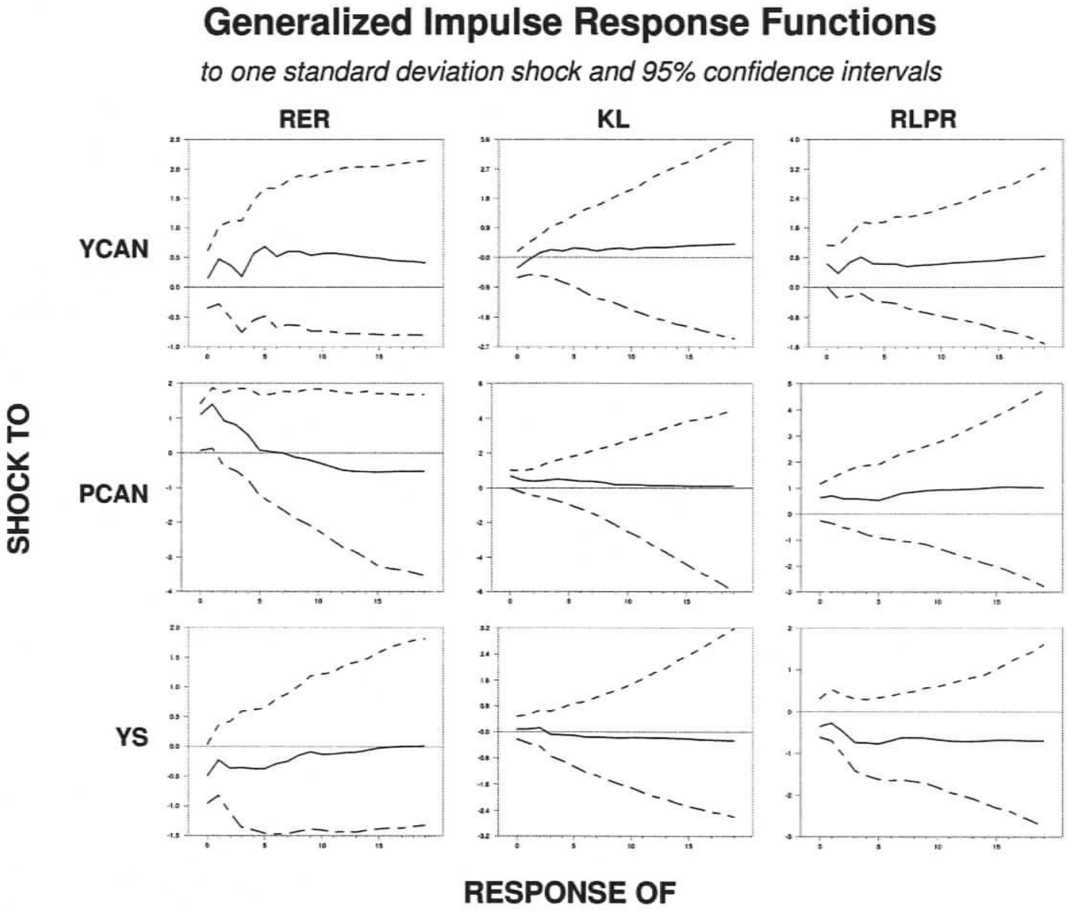

Figure 4.8
Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.9: Responses of Canadian variables to Canadian shocks

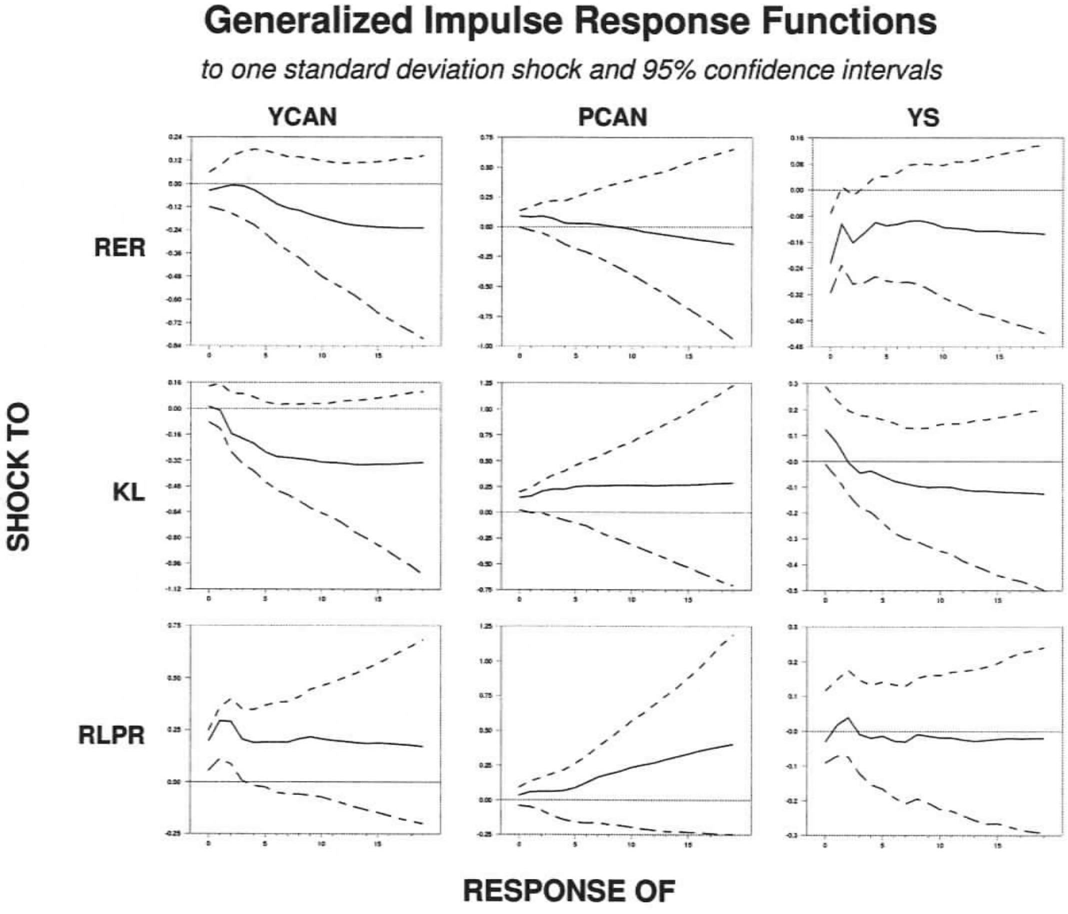

Figure 4.9
Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.10: Responses of Canadian variables to US shocks

