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THREE ESSAYS ON EXCHANGE RATE AND MONETARY POLICY

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ABSTRACT OF DISSERTATION

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A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Business and Economics
at the University of Kentucky

By
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There are four chapters in my dissertation. Chapter one gives a brief introduction of the three essays.

Chapter two empirically analyzes the interaction among conventional monetary policy, foreign exchange intervention and the exchange rate in a unifying model for Japan. I have several findings. First, the results lend support to the "leaning-against-the-wind" hypothesis. Second, conventional monetary policy has as great influence on the exchange rate as foreign exchange intervention in Japan. Third, intervention in Japan is ineffective or may be counter-effective, so escaping liquidity trap by intervention alone may not be a feasible way.

Chapter three empirically identifies the sources of exchange rate movements of Japan vis-à-vis the US, and investigates the role of the exchange rate in the macro economy adjustment. It finds that real shocks dominate nominal shocks in explaining the exchange rate movements, with relative real demand shocks as the major contributor. And the exchange rate market does not create many shocks. The overall result supports that the bilateral exchange rate in Japan is a shock-absorber rather than a source of shock.

Chapter four provides cross-country and time-series evidence on the extent of exchange rate pass-through at different stages of distribution - import prices, producer prices and consumer prices - for eight major industrial countries: United States, Japan, Canada, Italy, UK, Finland, Sweden and Spain. I find exchange rate pass-through incomplete in many horizons, though complete pass-through is observed occasionally. The degree of pass-through declines and time needed for complete pass-through lengthens along the distribution chain. Furthermore, I find that a greater pass-through coefficient is associated with an economy that is smaller in size with higher import shares, more persistent and less volatile exchange rate shocks, more volatile monetary shocks, higher inflation rate, and less volatile GDP.

KEYWORDS: Exchange Rate, Vector Autoregression, Foreign Exchange Intervention, Pass-Through, Sign Restrictions

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THREE ESSAYS ON EXCHANGE RATE AND MONETARY POLICY

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RULES FOR THE USE OF DISSERTATIONS

DISSERTATION

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To my parents, my husband and my son

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Chapter One
Introduction

My dissertation contains three independent essays addressing several key issues on exchange rate and monetary policy. The first essay examines the interrelationship among the exchange rate, monetary policy and foreign exchange intervention. The second essay investigates the sources of exchange rate movements and the role of exchange rate in macroeconomics adjustment. The third essay explores the dynamics of exchange rate pass-through to the import price, PPI and CPI, and the factors affecting the exchange rate pass-through. The first two essays deal with Japan while the third essay studies eight major industrial countries. In the following, I will provide a brief introduction to the three chapters.

Numerous past literatures analyze the relationship between conventional monetary policy and exchange rate, or foreign exchange intervention and exchange rate, or monetary policy and foreign exchange intervention. Rarely do they study the three together in a unifying model. To the best of my knowledge, Kim (2003) is the first and only work examining the interaction among the three, but he only studies the US. Given that Japan is the most active participant in foreign exchange market and Japan's monetary policy pays a lot attention to the exchange rate movement, coupled with the opportunity that the intervention data is made public in the past two years, I think Japan will be a special interesting subject for this topic.

A structural Vector Autoregression (VAR) model of eight variables is estimated with non-recursive contemporaneous restrictions on monthly data over 1991:01 to 2004:07. The empirical results provide strong evidence for the "leaning-against-the-wind" hypothesis and, somewhat less strong evidence for the "signaling" hypothesis as a model of central bank intervention in Japan. The results also suggest that, in Japan, conventional monetary policy has as great influence on the exchange rate as foreign exchange intervention. The dynamic response of the exchange rate to monetary policy supports the "overshooting" hypothesis. My findings also indicate that intervention in Japan seems ineffective or even counter-effective. This suggests that trying to escape the liquidity trap by foreign exchange market intervention alone may not be a sensible option.

In the second essay, I investigate the sources of movements of the yen-dollar exchange rate to explore the role of exchange rate in Japan and address the question whether the exchange rate is a shock-absorber or a source of shock.

