What is Driving Exchange Rates? New Evidence from a Panel of U.S. Dollar Bilateral Exchange Rates*

Jean-Philippe Cayen, Donald Coletti, René Lalonde, Philipp Maier

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Abstract

We use a novel approach to identify the factors that have been driving a panel of exchange rates of industrialized countries. Using both a principal factor and a state-space model we identify two common influences in a panel of six of U.S. bilateral real exchange rates: Australia, Canada, the euro, Japan, New Zealand and the United Kingdom. We link the first common factor to macroeconomic shocks in the United States and the second to world commodity prices. Using these two factors, we decompose the historical variation in each of the real U.S. dollar bilateral exchange rates. We find a strong role for U.S. factors in explaining the pattern of exchange rate developments over the 2002 to 2007 period. A smaller, although still significant, role is found for commodity prices. In the case of Canada, we also find an important role for the improvement in the Canadian fiscal situation in explaining the strength of the Canadian dollar, relative to the U.S. dollar. Domestic economic developments were also found to be quite important for explaining the weakness of the Japanese Yen.

1 Introduction

Recent years have been characterized by considerable swings in the value of key exchange rates (table 1). This coincided with historically unprecedented increases in the price of commodities. Not surprisingly, we have witnessed a surge in the value of the currencies of commodity-exporting nations like Australia, Canada, and New Zealand against the U.S. dollar. At the same time, however,

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we have also seen large appreciation of currencies of important commodity-importing countries or currency areas, like the euro area and the United Kingdom.[1]

As fluctuations in the exchange rate can affect economic activity, periods of high exchange rate volatility can pose considerable challenges for monetary policymakers. Understanding the factors driving exchange rate movements matters, because the appropriate policy response may depend on the source of the appreciation (Ragan 2005). Consider the case of a small and open commodity exporter with inflation targeting, like Canada. Assume, on one hand, an appreciation of the Canadian currency against the U.S. dollar, driven by an increase in commodity prices. This is an improvement in Canada's terms of trade and is likely to increase inflationary pressure. As a result, a monetary tightening might be warranted, if the central bank wants to keep inflation stable. Assume, on the other hand, an appreciation of the Canada-U.S. exchange rate driven by a cyclical slowdown in the United States. Given the importance of the United States for the Canadian export sector, we would likely see a fall in inflationary pressure in Canada, leading to lower monetary policy rates. This illustrates that to set monetary policy rates appropriately, a thorough understanding of the source of the shock affecting the exchange rate is required.

Unfortunately, most empirical models of exchange rate determination provide little guidance to policymakers. As documented by Meese and Rogoff (1983), Obstfeld and Rogoff (2000), and Cheung et al. (2005), models based on macroeconomic fundamentals have had rather limited success in explaining exchange rate movements. The empirical track record is better for models exploiting the relationship between commodity prices and exchange rates, as the empirical link between fluctuations in commodity prices and the real exchange rates has been found to be relatively stable. This holds in particular for major commodity exporting countries like Canada, Australia and New Zealand (Issa et al. 2006, Chen and Rogoff 2003, Djoudad et al. 2001, Bayoumi and Mühleisen 2007 and Amano and van Norden 1995). Amano and van Norden (1998) also find a robust empirical relationship between the real oil price and the real exchange rates of Germany, Japan and the United States.

This study proposes a novel approach to identify key determinants of exchange rate movements. We combine a data-driven approach with modelling the impact of commodity prices directly, moving from a minimal set of restricting to more restrictive, yet richer statistical frameworks. We use two different methodologies, a principal factor model and a state-space model, to identify patterns in a panel of six of U.S. bilateral real exchange rates. Both methodologies suggest that there are two key patterns or 'components' in our panel of exchange rates. Both approaches also indicate that the first component is positively correlated with movements in all bilateral U.S. exchange rates. We interpret this component as being driven by economic developments originating in the U.S. economy. The second common component is positively related

[1] The United Kingdom is a commodity importing country: although it was an oil net exporter between 1980 and 2006 (and net importer during the rest of our sample), overall it was a net importer of commodities.

to the exchange rates of commodity exporters, and negatively related for commodity importers. This suggests a link to developments in world commodity markets. Statistical evidence indicates that the second principal component is strongly cointegrated with real oil and non-energy commodity prices. Using this information, we then estimate an augmented state-space model that explicitly includes the relationship between second factor and commodity prices, and use this model to decompose the historical variation in each of the real U.S. dollar bilateral exchange rates into three distinct components: i) the 'U.S. factor', ii) the commodity-price factor and iii) a residual component that is related to developments in each specific country (or region). Our model also includes a fiscal variable in the country-specific component for Canada.

We find that the factor related to U.S. developments exerts significant upward pressure on the value of the bilateral exchange rates. The strongest effect of U.S. developments is found on the value of the euro/USD exchange rate, where U.S. shocks induce an appreciation of about 60 percent since 2002. During the same period, U.S. shocks have been least important for the Canadian dollar, as they have only accounted for about 25 percent of the total appreciation. Commodity prices explain roughly 5 to 15 percent of currency movements for the countries in our sample. These commodity effects are much smaller than typically found in studies that focus exclusively on the relationship between exchange rates and commodity prices. This indicates that by not taking into account U.S. shocks, the importance of commodity prices could be overestimated. Lastly, for most countries, the country-specific components does not tend to play an important role in explaining the behavior of exchange rates over this period, the two notable exceptions being Canada and Japan. For these two countries we present evidence linking the relative value of their currencies to fiscal developments. Both the fiscal improvement in the case of Canada and the fiscal deterioration in the case of Japan turns out to have important effects.

The paper is organized into five sections. Section 2 explores the data, and discusses the statistical approaches used to identify the common components across the panel of exchange rates. Section 3 presents the results of the basic state-space model, and discusses the two common components. Also, based on insights gained from the basic state-space model, we present an augmented state-space model that includes an explicit role for commodity prices and for Canada's fiscal situation. Section 4 shows a historical decomposition of movements in each of the bilateral exchange rates. Section 5 concludes, and discusses possibilities for further work.

2 Empirical methodology

2.1 Data exploration

Our empirical strategy is to exploit information from a panel of real U.S. dollar bilateral exchange rates to identify common patterns, which have been driving real exchange rates. Our panel covers real bilateral exchange rates for the period 1980Q1 to 2007Q2 between the United States and six countries or currency areas: Australia, Canada, the euro area, Japan, the United Kingdom, and New Zealand.[2] During this period, all currencies floated freely against the U.S. dollar.[3] Figure 1 graphs the real exchange rates of all countries in our sample.

To extract common movements in the panel of exchange rates we use two different approaches: principal factor analysis (Tsay, 2005) to provide a first exploration of the data, and – based on the insights gained from principal factor analysis – a state-space model (Stock and Watson 1991). Each approach has its advantages and disadvantages:

- The principal factor model is a purely statistical technique, which has the advantage of relying on a minimum of restrictions and assumptions. Consequently, results are driven by data, and are not likely to be subject to possible misspecifications.

- The state-space model is more flexible. We can increase the number of restrictions to impose more structure on the data (for example, the state-space model allows for an explicit link between a common component and commodity prices).[4] This helps understanding the driving forces behind the model, and it facilitates statistical inference. However, state-space models can be less robust, because they could be sensitive to assumptions regarding the stochastic processes of the unobservable common components.

To guide us in the estimation of the state-space model, we applied both approaches. Our findings are robust to the methodology chosen; in fact, the key insights are practically identical. However, the added flexibility of the state-space model, that allows us to include macroeconomic variables explicitly, makes this approach more suitable to decomposing historical movements in real exchange rates.

2.2 The principal factors approach

2.2.1 Methodology

Factor analysis is a statistical technique that is used to detect structure in relationships between variables. It is a purely empirical technique, and requires only very weak assumptions about the distributions of variables. Principal factor analysis has, for instance, been used to analyze term structures of bonds (Litterman and Scheinkman, 1991), correlations of interest rates across currencies

[2] We constructed the euro exchange rate data, over the period 1980 to 1998, by using data on the ECU-U.S. dollar exchange rate, excluding the U.K. pound and Danish krona. The real exchange rates are calculated using GDP price deflators. This sample is chosen because of data limitations associated with the quarterly IMF non-energy commodity prices index and because of the convergence of the behavior of inflation rates across the countries in our sample.