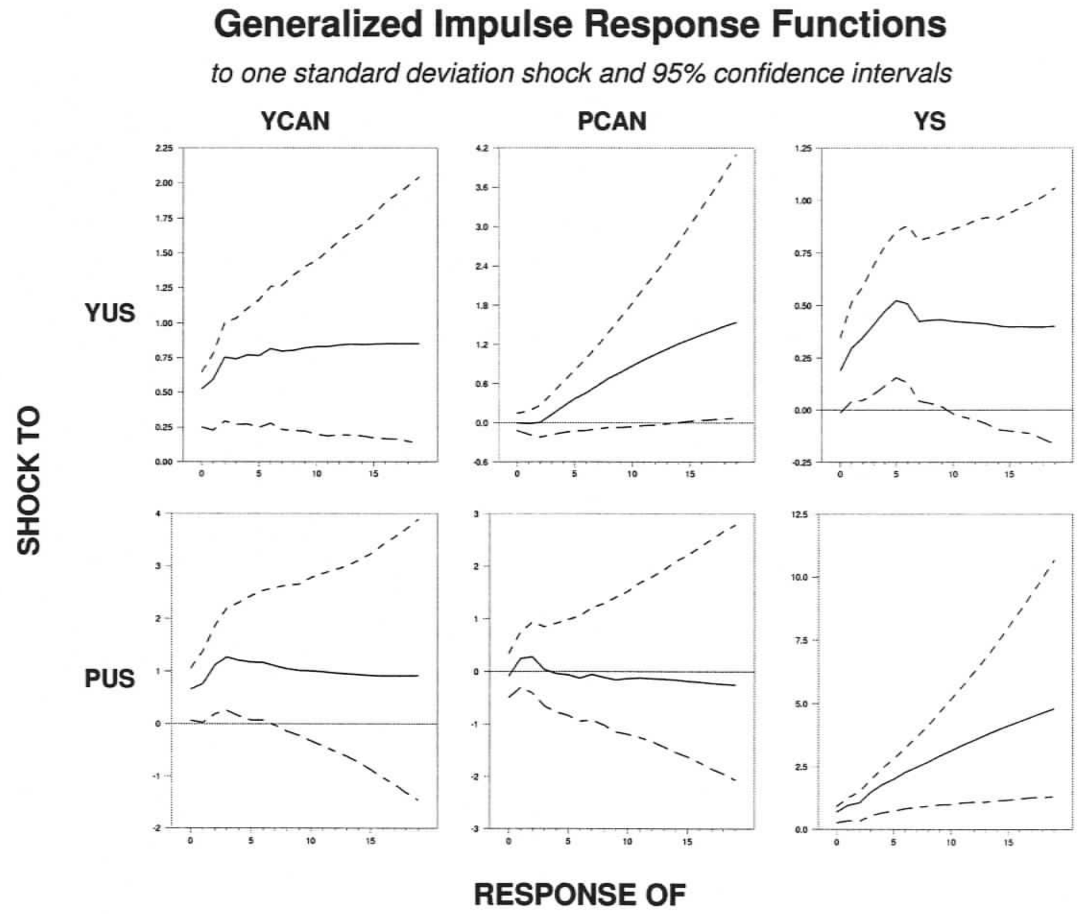

Figure 4.10

Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.11: Responses of Canadian variables to US shocks