I find that, in marked contrast to previous studies, exchange rate movements are well explained by economic fundamentals in Japan. Real shocks dominate nominal shocks in explaining the exchange rate movements, with relative real demand shocks as the major contributor. The estimated impulse response functions indicate that the real exchange rate depreciates in response to a positive oil price shock and productivity shock and appreciates to a positive demand shock. In these cases, exchange rate movements tend to alleviate the effects of the shocks on output. The results suggest that the exchange rate is more likely to be a shock absorber than a source of shock. In addition, I find that the exchange rate shocks account for around 35 percent of output volatility, which cast doubt on the "exchange rate disconnect puzzle".

The third essay provides cross-country and time-series evidence on the extent of exchange rate pass-through at different stages of distribution – import prices, producer prices and consumer prices – for eight major industrial countries: United States, Japan, Canada, Italy, UK, Finland, Sweden and Spain.

The analysis is based on a VAR model that includes the distribution chain of pricing. Instead of the conventional Choleski decomposition as used in previous studies, I propose to identify the exchange rate shock by the more recent sign restriction approach, which is more consistent with theories, more sensible, and less stringent than the usual approaches that exploit contemporaneous or long-run impacts of shocks. For the first time in the literature, estimates of pass-through based on the sign restriction approach are provided.

I find exchange rate pass-through to be incomplete in many horizons although complete pass-through is occasionally observed. The degree of pass-through declines and the speed of pass-through slows down along the distribution chain. I find that a greater pass-through ratio is associated with an economy that is smaller in size with higher import shares, more persistent and less volatile exchange rate shocks, more volatile monetary shocks, higher inflation rate and less volatile GDP.

Chapter Two

Monetary Policy, Foreign Exchange intervention and the Exchange rate

2.1. Introduction

Numerous past studies addressed various questions on interactions among conventional monetary policy, foreign exchange intervention and exchange rates. Conventional monetary policy is typically described as the interest rate or money setting policy, while foreign exchange intervention is described as another type of monetary policy. The first strand of literature examines the relationship between the two types of monetary policies, as in Lewis(1995), Bonser and Neal(1998), Kaminsky and Lewis(1996), Fatum-Hutchison(2004).

The second strand of literature analyzes the relationship between conventional monetary policy and the exchange rate. In terms of the effects of monetary policy on exchange rate, the often examined issues are: whether the monetary policy is the major source for the fluctuation of the exchange rate; whether uncovered interest rate parity (UIP) holds; does exchange rate "overshooting" arise.[1] Another line of this strand literature studies the reaction function of monetary policy, i.e. whether and how monetary policy reacts to the exchange rate, such as Schnabl and Danne (2005).

The third strand of literature studies the relationship between intervention and the exchange rate, issues addressed include: whether (sterilized) interventions are effective; if effective, through what channels does intervention affect the exchange rate and how intervention reacts to the exchange rate (Kaminsky-Lewis, 1996; Neumann, 1984).

Most of the studies analyzed only one type of the questions. Even some of the work examined a few issues, they examines each issue using different models (for example, Lewis 1995). However, all these issues are related and should be analyzed jointly. For example, intervention may affect money supply when it is not fully sterilized; even it is sterilized, intervention may signal future changes in monetary policy stance. Meanwhile, conventional monetary policy may affect interventions since it influences the exchange rates, with which interventions interact. The two types of policy actions together can generate the observed comovements of the exchange rate. Furthermore, measuring the effects of monetary policy on

[1] UIP is one of the building blocks of the "overshooting" hypothesis. If domestic interest rate falls relative to foreign interest, UIP requires that the domestic currency be expected to appreciate. Liquidity effect requires a money expansion. By long-run purchasing power parity, domestic currency must ultimately settle at a depreciated value after the monetary expansion. So appreciation to a depreciated long-run value implies an initial large depreciation that overshoots the long-run value.

aggregate activity has also long been a central issue in quantitative monetary economics, but most studies only incorporate the conventional monetary policy without foreign exchange intervention, which may bias the result.