[3] The U.K. pound was briefly pegged within the European Monetary System (EMS) between 1990 and 1992.

[4] To do a similar analysis with the principal factor approach, one needs to estimate, ex-post, a separate equation, using one of the common factors as a dependent variable.

(Lekkos, 2001), or the effects of exchange rate flexibility on the correlation of business cycles (Caporale and Pittis, 1995). The study most closely related to ours is Dufrenot and Yehoue (2005), who use a dynamic factor model to estimate equilibrium exchange rates and to detect possible exchange rate misalignment. Our approach differs from Dufrenot and Yehoue (2005) in that (i) we focus on a panel of exchange rates for industrial countries rather than developing countries, ii) we use a static factor model, and (iii) we use real bilateral exchange rates, not real effective exchange rates, because we are interested in identifying the extent to which all exchange rates in our sample respond to common U.S. shocks.

Principal factor analysis identifies factors that account for most of the variations in the covariance or correlation matrix of the data. Underlying this technique is the premise that unobservable internal characteristics (or attributes) exist, in which the sample elements differ. These characteristics are commonly referred to as 'latent factors', and are assumed to account for the variation and co-variation (or correlation) across a range of observed phenomena.

Formally, factor analysis stipulates that p observed random variables X ($X = (x_1, ...x_p)'$) can be expressed as linear functions of m ($m < p$) hypothetical common factors F ($F = (f_1, ...f_m)'$), plus an error term. In this study we use p exchange rates X, and assume that the mean and covariance matrix of X are given by μ and Δ. Then, the classical (or static) factor model is given in matrix notation by:

$$X - \mu = LF + \epsilon$$

where $L = [l_{ij}]_{p \times m}$ is the matrix of factor loadings, l_{ij} is the loading of the ith variable on the jth factor, and ϵ_i is the specific error of X_i.

2.2.2 Estimation strategy

An assumption underlying the static principal factor model is that the underlying series do not exhibit serial correlation, and are stationary (Tsay, 2005). The evidence on both assumption is somewhat inconclusive: Checking for stationarity of the exchange rate series using Augmented Dickey Fuller (ADF) tests, we find that most real exchange rates are integrated of order one, with the exception of the United Kingdom and New Zealand (see Table 2). As regards serial correlation, we find statistically significant, but very small AR(1) terms of about 0.3 for all of the differenced real exchange rate series. This means that we have several options: we can estimate a static or dynamic model, and we can estimate in levels or first differences.

Level vs. first differences We start by estimating a static principal factor model using the *level* of the real exchange rate. When testing for cointegration between the principal factors and the exchange rate series, we found that the principal factors and the exchange rates for Australia and the euro area were cointegrated, whereas the series for the other countries were not.[5] This suggests that an estimation in first differences is preferable.

Static vs. dynamic model The static factor model outlined above can be made dynamic by including lags of the observed random variables. Dynamic factor models, as discussed in Forni and Lippi (2001), capture the time series dimension of the underlying data. A drawback of dynamic factor models is that assumptions need to be made about the time dimension, which make dynamic factor models more prone to misspecification. As the AR(1) term is very small, we present the results for the static model in the main text, but show that a dynamic model gives very similar results in appendix A.

Taken together, these considerations suggest using a static principal factor model, estimated in first differences. This has the advantage of imposing a minimum of restrictions on the data.

2.3 The basic state-space model

2.3.1 Methodology

State-space modelling is an alternative approach that can be used to extract common movements among a set of aggregate time-series. State-space models are a generalization of the linear regression model, and have, for instance, been used by Stock and Watson (1991) to build an index of indicators that provides information about the overall state of the economy. Fernandez Macho, Harvey and Stock (1987) discuss state-space modelling to extract common trends among variables that are cointegrated.

The state-space representation can be summarized by the following set of equations:

$$X_t = \gamma C_t + \nu_t \quad (1)$$
$$\phi(L) C_t = \eta_t \quad (2)$$
$$D(L) \nu_t = \epsilon_t \quad (3)$$

where X_t is a n x 1 vector representing our panel of real U.S. dollar bilateral exchange rates, C_t is a set of m common factors, and ν_t is a n-dimensional component that represents idiosyncratic movements in the series. The common components C_t enter each n equations in (2), but with different weights (γ).

2.3.2 Estimation strategy

As with the principal factor model, a key issue regards stationarity of the data. Again, there are two possibilities: first, we can assume that the ν_t and the C_t

[5] Our estimates using the level specification are qualitatively similar to those using the first difference specification. This is not surprising, given that some of the exchange rate series in our sample are cointegrated with the principal factor, and some are not.

contain (some) unit roots. Alternatively, we can assume that these stochastic trends enter through C_t. This is equivalent to saying that the members of X_t are cointegrated, and in this case, the idiosyncratic shocks are stationary by construction. Given that we do not find cointegration for all countries, we allow for the possibility that the idiosyncratic components are non-stationary.

To make the vector of C_t components the unique source of comovements across the exchange rate series, we assume that the ν_t and the C_t are mutually uncorrelated. for all leads and lags. This is possible if we assume that the matrix $D(L)$ is diagonal and that the errors terms η_t and ϵ_t are mutually uncorrelated. In addition, to identify C_t, restrictions on the variance-covariance matrix of η_t (Σ_η) and on γ are required. Fernandez Macho, Harvey and Stock (1987) impose three restrictions: they set Σ_η equal to a diagonal matrix, restrict $\gamma_{ij} = 0$ for $j > i$, and set $\gamma_{ii} = 1$ for $i = 1, ...m$. We set Σ_η as a diagonal matrix, but rather than restricting γ_{ii} to be equal to 1 for $i = 1, 2$, we set the two diagonal elements of Σ_η equal to 1 ($\sigma_{\eta 1} = \sigma_{\eta 2} = 1$). Instead of the restrictions for γ_{ij}, we differentiate the two common components by the following ARIMA processes:

1. For one common component, we assume an ARIMA(1,1,0) process, which captures the autocorrelation found in the first difference of the real exchange rate series;

2. For the other component we assume an ARIMA(1,0,0) process.

We estimate the state-space model by a combination of a Kalman filter and maximum likelihood.

3 Identifying factors driving currency movements

3.1 The two common factors

We first estimate the static principal factor model. Figure 2 plots the eigenvalues of the principal factors, ranked from the largest to the smallest (this is also known as 'screeplot'). As can be seen, the screeplot suggests retaining the first two factors, whereas the other factors are very small. The eigenvalues of the first two factors are 2.4 and 0.6, respectively. The loading factors are given in table 3.

Similarly, the state-space model finds evidence supporting two statistically significant common components (see table 4). The loading factors from the state-space model are very similar to those derived from the principal factor approach. Both approaches suggest that the first component is positively related to *all* exchange rates. This represents a common movement of all currencies in our sample, indicating a simultaneous appreciation against the U.S. dollar. Second, the sign of the second component is *not* identical for all countries, which indicates that the second component captures developments that do not affect all countries symmetrically. More specifically, the second component is positively correlated with real exchange rates of Australia, Canada, and New

Zealand, but is negatively correlated with the euro and Japan's and the United Kingdom's real exchange rates (all against the U.S. dollar).

While statistical models are useful to detect patterns in the data, additional evidence is required to provide an economic interpretation of the factors identified. In what follows, we provide evidence that links the first factor to U.S. shocks and the second factor to commodity price movements.