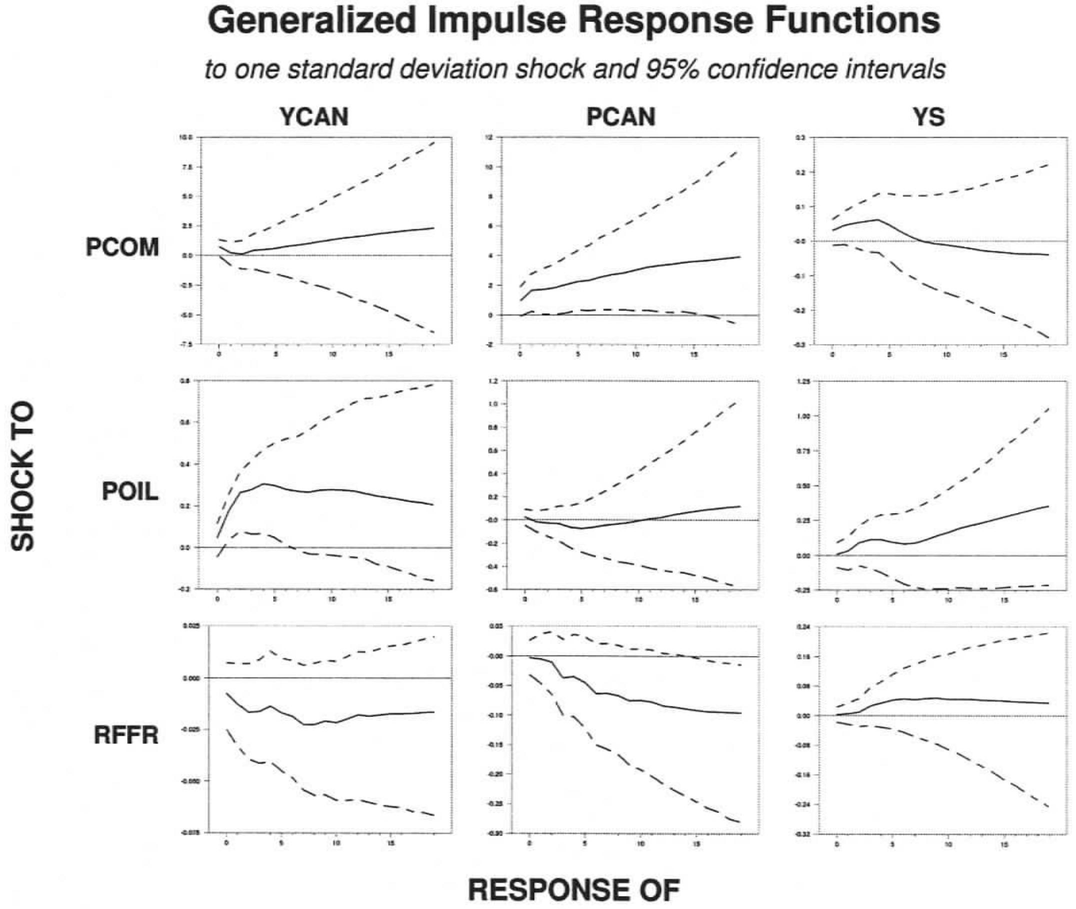

Figure 4.11
Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.12: Responses of Canadian variables to US shocks

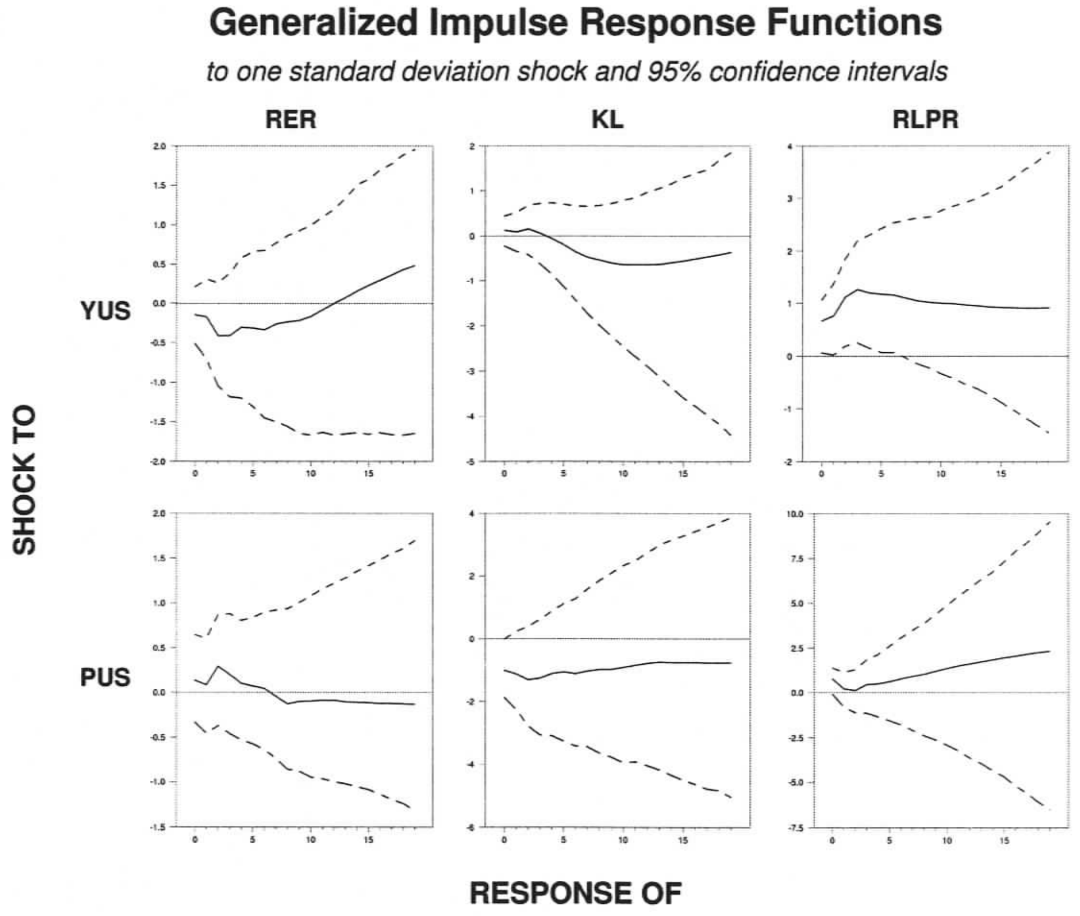

Figure 4.12

Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.13: Responses of Canadian variables to US shocks