For the purpose of jointly analyzing all these issues in one framework, this paper develops a structural vector autoregression (VAR) model. The structural VAR model is useful in that it allows conventional monetary policy, foreign exchange intervention and exchange rate shocks in one model, and it can incorporate multi variables to control for the effects of exogenous policy actions. As a consequence, I can examine more accurately the policy effects on aggregate activity. What is more, I can answer many questions mentioned above.

The model draws loosely on the one introduced by Kim (2003). However, he studies the U.S. for the post Bretton-Woods period, while I study Japan. Different economic structure will make the models different, from the selection of the variables to the identification schemes. I think it is of primary importance to study Japan for several reasons. First, Japan has long been the most active participant in the foreign exchange market among the major industrial countries: the total volume of the Bank of Japan (BoJ) intervention exceeds the sum of both the Fed Reserve of the U.S. and the Bundesbank of Germany, and the BoJ is much more likely to intervene unilaterally than either the Fed or the Bundesbank. Second, monetary policy of Japan pays a lot attention to the exchange rate movements (Glick and Hutchison 1994). Third, the Japanese authorities had not released the intervention data to non-officials (even for academic research) until July 2001. Previous studies of Japanese intervention have relied on monthly/quarterly changes in foreign exchange reserves (Glick and Hutchison 1994) or go to newspaper or wire service to create proxy. As Neely (2000) points out, changes in foreign exchange reserves may not be a good proxy for official intervention data. Since international reserves are assets that can be used directly for settlement of international debts and payments to foreign countries, reserves will change not only when central banks conduct foreign exchange intervention operations but also for other reasons. The Ministry of Finance (MoF) now discloses the day, the amount and the currency of intervention with a 1-3 month delay, which provides a very good opportunity for research. Fourth, Japan has experienced slow growth, recession and sustained deflation over the course of the 1990s. With the decline in economic performance, short-term interest rates were reduced gradually and the call money rate reached the zero minimum point by early 1999. Study the interaction among the two types of policies and the exchange rate can provide some policy implications about how to stimulate the economy out of recent recession more rapidly.

The next section provides a literature review. Section 2.3 describes the model. Section 2.4 presents the empirical results. Section 2.5 examines the robustness of the results. Section 2.6 provides some policy implications. Section 2.7 concludes with the summary of the results.

2.2. Review of the Literature

Many past studies examined the relationship among conventional monetary policy, foreign exchange intervention and the exchange rate. In terms of the interaction between the two policy actions, the most frequently examined issues are the "signaling" and the "leaning-against-the-wind" hypotheses. Under the "signaling" scenario, a sterilized purchase (sale) of the yen reflects a desire for a stronger (weaker) yen currency, and this desire eventually leads to a tighter (looser) monetary policy. So intervention signals the future monetary direction. Sometimes, monetary policy may cause the exchange rate to appreciate or depreciate too much, and interventions are conducted to moderate or even reverse the trend of exchange rate movements. This is called "leaning-against-the-wind" hypothesis.

Bonser-Neal, Roley and Sellon (1998) regresses the weekly change in the Federal funds rate target on the cumulative value of deutsche mark and yen intervention during the two weeks before the week of the target change, and the result suggests that interventions by the U.S. monetary authorities on average help predict future changes in the Federal funds rate target. To test whether the intervention reacts to changes in the Federal funds rate target, they regress the cumulative amount of intervention during the two weeks after the change in the target Federal funds rate target on the change in the target Federal funds rate and on lagged intervention. The result indicates that a rise in the Federal funds rate target is associated with a future decrease in the dollar purchase, which also supports the "leaning-against-the-wind" policy actions. However, they don't include the exchange rate in the regression, so the exchange rate falls in the error term. While the exchange rate movements tend to affect monetary policy and intervention either directly or indirectly, the error term will be correlated with the independent variable (foreign exchange intervention or Federal funds rate target), thus the results are biased.

Using Markov-switching model, Kaminsky and Lewis (1996) also find evidence for the "signaling" and "leaning-against-the-wind" policies. Importantly, they find that while intervention signals future monetary policy changes, the predicted changes in monetary policy are typically in the opposite direction of that suggested by the signaling story. For example, dollar sales in the foreign exchange market are frequently followed by the contractionary monetary policy in the U.S.