3.1.1 The first common component (the "U.S. component")

The first common component extracted from the principal factor model is very similar to the one generated by the state-space model (see Figure 3). It identifies a common movement in the direction of *all* bilateral U.S. dollar exchange rates, i.e. the U.S. dollar appreciates or depreciates against all currencies simultaneously. An obvious interpretation is that the first common component is related to shocks originating in the United States.[6] Intuitively, one could think of this component as one driven by U.S. economic developments, which affect all currencies in our sample. This includes the effects of U.S. monetary and fiscal policy shocks, U.S. productivity shocks, etc., to the extent that all bilateral exchange rates react in the same direction. We label this factor 'the U.S. factor'. Note that the sensitivity of individual bilateral exchange rates to U.S. shocks is not uniform, as the loading factors differ across countries (tables 3 and 4).[7]

As regards the interpretation of the first common component, figure 3 suggests that major swings are related to well known economic events. The appreciation in the initial years of the Reagan presidency is followed by the depreciation in the mid-1980s, when the deterioration in the U.S. fiscal position and the growing U.S. current account deficit have affected the value of the U.S. dollar. In the mid-1990s, the U.S. factor suggests an appreciation, which coincides with the surge in U.S. tradable productivity and the improvement of the U.S. fiscal position. Lastly, the large fall of the first common component that started in 2002 coincides with a sharp deterioration of the U.S. fiscal position and emergence of a large U.S. current account deficit (as expressed as a share of GDP).[8]

To establish empirical relationships between the first common component and macroeconomic variables, we are currently working on a structural VAR model, where the structural shocks are identified using sign restrictions (derived from a global DSGE model).

[6] This result is confirmed by simulations of a global DSGE model. In the Bank of Canada's version of the Global Economy Model (BoC-GEM), the world is divided into 5 regions: Canada, emerging Asia, commodity exporters, the United States and the remaining countries. Simulations show that only shocks originating from the United States induce symmetric reactions (with respect to sign) of all the bilateral U.S. dollar real exchange rates.

[7] Further research will investigate the relative sizes of the loading factors.

[8] See Faruqee et al. (2007), and Erceg, Gust, and Guerrieri (2005) for a discussion on the causes (including U.S. shocks) of the recent emergence of global imbalances. See Bailliu et al. (2007) for an empirical model to investigate multilateral adjustment.

3.1.2 The second common component (the "commodity component")

The second common factor is shown in Figure 4. Again, principal factor analysis and the state-space model provide very similar estimates. According to both models, the second common component is positively related to the real exchange rates of commodity-exporting countries, and negatively related to real exchange rates of commodity-importing countries. Figure 5 visualizes this relationship: it shows a scatter plot of each country's net commodity imports, relative to the United States, and the loading factors estimated in the state-space model.[9] It is apparent from the scatter plot that there is a clear relationship between the commodity net export position of each economy, relative to the United States, and the sign of the loading factors.

If this factor reflects the effects of commodity price movements on exchange rates, the second factor should also be closely associated with fluctuations in commodity prices. Figures 6 and 7 plot the second common factor from the state-space model and the IMF's real non-energy commodity prices index and the real price of oil, respectively.[10] As can be seen, the second principal factor seems to share a common trend with world commodity prices. The Saikonnen (1991) cointegration test confirms the tight relationship between the second component and commodity prices, as the test results reject the null hypothesis of no cointegration between the second principal component, the real price of oil, and the real non-energy commodity price index (see table 5 and figure 8). This relationship holds for the second factor, regardless of the estimation methodology (principal factor approach and state-space model). Having established the link between the second factor and commodity prices, we label this component 'the commodity factor'.

3.2 Decomposing exchange rate movements

Having identified two common factors, we decompose movements in each of the real bilateral U.S. dollar exchange rates into three stochastic components: one explained by the U.S.-driven principal factor; one related to the factor driven by commodity prices; and a country specific component. None of the country-specific components are cointegrated with the commodity component, which indicates that differences in the country-specific components are not driven by commodity prices (nor is the first component). Hence, the country-specific components are driven by other factors.

Before we continue, we examine whether currencies have large country-specific component, as we could model them explicitly in the state-space frame-

[9] Net commodity imports, relative to the United States, are defined as the nominal commodity net export position of each country, expressed as a share of nominal GDP, divided by U.S. net exports of commodities, expressed as a share of U.S. GDP.

[10] Our commodity price measures are the IMF non-energy commodity price index and the West Texas Intermediate (WTI) crude oil price. Both are expressed in U.S. dollar terms and are deflated by the U.S. GDP price deflator. Our analysis covers the 1980Q2 to 2007Q1 period due to the availability of quarterly IMF non-energy commodity price data.

work. Figure 9 indicates that the country-specific components for Canada and Japan, as estimated by the basic state-space model, are relatively large. A well-known, common feature for both countries is that their fiscal dynamics are very different from that of the United States:

- Canada had a relatively large deficit in the 1990s, but its fiscal performance improved considerably, relative to the United States (the total Canadian government debt-to-GDP ratio peaked at about 100 percent in 1995 to reach about 30 percent in 2007).
- Japan's fiscal performance, relative to the United States, deteriorated steadily since the early 1990s.

As empirical evidence suggests that fiscal performance and exchange rates may be related (Dornbusch et al. 1980, Kim and Roubini 2008), we next explore ways to augment the basic state-space model.

3.3 The augmented state-space model with commodity prices

One advantage of the state-space approach, compared to the principal factor approach, is that we can incorporate explanatory variables into the model *directly*. This reduces the number of restrictions that needs to be put on the state-space model. Based on the insights about the common factors derived above, we make three modifications to the state-space model:

- First, we incorporate the existing cointegration relationship between the second common factor and the IMF's real non-energy commodity prices index (p^{NE}) and the real price of oil (p^{oil}) in the equation for the second principal component.
- Second, we add a fiscal variable to the Canadian specific component. As fiscal variable, we use the relative debt-to-GDP ratio of Canada versus the United States (i.e. debt-to-GDP for Canada, divided by debt-to-GDP for the United States).[11] Given the importance Japanese debt dynamics, we could also add the respective Japanese fiscal variable to Japanese specific component. However, the evidence for cointegration between the domestic Japanese component and the relative debt-to-GDP ratio is slightly weaker than for Canada,[12] which is why we report estimates without Japanese fiscal variable (the results for both models are very similar, though).

[11] Note that the unit root test on this variable cannot clearly reject the possibility that the series is I(2), depending on the number of lags included. However, given that economic intuition indicates each of the series should be bounded, we assume that the related debt-to-GDP ratio for Canada and the United States is I(1).

[12] Over the entire sample, cointegration of both series is rejected at the 10 percent level; however, evidence of cointegration for the Japanese domestic component and Japan's relative debt-to-GDP ratio is found when excluding the first three years from the sample.

- Third, the free trade agreement between Canada and the United States, as well as the liberalization of Canadian energy policy in the 1990s – including deregulation of the North American natural gas market – affected the relationship between the Canadian dollar and energy commodity prices. Previous studies have found that these developments changed the way energy commodity prices affect the Canadian dollar (Issa et al., 2006). To capture this structural break, we add a 0/1 dummy variable (D^{93}).[13]

By imposing these restrictions to augment the state-space model, we no longer have to assume ARIMA processes for the equations of the two common factors. Instead, we can estimate the data-generating process of each equation of the model freely. It turns out that each common factor is best represented by a unit root with an AR(1) process.[14]

The augmented state-space model now looks as follow:

$$\begin{aligned} X_t^i &= \gamma_1 C_t^1 + (\gamma_2 + D^{93}\gamma_{ENE}^{CAN})C_t^2 + \nu_t^i && (4)\\ \Delta C_t^1 &= \phi_1 \Delta C_{t-1}^1 + \eta_t^1 && (5)\\ \Delta C_t^2 &= \phi_2 \Delta C_{t-1}^2 - \lambda_1 (C_{t-1}^2 - \beta_1 p_{t-1}^{NE} - \beta_2 p_{t-1}^{oil}) + \eta_t^2 && (6)\\ D(L)\nu_t^i &= \epsilon_t^i \text{ for all i, except Canada} && (7)\\ \triangle \nu_t^{CAN} &= \rho^{CAN} \triangle \nu_{t-1}^{CAN} - \lambda^{CAN}(v_{t-1}^{CAN} - \beta^{CAN} gdebt_{t-1}^{CAN} -) && (8)\\ & \quad + \epsilon_t^{CAN} && (9) \end{aligned}$$

where p^{oil} and p^{NE} denote the real prices of energy- and non-energy commodities, $gdebt_{t-1}^{CAN}$ denotes the relative debt-to-GDP ratio, $D^{93}$is the dummy variable for energy liberalization in Canada (the structural break variable), and γ_{ENE}^{CAN} denotes the commodity factor for Canada after the 1993 structural break.