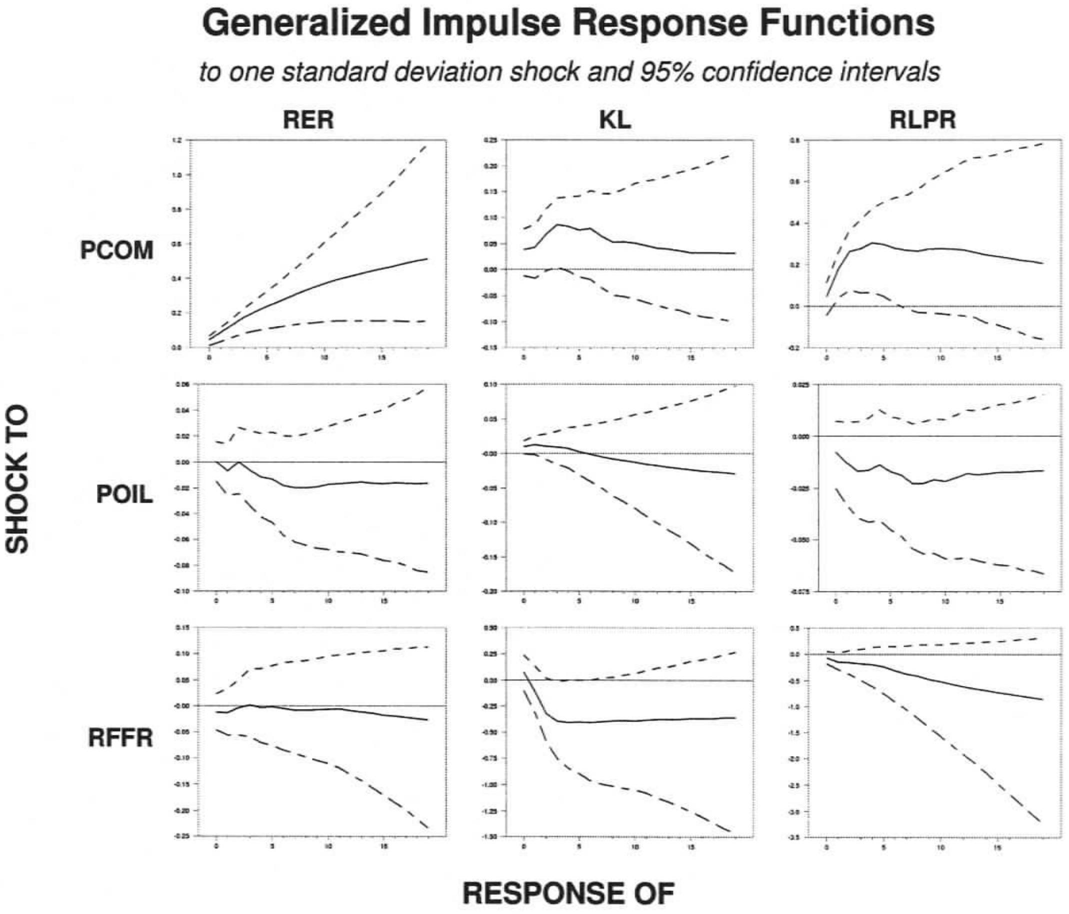

Figure 4.13
Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.14: Responses of US variables to US shocks

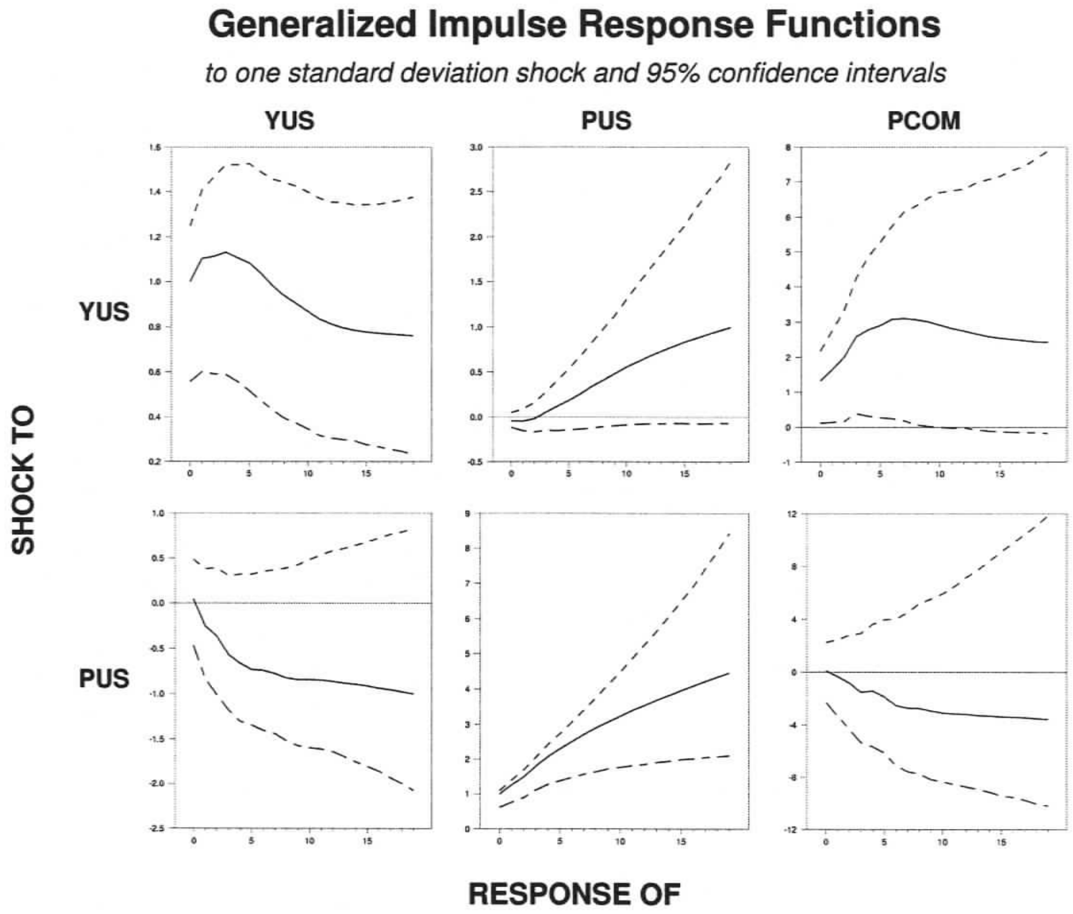

Figure 4.14

Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.15: Responses of US variables to US shocks