Lewis (1995) estimates bivariate VARs using monetary policy variables (either M1, the monetary base, nonborrowed reserves, or the Federal funds rate) and the foreign exchange intervention. She finds that lagged intervention is significantly related to future changes in weekly or biweekly Federal funds rates and biweekly M1 and monetary base. But in some cases the coefficients are of the opposite signs from the "signaling" hypothesis. These same data also provides some support for the "leaning-against-the-wind" hypothesis.

To summarize, the above studies all find support for the "signaling" and the "leaning-against-the-wind" hypotheses for the U.S. However, all of the studies mentioned above included only monetary policy variables and interventions. While the two types of policies will respond to the common economic situation, it is possible that there is no relationship between them as implied by the "signaling" or "leaning-against-the-wind" hypotheses. So the results may be biased due to the omission of important macro variables that can characterize the economic condition.

In terms of the effects of monetary policy on the exchange rate, the literature focuses on the following questions: 1) Does monetary policy explain a large share of exchange rate variance? 2) Does the exchange rate overshoot, or more specifically, does the exchange rate peak immediately after a monetary policy shock? 3) Is the dynamic response of the exchange rate roughly consistent with UIP? Eichenbaum and Evans (1995) use three monetary policy indicators and estimate five- and seven-variable VARs for five exchange rates. Their results report that monetary policy usually accounts for over 20% of the variance of the real and nominal exchange rates. Exchange rates do overshoot, but the overshooting systematically occurs after two years, which is termed as "delayed overshooting". Also they find that the estimated response paths of the exchange rates depart form UIP in that a fall in domestic interest rate is offset by a depreciation of domestic currency. However, they assume a recursive Wold-chain ordering of "the U.S industrial production (Y), the U.S consumer price level (P), the foreign industrial production (Y*), the foreign interest rate (i*), the ratio of nonborrowed to total reserve (NBRX), the U.S. 3-month treasury bill rate (i), the exchange rate (s)".[2] This ordering implies 6 assumptions: Y, P, Y*, and i* do not respond to the U.S. policy shocks within the month that they occur, and the policy does not respond to the shocks to i and s within the month. However, at least 2 of the 6 identifying restrictions are questionable: 1) It is unlikely that surprising movements in the exchange rate and domestic interest rates will be ignored by the Fed since the data is available up to the minute when their policy decisions are taken. 2) The U.S. is the largest economy and has great influence on the other countries; it is hard to imagine why foreign short-term interest rates do not respond to the U.S. policy. By searching all possible identification allowing simultaneity among monetary variables and the exchange rates, and making inference from the point estimate, Faust and Rogers (1999) find that the peak of exchange rate response to policy shocks may come nearly immediately after the shock, which is consistent with the overshooting model. However, they find that a monetary policy seems to generate a large UIP deviation[3]. While UIP is a building block of Dornbusch's overshooting model, so their overshooting apparently cannot be explained by Dornbusch's overshooting. They also find that monetary policies do account for some share of exchange rate forecast error variance (2 to 30 percent). Kim and Roubini (2000) use a "structural VAR" approach with non-recursive contemporaneous restrictions to study non-U.S. G-7 countries. The shape of the response is roughly consistent with what the UIP implies: i.e. a monetary contraction is associated with an initial impact appreciation followed by a subsequent persistent and significant depreciation. The UIP deviation or forward premium is quite noisy for the short-run and not significant from zero over the whole horizon. They find that monetary policy shocks explain a very large proportion of the exchange rate fluctuation in the short run for the non-U.S G-7 countries.

This strand of literature either assumes Wold-chain recursive ordering or fails to incorporate both types of monetary policies. First, there is no clean consensus about the ordering, and the relationship estimated of the variables depends heavily on the ordering. Again, not incorporating both types of monetary policies will introduce bias in the measurement, as the two policies are intervening with each other and both are related to the exchange rates.

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[2] The ratio of nonborrowed to total reserve is the indicator of monetary policy stance in this model specification.