Tables 6, 7, and 8 present the estimated coefficients of the augmented state-space model. As can be seen, the signs of the loading factors remain unchanged, and all continue to be significant. The speed of adjustment parameter of the cointegration relationship between the second common factor and commodity prices is very high ($\lambda = -0.22$), and the high t-statistics for λ (t-stat$_\lambda = 4.67$) clearly support the presence of a cointegration relationship between the second

[13] While rising energy commodity prices used to cause a depreciation of the Canadian dollar, the effect has changed in 1993. Since 1993, rising energy commodity price result in an appreciating Canadian currency. See Issa et al. (2006) for details.

[14] Adding a second lag for each component yields insignificant estimates for this variable. The specification of the idiosyncratic movements in the real exchange rate series (ν_t^i) is not the same for all countries. For Canada, Japan, New Zealand and the UK, we can not reject the assumption that the specific components of their real exchange rate follow a unit root process. In fact, the specific component of the real exchange rate of Japan and the UK are best represented by a unit root with an AR(1) process ($\Delta\nu_t^i = D^i \Delta\nu_{t-1}^j + \epsilon_t^j$), whereas the one for New Zealand is best represented by a simple unit root ($\Delta\nu_t^{NZ} = \Delta\nu_{t-1}^{NZ} + \epsilon_t^{NZ}$). For the specific components of Australia and Europe, we can reject the unit root assumption. These two specific components are best explained by AR(1) processes ($\nu_t^j = D^j \nu_{t-1}^j + \epsilon_t^j$).

common factor and energy and non-energy commodity prices.[15] Note lastly, that the second common component is linked equally closely to energy- and non-energy commodities, as both variables are highly significant, and the coefficient estimates also also very close (0.52 and 0.60, respectively).[16]

As regards the country-specific components, they are non-stationary for Canada, Japan, New Zealand and the U.K., but stationary for Australia and the euro area. In line with integrating the relative debt-to-GDP ratio for Canada, note the evidence supporting a cointegration relationship between the Canada-specific component and the Canadian total government debt-to-GDP ratio. This supports our assumption that Canada's exchange rate might be affected by differences in the relative fiscal performance of the U.S. and the Canadian economy. Future work will help us better understand the factors that are driving the country-specific components of the other regions.

Figure 10 shows the estimates of the two common factors that come from the enhanced state-space model. Note that the behavior of the two common factors is not significantly different in the augmented state-space model, compared to the basic specification. This is a further indication that our results are robust.

4 Interpreting the country-specific components

Having derived our final state space specification, we now decompose individual real exchange rate movements along the lines of section 3.2 into three components: 'U.S. shocks', 'commodity price movements', and domestic movements. This allows to determine the relative importance of U.S. shocks and commodity prices, relative to country-specific economic developments. Figures 11-18 show the three stochastic components for all countries. The vertical axis is in percentage points and the different components are centered on zero.[17] We briefly discuss the country-specific components, and also check whether they match key economic events in the different countries.

4.1 Australia

Figure 11 shows that over the entire sample, movements of the real Australian exchange rate relative to the U.S. dollar are clearly dominated by the two common components. In addition, we can reject the hypothesis of no cointegration between the real Australia-U.S. exchange rate and the two principal factors. The U.S. factor plays the predominant role, accounting for about 75 percent of the total appreciation of the Australian dollar relative to the U.S. dollar, over the 2002-2007 period. This could reflect that although the direct trade links

[15] We are not aware of a test for cointegration using a state-space model. However, the Boswijk (1994) test for the presence of cointegration in an error-correction model confirms cointegration between the three series.

[16] We estimate the model for two sample periods, 1980Q1-2007Q2 (post-Volcker) and an extended sample 1972Q3-2007Q2 (post-Bretton Woods). Our findings are robust across samples.

[17] Note that the main information is contained in the change in the level over a given period of time, not in the absolute level, nor the sign of the stochastic components.

with the United States are small, the country is exposed to U.S. shocks through third parties (notably through its trade with Japan and emerging Asia), and through financial linkages. The rise in world commodity prices explains the remaining 25 percent. Domestic shocks seem of minor importance.

4.2 Canada

The country-specific factor explains a larger share of the variance of the bilateral U.S. dollar exchange rate for Canada than it does for Australia. As mentioned before, differences in the fiscal position between Canada and the United States seem to play an important role, as we cannot reject the hypothesis that the Canada-specific factor is cointegrated with the Canadian fiscal position. As figure 14 show, a substantial part of the appreciation of the bilateral Canadian-U.S. exchange rate is likely to be related to the fall in the Canadian debt/GDP ratio, relative to the United States. Hence, the Canada-specific factor is likely to reflect the severe deterioration in the Canadian fiscal position over the 1980s and early 1990s, and the sharp turnaround shown since the late 1990s.

As regards the most recent period of appreciation of the Canadian dollar between 2002 to 2007, the two common factors together explain about 60 percent of the appreciation in the Canada-U.S. exchange rate. Of this rise, the U.S. factor explains about 56 percent and commodities explaining about 44 percent (see Figure 12). The loading factor for the commodity component are shown in table 9. Note that our results point to substantially lower effect of commodity price movements on the Canadian dollar than previous studies (Amano and van Norden, 1995; Bayoumi and Mühleisen, 2006; Issa et al., 2007).

4.3 Europe and the United Kingdom

Like Australia, the two common factors explain almost all of the variation in the real Euro-U.S. dollar exchange rate (in fact, we are able to reject the hypothesis of no cointegration between the real euro-U.S. dollar exchange rate and the two common factors). According to Figure 15, between 2002Q1 and 2007Q2, U.S. shocks induced an appreciation in the euro-U.S. dollar exchange rate of around 60 percent. At the same time, Figure 15 shows that the recent increase of commodity prices generated a depreciation of roughly 15 percent of the euro relative to the U.S. dollar. And lastly, note that the country-specific component for the euro area is very small. This could reflect that the euro area – a currency area composed of more than 10 individual countries – has been less prone to idiosyncratic shocks than other countries during our sample period.

For the United Kingdom, Figure 16 shows that domestic factors played an important role for pound-U.S. dollar exchange rate. In particular, note the upward pressure on the pound-U.S. dollar exchange rate in the early 1980s and second, the large drop in the U.K. pound in the early 1990s. This fall in the value of the U.K. pound is likely to reflect the ERM crisis, which forced the United Kingdom to abandon its tight peg to the German Deutschmark. Over the 2002 to 2007 period, our decomposition suggests that U.S. factors led to a 45 percent appreciation of the currency relative to the U.S. dollar, while commodity prices had only a modest downward impact (note that the United Kingdom was a net exporter of oil during our sample, but still a net importer of commodities as a whole).

4.4 Japan

The country-specific factor for Japan shows a very distinct pattern (Figure 17). Domestic developments have resulted in upward pressure on the Yen until the mid-1995, and substantial downward pressure since the start of the Japanese deflation and the associated economic difficulties. Between 2002 and the end of our sample, the main factor influencing the bilateral exchange rate for Yen and the U.S. dollar is country-specific. In addition, commodity prices also exert some downward pressure on the Yen-U.S. dollar exchange rate (about 10 percent), reflecting Japan's dependency on imports for both energy- and non-energy commodities. On the other hand, there is significant upward pressure on the yen coming from U.S. macroeconomic developments over the 2002 to 2007 period (approximately 35 percent), which offsets much of the downward pressure coming from the other two components.