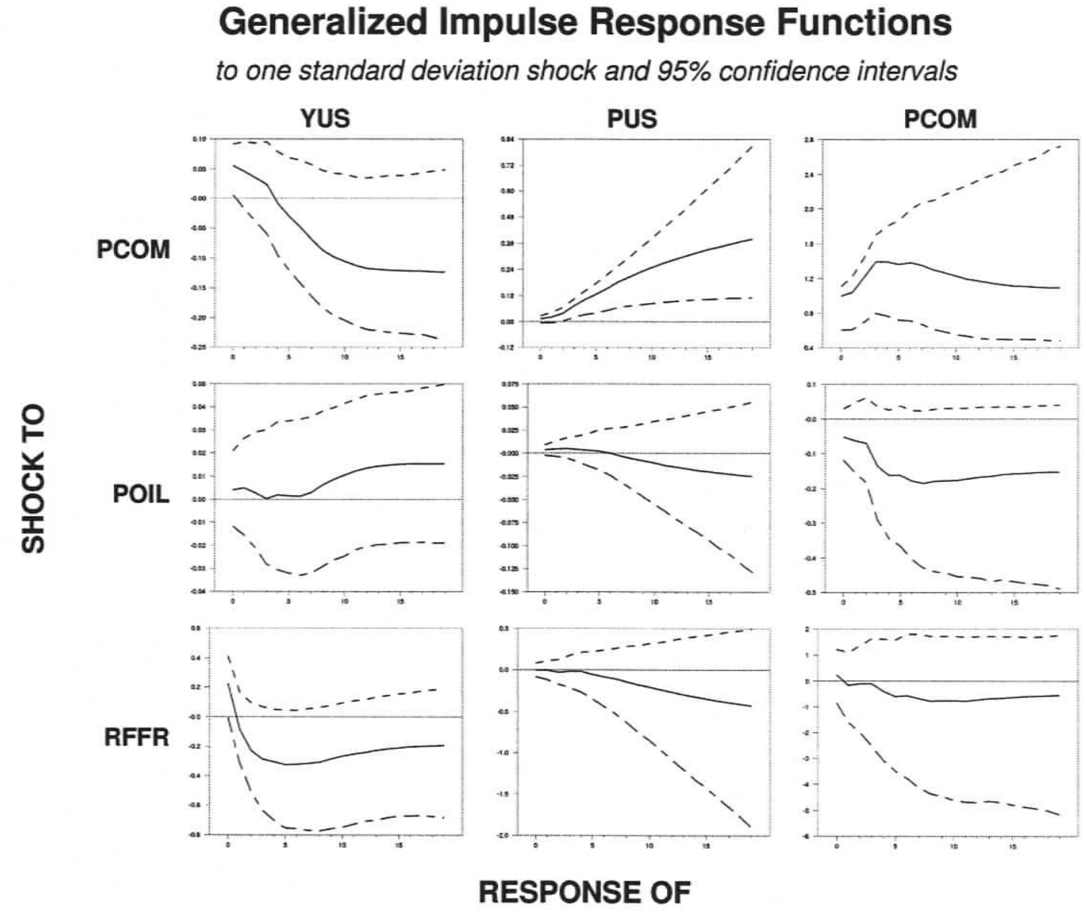

Figure 4.15
Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.16: Responses of US variables to US shocks