4.5 New Zealand

The case of New Zealand is intriguing. New Zealand is a large commodity exporter, but its exports are largely concentrated in food and agricultural products. As a result, the rise in global commodity prices – which until recently has been most prominent in energy and industrial materials – plays a less important role in explaining the appreciation of New Zealand's real exchange rate against the U.S. dollar than for other commodity-exporting countries in our sample. Between 2002 and 2007, the U.S. factor accounts for the bulk of the appreciation of the currency. This large sensitivity to U.S. shocks reflects the high degree of openness of New Zealand's economy.

5 Conclusion

Understanding movements in exchange rates is a notoriously difficult task. The problem has been a particularly difficult one since 2002. Following the sharp rise in world commodity prices, the currencies of commodity exporters like Australia, Canada and New Zealand have performed very strongly against the U.S. dollar. On the other hand, we have also seem a broad-based depreciation of the U.S. dollar against other important commodity importing regions like Europe and the United Kingdom. The strong performance of currencies of commodity importing countries could not be explained by models linking commodity prices to exchange rates.

To reconcile these developments we studied a panel of six bilateral U.S. dollar exchange rates. We use two statistical approaches: principal factor analysis and a state-space model. Each approach identified two common factors. The first common factor is positively correlated with movements in all the U.S. bilateral exchange rates in the panel. This suggests that this factor is driven by U.S. shocks (the 'U.S. factor'). The second common factor is positively related to exchange rates of commodity exporters, and negatively related to commodity importers. It is also strongly cointegrated with the real prices of energy and non-energy commodities (hence its designation as the 'commodity factor'). These results were derived by moving from a minimum set of restricting to more restrictive models, which allow statistical interference, and our key findings are very robust to the estimation approach and to the sample period.

Our analysis suggests a strong role for U.S. factors in explaining the pattern of exchange rate developments over the 2002 to 2007 period. A much smaller, albeit still significant, role is found for commodity prices. In the case of Canada, we also found an important role for the substantial improvement in the (relative) fiscal situation in explaining the strength of the Canadian dollar, and domestic economic developments also seem to play an important role in explaining the weakness of the yen.

Several extensions of this work are possible. While we provide strong evidence that the second principal component is driven by movements in the energy and non-energy commodity prices, further research is needed to better understand the driving forces behind the common component driven by U.S. shocks. We are working on identifying the types of U.S. shocks that explain the 'U.S. factor', i.e. the currency movements of the U.S. dollar relative to the six currencies considered in this paper. We are exploring two avenues: first, we are working to extend further the state-space model to explicitly incorporate key macro economic variables, and to test for their statistical significance. Second, an alternative approach is to estimate a structural VAR, where the shocks are identified using sign restrictions (derived from the properties of a global DSGE model). And lastly, we need to explore possible economic explanations for the behaviour of the country-specific factors in more detail.

A Dynamic principal factor analysis

A drawback of the static factor model exploited in section is that it does not exploit the time series structure in the data, as the approach focuses exclusively on cross section relationships. Dynamic factor models, as discussed in Lütkepohl, H. 2005 (2005) and Forni and Lippi (2001), explicitly also accounts for variation across time. As mentioned in section 2.2, the classical (static) principal factor model is given by

$$X - \mu = LF + \epsilon$$

The classical factor model captures variation across countries. If X consists of time series variables, however, the factors might be autocorrelated. To exploit this additional dimension, a dynamic principal factor model can be used. It can be thought of as capturing co-movement not only across countries, but also across time.

A dynamic factor model is given by

$$\begin{aligned} X - \mu &= LF + \epsilon & (10) \\ f_t &= A_1 f_{t-1} + A_2 f_{t-2} + ...A_p f_{t-p} + \nu_t & (11) \\ \epsilon_t &= C_1 \epsilon_{t-1} + C_2 \epsilon_{t-2} + ...C_q \epsilon_{t-q} + \xi_t & (12) \end{aligned}$$

where ν_t and ξ_t are white noise processes. To capture the AR(1) process, we estimate a dynamic principal factor model with one lag (additional lags are add more noise, but do not change our results). The differences between the static and the dynamic factor model are very small, as shown in figures 19 and 20. This is further evidence that our estimates are robust to the estimation method chosen.

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Table 1: Real Bilateral Exchange Rates: Percentage Change 2002Q1 to 2007Q1

	AU	CA	EU	JA	UK	US	NZ
AU	-	13	15	90	22	70	0
CA	-12	-	1	68	7	50	-12
EU	-13	-1	-	66	6	48	-13
JA	-47	-40	-40	-	-36	-11	-48
UK	-18	-7	-6	56	-	39	-18
US	-41	-33	-32	12	-28	-	-41
NZ	0	14	15	91	22	70	-

Table 2: Augmented Dickey-Fuller Unit-Toot Tests, sample period 1972q2 to 2007q1

Log level of the U.S. real bilateral exchange rate	No Trend	Trend
Australia (AU)	-2.40	-2.11
Canada (CA)	-1.70	-2.11
Euro (EU)	-1.88	-2.39
Japan (JA)	-1.66	-2.42
United-Kingdom (UK)	-1.52	-3.49
New Zealand (NZ)	-3.33	-3.53
Critical Value (5 percent)	-2.89	-3.44

Table 3: Principal Factor Analysis: Loading Factors

Country	Factor 1	Factor 2
AU	0.61	0.45
CA	0.43	0.37
EU	0.79	-0.34
JA	0.52	-0.25
NZ	0.74	0.21
UK	0.74	-0.26

Table 4: State Space Loading Factors (normalized data)

Country	Component 1	T-stat	Component 2	T-stat
AU	0.66	10.06	0.48	6.57
CA	0.44	5.52	0.29	3.06
EU	0.70	12.92	-0.53	-8.84
JA	0.46	6.13	-0.33	-3.78
NZ	0.71	11.37	0.13	1.75
UK	0.63	10.11	-0.35	-4.72

Table 5: Saikonnen cointegration Tests: second common component

		Factor Model	State Space Model
Test Statistic		-4.21	-4.00
Critical Values	1 percent	-4.43	-4.43
	5 percent	-3.82	-3.82
	10 percent	-3.51	-3.51

Table 6: Estimation of the Structural State Space Table A

Parameter	Coefficient	T-Stat
γ_1^{AU}	0.57	10.76
γ_1^{CAN}	0.39	6.07
γ_1^{EU}	0.80	16.47
γ_1^{JA}	0.54	6.88
γ_1^{NZ}	0.66	10.39
γ_1^{UK}	0.70	10.78
γ_2^{AU}	0.60	12.27
γ_2^{CAN}	0.16	2.24
γ_2^{EU}	-0.32	-6.73
γ_2^{JA}	-0.20	-2.72
γ_2^{NZ}	0.22	3.45
γ_2^{UK}	-0.21	-3.31
γ_{ENE}^{CAN}	0.28	2.62

Table 7: Estimation of the Structural State Space Table B

Cointegration Parameters	Coefficient	T-Stat
λ	0.21	4.54
β_1	0.53	4.87
β_2	0.60	3.36
λ^{CAN}	0.16	4.23
β^{CAN}	0.48	6.98

Table 8: Estimation of the Structural State Space Table C

AR 1 Coefficient	Coefficient	T-Stat
ϕ_1	0.35	3.74
ϕ_2	0.28	2.91
ρ^{CAN}	0.22	2.26
v^{JAP}	0.28	2.99
v^{UK}	0.25	2.61
v^{AU}	0.81	5.63
v^{EU}	0.56	3.05