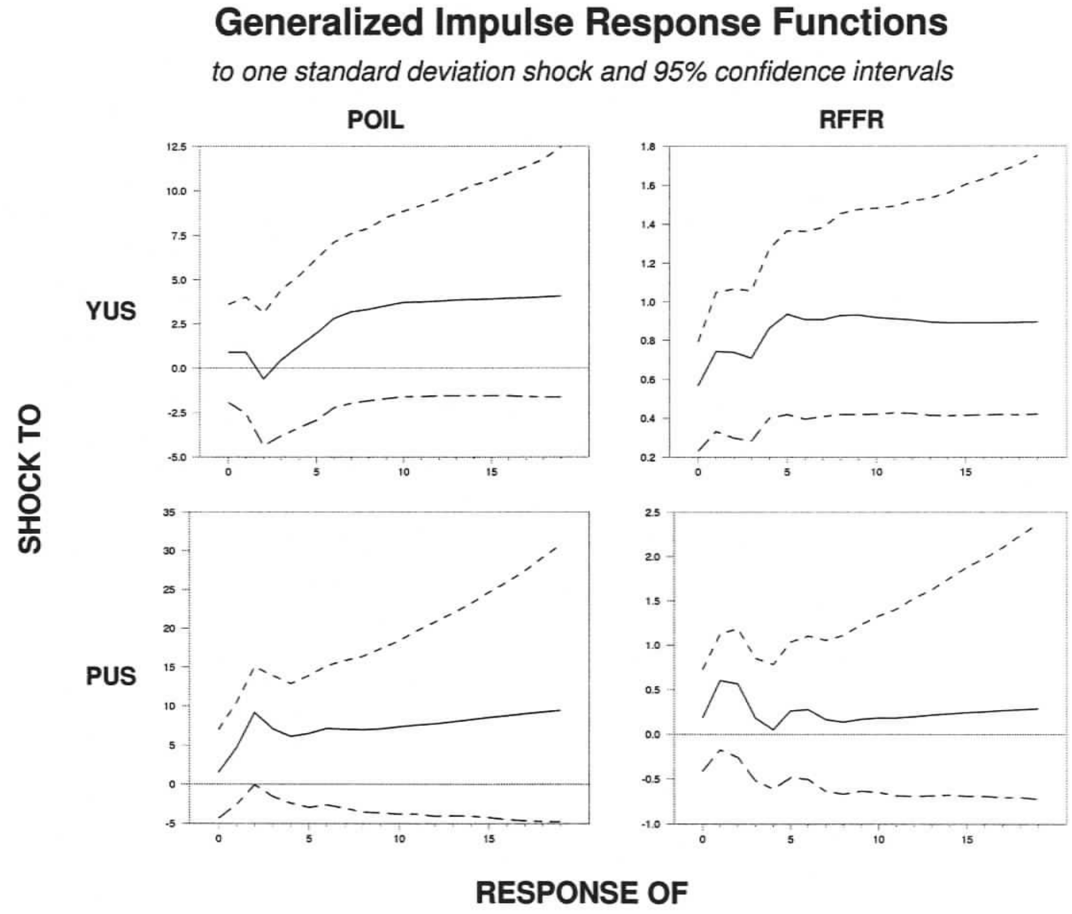

Figure 4.16
Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

Figure 4.17: Responses of US variables to US shocks

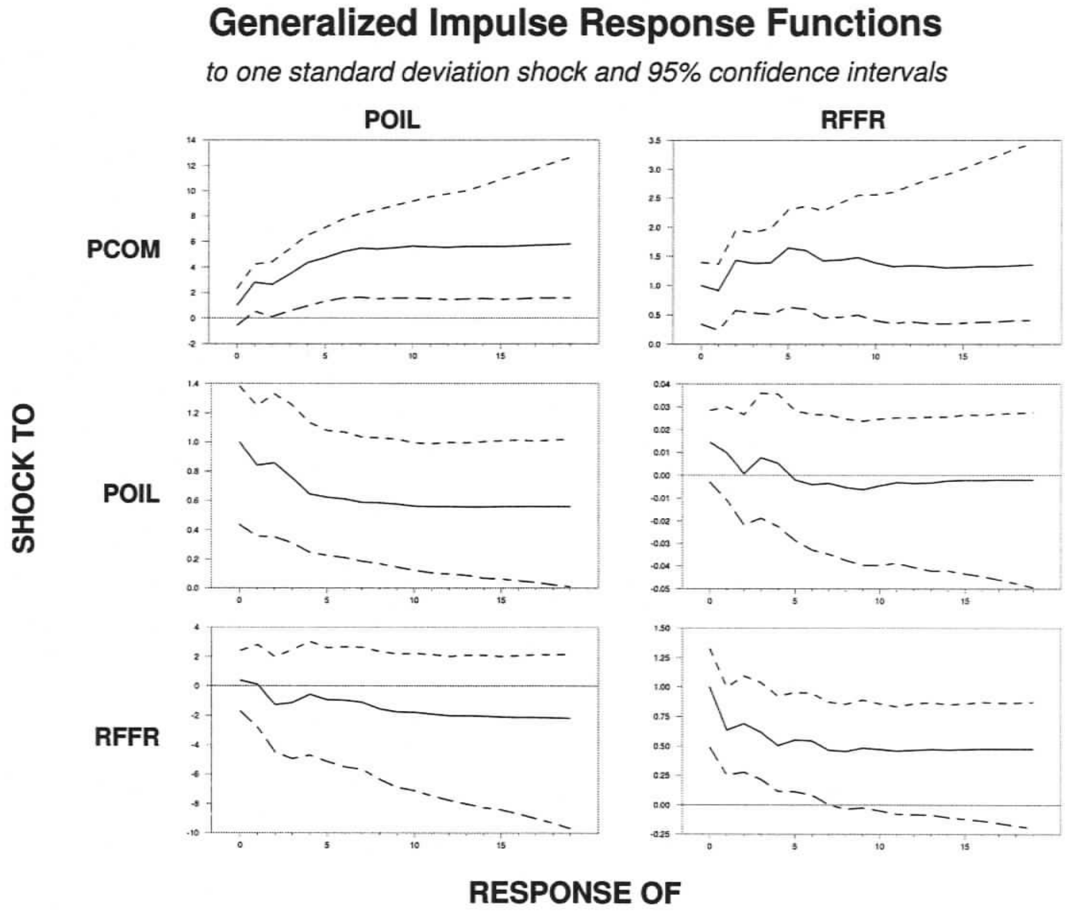

Figure 4.17
Generalized responses of logarithms of the variables to shocks. 95% confidence intervals are constructed by the bootstrap-after-bootstrap method of Kilian (1998).

and substitute more labour intensive methods.

We develop a VECM model for Canada to analyse the factor-cost hypothesis. This hypothesis has not been tested explicitly for Canada, though it is often discussed in the literature as an important explanation of the productivity gap. The model allows for the separation of other factors such as cyclical fluctuations in aggregate demand, shocks to commodity prices and monetary policy. We use this model to test the factor-cost hypothesis directly by considering how shocks to the real exchange rate affect the Canada-US relative capital-labour ratio and labour productivity. Forecast error variance decompositions are then used to assess the importance of shocks and, ultimately, the importance of the factor-cost hypothesis in explaining movements in relative labour productivity.

We find that a depreciation of the Canadian dollar reduces the relative capital-labour ratio and labour productivity in Canada in accordance with the factor-cost hypothesis. The contribution of this channel, however, in explaining declining capital-labour ratios and labour productivity in Canada is only about 10-13%. Innovations in the relative capital-labour ratio and labour productivity play a more important role in explaining relative labour productivity's variance decomposition, accounting for 29% and 40% percent respectively.

Since movements in the real exchange rate are unlikely to be a major factor in explaining the productivity gap, further research should focus on other factors. Several studies indicate that the gap is concentrated in high technology industries, so an additional analysis by industry may be needed to improve our understanding of industry-specific shocks. The capital-labour ratio may also be affected by other factors than the exchange rate alone, such as technological developments and labour markets. Consequently, further research should address the question of capital formation in greater detail. The main contribution of our paper is that we rule out the real exchange rate as a major driving force in explaining the Canada-US productivity gap.

Chapter 5

Conclusions

This dissertation analyzes the relationship among real variables and the real exchange rate. The theoretical literature postulates that real variables affect the real exchange rate through the relative price of nontraded goods. Chapter 2 questions this postulate. I find that real variables are equally important for the two relative prices that constitute the real exchange rate, which are the relative price of traded goods and the relative price of nontraded goods. However, the relative price of traded goods is more important for the real exchange rate as found by Engel (1999). I complement these results by finding that real shocks almost entirely propagate through the relative price of traded goods to the real exchange rate.

A possible explanation of this puzzling result, which contradicts theoretical considerations, is that real shocks affect the relative price of traded goods by affecting the nominal exchange. If this is the case, one should expect a decline in the contribution of real shocks through the relative price of traded goods, as the horizon increases, due to goods arbitrage. I find, however, that the contribution of real shocks through the relative price of traded goods does not decline. Rather, the contribution actually increases.

There are several approaches as to how these results can be potentially explained theoretically. Any approach has to break the law of one price for traded goods in order to give a role to the relative price of traded goods in the transmission mechanism. One approach is to assume pricing to market in local currencies. The law of one price is violated because the nominal exchange rate fluctuates while prices are sticky. This approach is pursued in Benigno and Thoenissen (2003) and Engel (2004). However, prices cannot be sticky forever; it is usually assumed that price stickiness can persist by no more than one year. Consequently, models with sticky prices should imply the convergence to the law of one price within one year, suggesting that these models cannot explain the findings of Chapter 2. Another approach is price setting by monopolists under translog preferences as analyzed by Bergin (2003). This approach implies that the relative price of traded goods appreciates in response to productivity shocks in manufacturing. The empirical analysis of Chapter 3 reveals that the relative price of traded goods depreciates in response to productivity shocks.

In Chapter 3, I develop a model that analyzes whether the empirical findings can be explained by the introduction of home bias in the standard Balassa-Samuelson model. Home bias has several desirable features. First, it breaks the law of one price for the composite traded good. Second, it implies that the relative price of traded goods depreciates in response to productivity shocks. Third, it allows the impact of real variables on the relative price of traded goods even in the long run. However, the model demonstrates that relative prices should be equally important in the transmission mechanism, while the empirical evidence assigns an almost exclusive role to the relative price of traded goods.

The above discussion assumes that real variables affect the real exchange rate. It is possible that the causation may run in the opposite direction. The factor cost hypothesis says that fluctuations in the real exchange rate affect the cost of imported machinery and equipment. During depreciations of the Canada-US real exchange rate, capital becomes relatively more expensive than labour for Canadian producers. Consequently, they adopt labour-intensive technologies that drive down labour productivity. This hypothesis has attracted a lot of attention in Canada, since the gap between labour productivity in Canadian and US manufacturing has widened significantly since 1993. In Chapter 4, I analyze this hypothesis with Canada-US data. I find that while exchange rate fluctuations do affect labour productivity and the capital-labour ratio in Canada, their influence is not enough to explain the major part of the gap.

Appendix A

Data sources and construction for Chapters 2 and 3

The relative prices of tradables (x_t) and nontradables (y_t) are based on consumer price indexes (CPIs) and personal consumption deflators (PCDs). As a proxy for tradables, I use commodities and as a proxy for nontradables, I use services. Of course, such measures are far from perfect. Services may include some items that are tradable like energy services, while commodities may include nontraded marketing services. The average weights of nontraded goods in the consumption basket, α and α^*, are found by estimating the following simple regressions:

$$\Delta p_t = (1-\alpha)\Delta p_t^T + \alpha \Delta p_t^N + e_t$$

$$\Delta {p_t}^* = (1-\alpha^*)\Delta p_t^{T*} + \alpha^* \Delta p_t^{N*} + e_t^*$$

where Δ is the first-difference operator.

The following weights are obtained

	Canada	US
CPI	0.4221	0.4684
PCD	0.5304	0.5210

The estimates are then used to construct y_t according to (2.3), so that y_t is generated by prior estimation. This adds uncertainty which affects all subsequent inference in the models (see, e.g., the discussion in Pagan, 1984, for the impact of generated regressors). CPIs for commodities and services for Canada and the United States are taken from CANSIM tables 451-0009 and 326-0001 and seasonally adjusted using a multiplicative seasonal adjustment. Personal consumption deflators are taken from CANSIM table 380-0002 and Bureau of Economic Analysis (BEA) table 1.1.4. The price index for US consumption deflators for traded goods is obtained by weighting price indexes for durable and nondurable goods. For Canada, deflators are constructed by dividing nominal expenditures by real expenditures. The Canada-US nominal exchange rate is taken from CANSIM (identifier v37426).

Commodity price indexes for Canada in US dollar terms for energy and nonenergy commodities (identifiers v36384 and v36383 respectively) are deflated by US CPI to obtain PENERGY and PCOM.

As a measure of relative productivity in the tradable sectors, I use relative labour productivity in manufacturing. The productivity data are not available for Canada at the quarterly frequency at the desirable level of disaggregation. As a measure of labour, I use total actual hours worked, adjusted for seasonal variation and holiday effects. As a measure of output, I use a value-based measure for Canada, and gross output for the United States. The relative productivity in nontradables measure is based on the relative labour productivity in private service-producing industries. For the United States, I use personal consumption on services part of real GDP from National Income Personal Accounts (NIPA) table 1.1.3 as a measure of output, and aggregate weekly hours as a measure of labour input. For Canada, I use the personal expenditure on services part of real GDP (identifier: v1992048) as a measure of output, and employment from CANSIM tables 281-0001 and 281-0020 for private service-producing industries as a measure of labour input.[1]

To estimate the home bias, I use input-output tables for Canada and the United States in 1997. Total supply minus exports and imports for manufacturing industries is used as a proxy of consumption of domestically produced manufactures (C_H). Total supply minus exports for manufacturing and natural resources industries is used as a proxy of consumption of tradables (C_T). The ratio of these proxies gives an estimate of β. For the United States, the ratio of imports of manufacturing products to total supply minus exports for natural resources and manufacturing is used to estimate β^*. This would give an upper limit on the parameter, since the

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[1] Transportation, storage, communication, utilities; trade; finance, insurance and real estate; business and personal services.