Table 9: Loading factor for the commodity common component for Canada

Period	Loading factor
1980-1933	0.16
1993-2007	0.44

Figure 1: Real U.S. Dollar Bilateral Exchange Rates

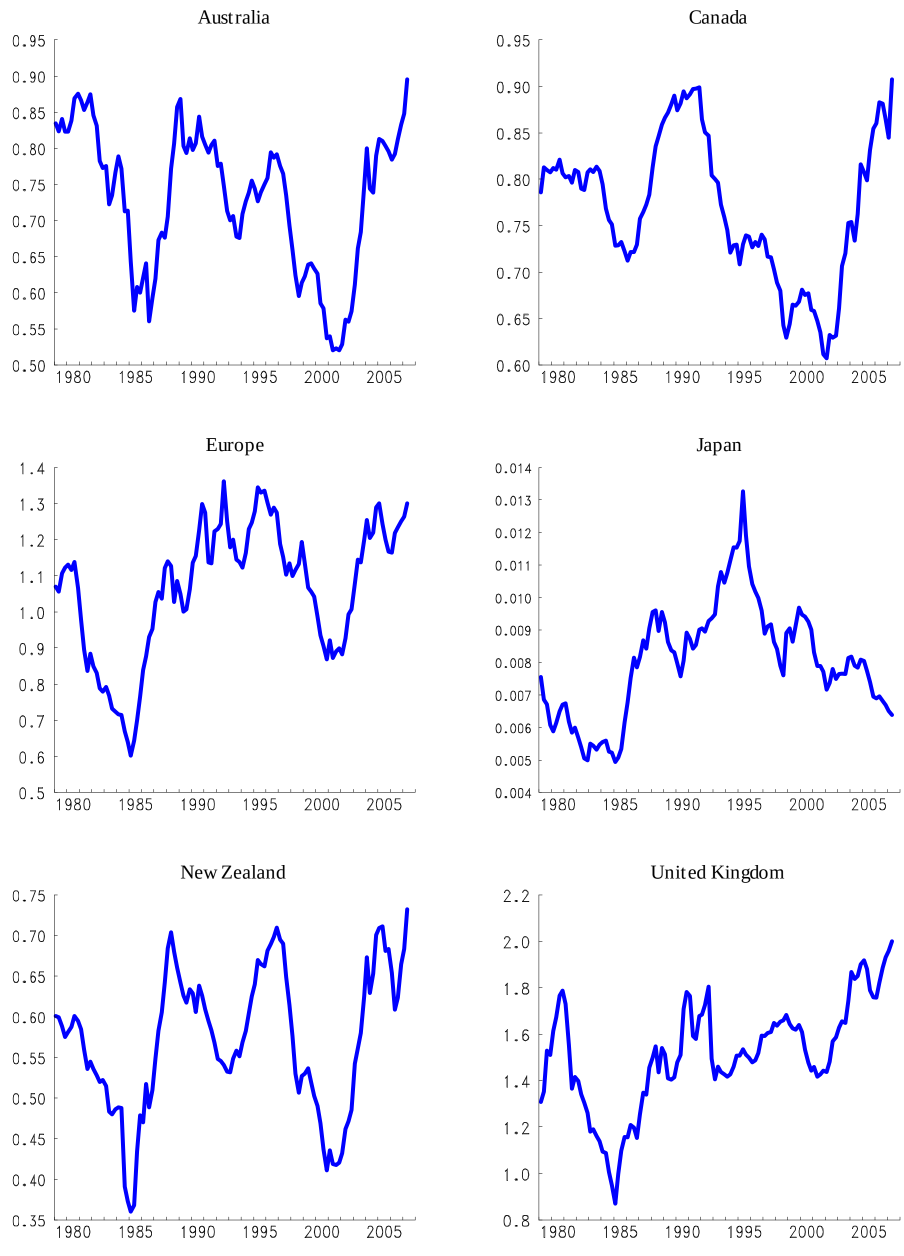

Figure 2: Screeplot (static principal factor analysis)

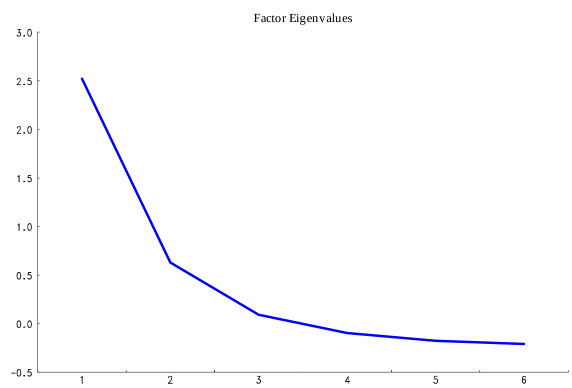

Figure 3: First Component

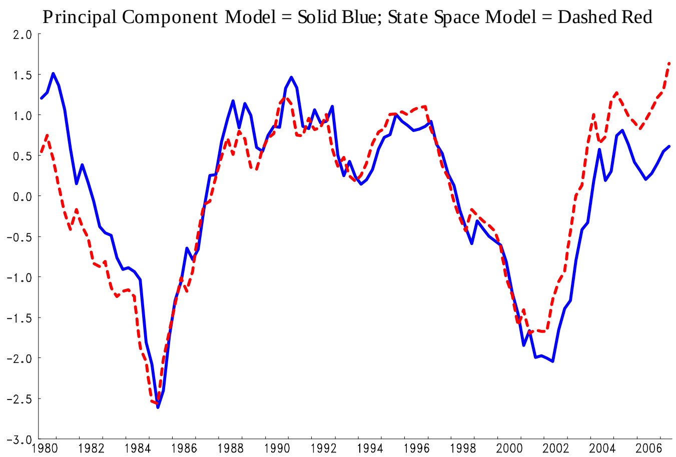

Figure 4: Second Component

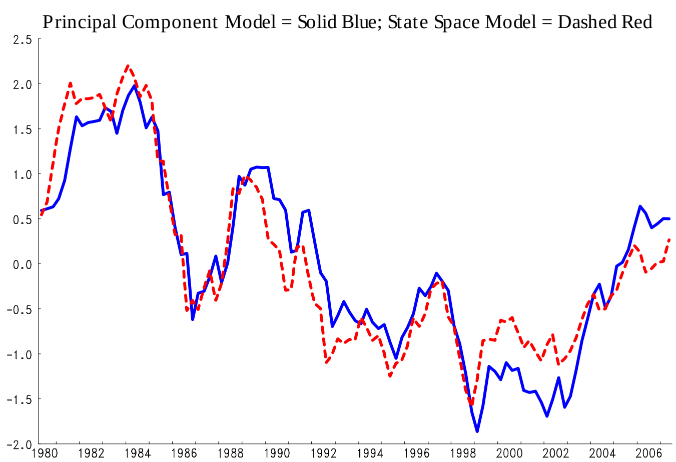

Figure 5: Loading Factor 2 vs. Net Commodity Imports relative to the US

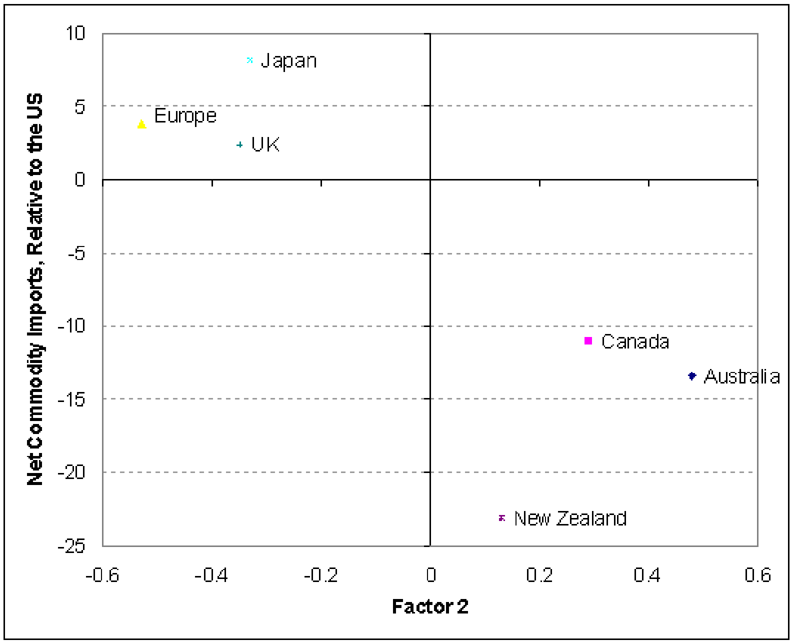

Figure 6: Principal Factor 2 and Non Energy Commodities (Log-level)

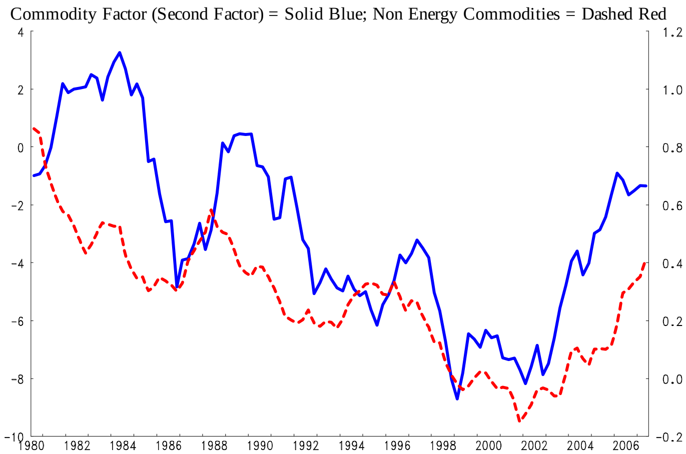

Figure 7: Principal Factor 2 and Oil (Log-level)

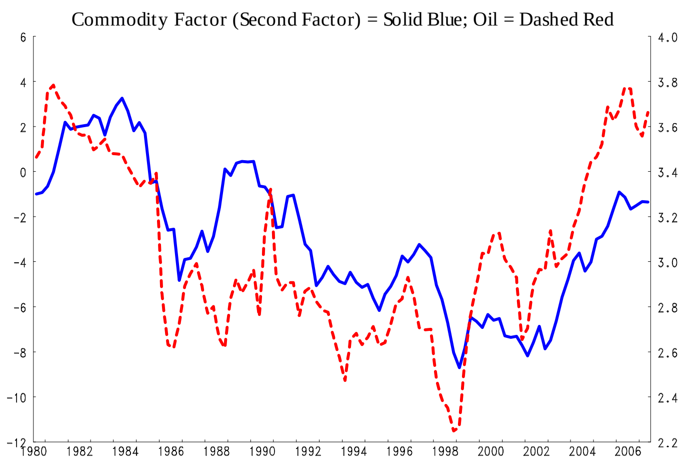

Figure 8: Level and Trend of PF2

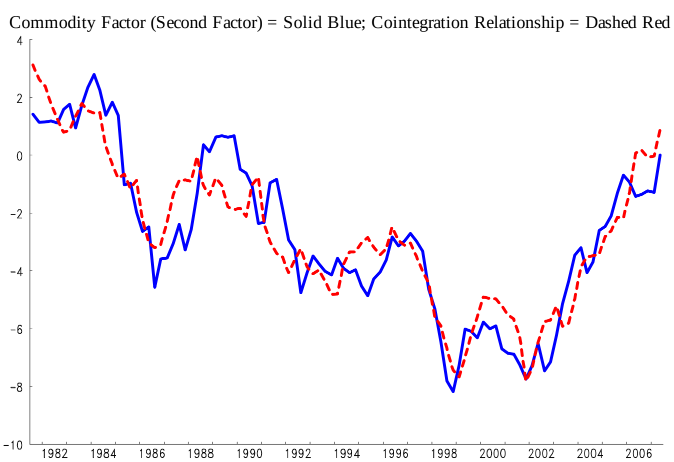

Figure 9: Country-specific component (basic state-space model)