United States imports manufacturing goods from many countries, not only Canada. Consequently, I multiply this number by a share of imports from Canada to total imports to the United States.

Canada	US
$\beta = 0.29$	$\beta^* = 0.02$

The estimates show some evidence in favour of home bias. Benigno and Thoenissen (2003) report for the UK-Euro area the weights are 0.51 and 0.09 respectively, i.e. UK consumes 51% of their domestically produced manufacturing goods while the euro-area imports only 9% of goods produced in UK. For the Canada-US pair, the difference is not so large because Canada imports a high share of manufacturing goods from the US

Appendix B

Data sources and construction for Chapter 4

B.1 Construction of the relative productivity and capital-labour ratio data series

The relative Canada-US labour productivity and the capital-labour ratio are constructed for the purposes of this study over the sample from 1961q1 to 2000q4. Official Canadian labour productivity data for manufacturing are available only at annual frequency. We construct quarterly series in this paper. As a measure of labour, we use total actual hours worked. Employment data for Canadian manufacturing are taken from Statistics Canada terminated tables 281-0001 and 281-0020, and, where necessary, seasonally adjusted using the Bank of Canada's X-11 ARIMA program. Employment data were then multiplied by average actual hours worked in manufacturing from the Labour Force Survey. Average hours were adjusted for holiday effects and seasonal effects using the Bank of Canada's procedures. We had to link total hours worked at two points due to different methodologies employed. We adjusted levels of series such that the annual average equals to total hours worked from Table 383-0003 in 1965 and 1985. The employed methodology would be different from the methodology employed at Statistics Canada for the construction of annual labour productivity series mainly in quality adjustments. Statistics Canada uses a bottom-up approach to productivity. In the case of labour productivity, indices are computed for 147 industries and then aggregated up using different weights, based on relative wages (see Statistics Canada - Catalogue no. 15-204, Appendix 1). In this paper, we use estimates for manufacturing obtained at the aggregated level.

As a measure of output, we use a value-based measure (GDP by industry) for Canada and gross output for the United States. Unfortunately, Canadian and US statistical agencies use different measures for quarterly output data. However, we believe that these differences in output measures should not have a significant impact on the results. We constructed relative Canada-US productivity in manufacturing series using a value-added measure of output for the two countries starting in 1977, in order to compare it to the series used in this study. For the period 1977-2000, the two series have similar trends and dynamics while there are some differences in annual growth rates.

As a measure of capital, we use a geometric (infinite) end-year stock of machinery and equipment in chained dollars. Capital series are available only at annual frequency, and we obtained quarterly values by using cubic spline interpolation in FAME (UNIX program to work with databases). We assume that quarterly variation in capital stock is not important for our purposes. The relative factor costs variable was constructed by using GDP price indexes for machinery and equipment and hourly labour compensation measures for Canada and the United States. The time series for this variable is shorter than other variables in the model and it starts in 1969. We acknowledge that data of better quality are certainly desirable for empirical work. But given that such data do not exist at present, we prefer to conduct our analysis with data at hand rather than not conducting any analysis at all.

B.2 Sources of the data

Table B.1: Sources of the data

Variable	Description	Source
YCAN	the logarithm of Canadian GDP at market prices in chained 1997 dollars	Statistics Canada
PCAN	the logarithm of Canadian implicit chain price index divided by 100	Statistics Canada
RER	the logarithm of closing nominal US/CAN exchange rate multiplied by Canadian and divided by US GDP deflators	Statistics Canada
YS	the difference between 3 month prime corporate paper rate and average yield on 10+ year Government of Canada marketable bonds. The difference is multiplied by 0.01.	Statistics Canada

Table B.2: Sources of the data (continued)

Variable	Description	Source
KL	the logarithm of relative Canada-US capital-labour ratio in manufacturing index. For Canada, as a measure of capital we are using a geometric (infinite) end-year stock of machinery and equipment in chained dollars. Quarterly values are obtained by using cubic spline interpolation in FAME. Capital is then divided by total actual hours worked. For the US, a similar measure of capital is obtained from the Bureau of Economic Analysis. Capital is then divided by man-hours obtained from the US Department of Labor.	Statistics Canada Bureau of Economic Analysis US Department of Labor
FC	is the logarithm of the relative Canada-US factor costs constructed as a chained GDP price index for machinery and equipment divided by an hourly labour compensation measure. An hourly compensation measure for Canada is taken from Statistics Canada after 1987, and constructed as the ratio of labour income to total hours worked. For the United States, compensation per hour index for the non-farm business sector is used.	Statistics Canada Bureau of Labor Statistics Bureau of Economic Analysis
YUS	the logarithm of US GDP in chained 1996 dollars	Bureau of Economic Analysis

Table B.3: Sources of the data (continued)

Variable	Description	Source
PUS	the logarithm of chain-type GDP price index.	Bureau of Economic Analysis
RFFR	US Federal Funds Rate times 0.01 and minus the US inflation rate measured as log-difference of US GDP deflator.	Statistics Canada
PCOM	the logarithm of the Bank of Canada non-energy commodity price index minus the logarithm of US GDP deflator.	Bank of Canada
POIL	the logarithm of the Bank of Canada price of oil index minus the logarithm of US GDP deflator.	Bank of Canada
RLPR	the logarithm of relative Canada-US labour productivity in manufacturing. For Canada, labour productivity is obtained by dividing GDP at factor cost in constant 1992 dollars by total actual hours worked. For the US, labour productivity in manufacturing is obtained from the US Department of Labor	Statistics Canada US Department of Labor