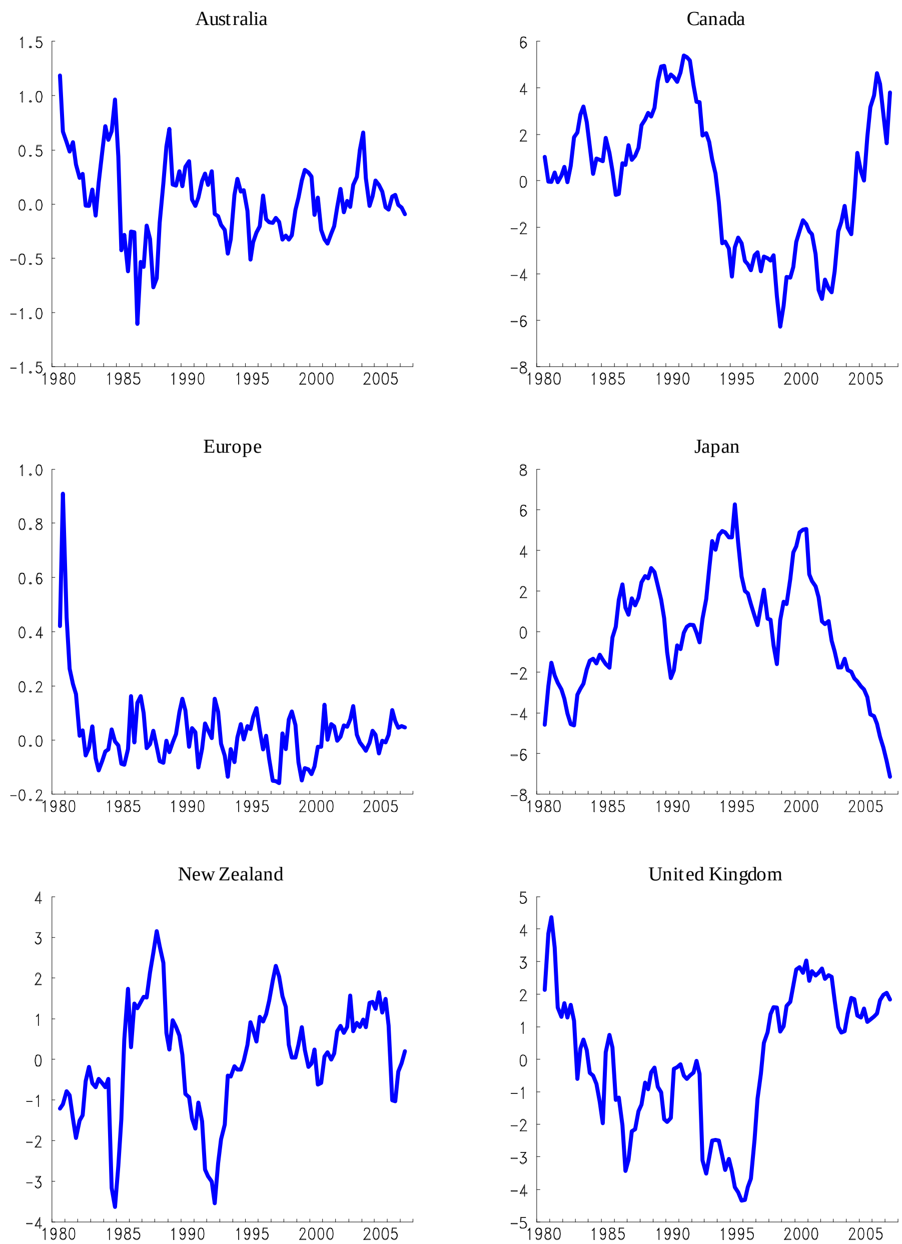

Figure 10: Enhanced State-Space Model

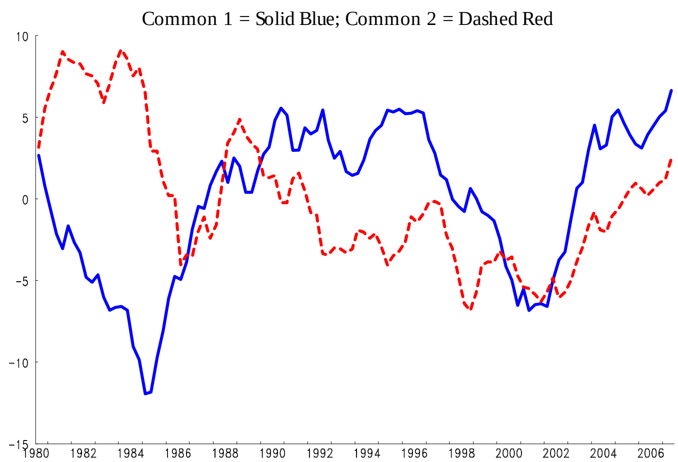

Figure 11: Australia Exchange Rate Stochastic Components

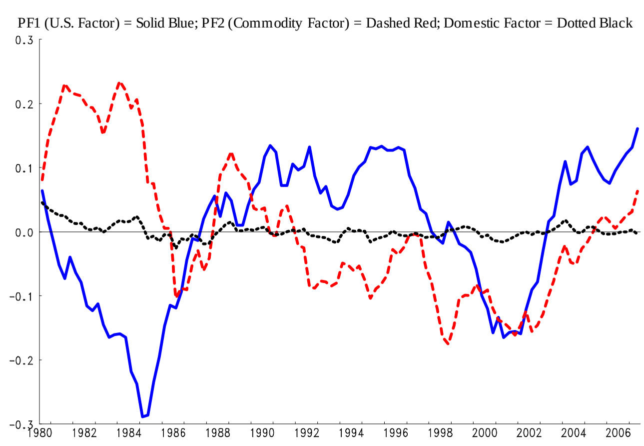

Figure 12: Canada Exchange Rate Stochastic Components

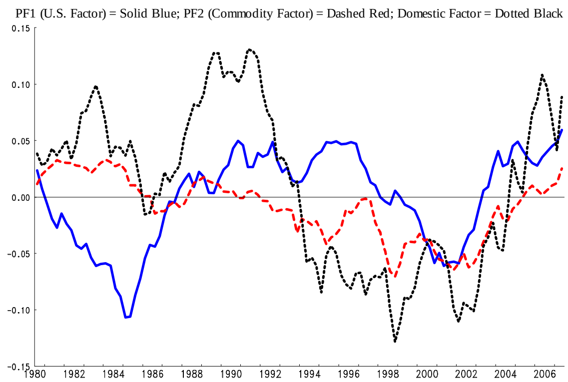

Figure 13: The country-specific component for Canada and the (inverted) relative debt/GDP ratio for Canada and the United States (right axis)

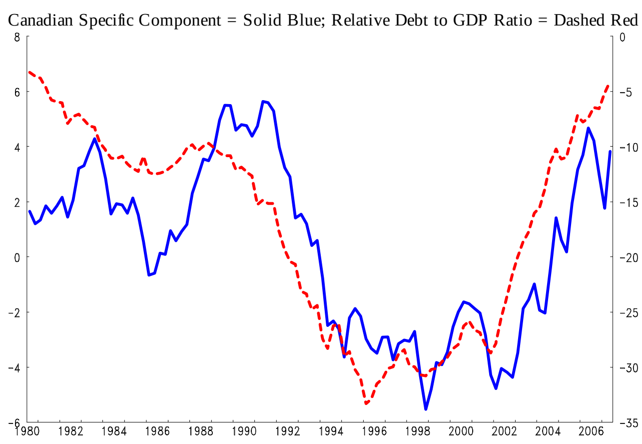

Figure 14:

Figure 15: Euro Area Exchange Rate Stochastic Components

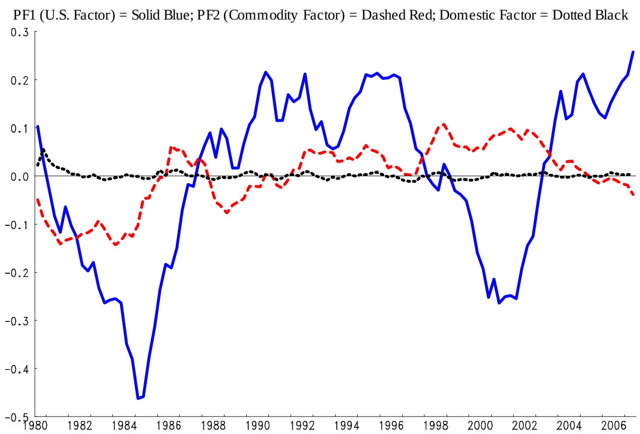

Figure 16: U.K. Exchange Rate Stochastic Components

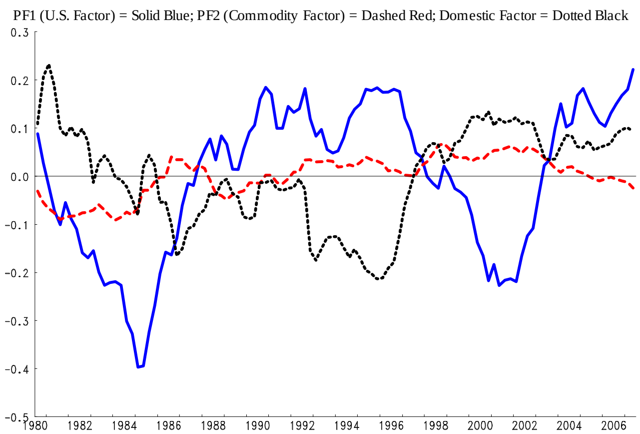

Figure 17: Japanese Exchange Rate Stochastic Components

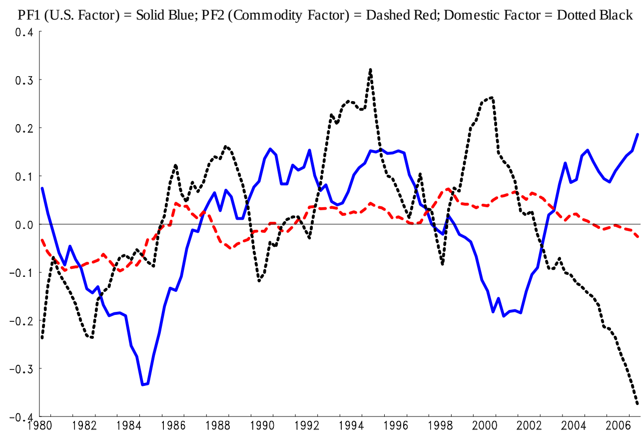

Figure 18: New Zealand Exchange Rate Stochastic Components

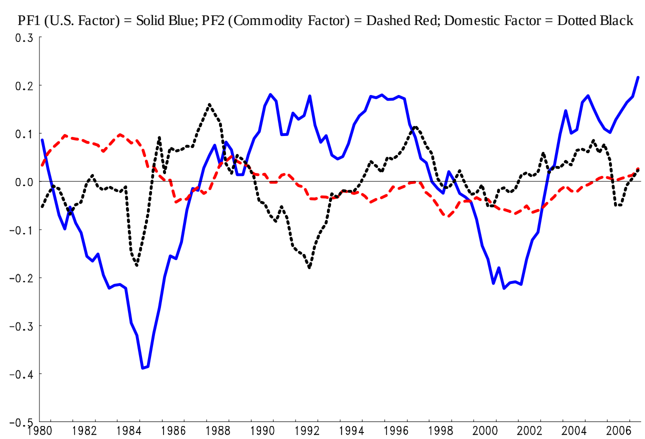

Figure 19: Principal factor 1: Static vs. dynamic model

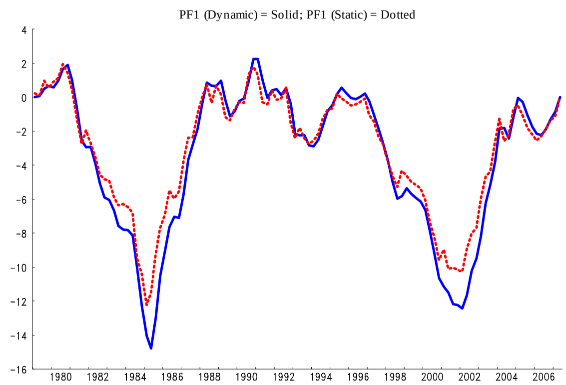

Figure 20: Principal factor 2: Static vs. dynamic model