[3] UIP deviation is the forward premium. If UIP holds, we expect the forward premium to be zero. However, in Faust and Rogers (1999), they find the premium is consistently significant and large.

In terms of intervention and the exchange rate, the most important question confronting researchers is: whether (sterilized) intervention is successful in influencing exchange rate movements. Various studies on Japan's intervention provide mixed support for the hypothesis that intervention influences exchange rate in the desired direction. Most of those works adopt traditional event study[4] or time series event study, while using an explicitly identified structural analysis is the rarest form. For example, Fatum and Hutchison (2003) use traditional event study approach to identify separate intervention "episodes" and analyze the subsequent effect on the yen/dollar exchange rate. They find strong evidence that sterilized intervention systematically affects the exchange rate in the short run. However, choosing an event window is not always innocuous[5]. While longer event windows permit researchers to judge the overall effect of related interventions, they also increase the possibility of omitting important variables that influence the exchange rates. More seriously, monetary authorities might intervene until the exchange rate moves in the desired direction. Even if intervention has no effect on exchange rates, the intervention appears to be successful if the authority keeps intervening until it observes the desired outcome. Another paper of Fatum and Hutchison (2004) analyze the most recent five-year BoJ intervention data. The study finds that intervention was effective during 1999 to 2002 sub-sample, while intervention had no significant impact on the exchange rate during the 2003 sub-sample, and the intervention was counterproductive for the first quarter of 2004.

Ramaswany and Samiei (2000) and Ito (2003) are examples of time series event study. Ramaswany and Samiei (2000) estimate a forward looking model of the exchange rate to show that foreign exchange interventions have had small but persistent effects on the yen/dollar rate on the whole. Ito (2003) uses GARCH(1,1) specification to analyze the time period from April 1991 through March 2001. He shows that the intervention was more frequent and more predictable during the April 1991 to June 1995 period, but the intervention is systematically associated with exchange rate changes in the opposite direction of what was presumably intended during the sub-sample, for example, a dollar purchase was associated with yen appreciation. Time series event study usually sets up the timing of the data so that intervention occurs before the exchange rate (for example, lagging the intervention term by one period).

[4] An event study looks at the behavior of exchange rate around periods of intervention. However, this does not necessarily mean that intervention causes the exchange rate behavior.

[5] To conduct a traditional event study, one must define the events, a window around the event. Events might be defined as a single intervention or a series of interventions in the same direction within short time.

Given the intervention can affect the exchange rate within minutes, extremely high frequency data are needed, which is hard to obtain.

While most of the work on Japan's intervention use event studies, this paper estimates a structural VAR model adapted from the monetary policy literature to examine the effects of intervention. Though structural VAR model may have its own problem (such as identification, the unusual distribution of intervention), it can circumvent the problems unique to the event studies mentioned above, thus add to the richness of the literature on intervention. Rather than impose a recursive ordering which is highly incredible, I impose the identifying assumptions that are consistent with the economic structure. The specification permits two-way contemporaneous interaction between the intervention and the exchange rate, the intervention and the monetary policy. The inclusion of monetary policy indicator and macro variables might mitigate the problem of omitted variables bias. Moreover, I can find answers to various questions raised in the three strands of literature in one framework.

2.3. The model

The economy is described by a structural form equation:

$$G_0 y_t = \Gamma_0 + \Gamma(L) y_{t-1} + e_t \qquad (1)$$

where G_0 is the contemporaneous coefficient matrix; Γ_0 is an $n \times 1$ matrix of the constants; $\Gamma(L)$ is a matrix polynomial in the lag operator L, y_t is an $n \times 1$ data vector that includes: foreign exchange intervention, call money rate, money demand, industrial production, consumer price index, Federal funds rate, world oil price, exchange rate. e_t is an $n \times 1$ serially uncorrelated structural disturbance vector and $\text{var}(e_t) = \Lambda$, where Λ is a diagonal matrix, so the structural disturbances are assumed to be mutually uncorrelated.

The description of the variables is as follows:[6]

[6] The intervention data is from the website of Japan's Ministry of Finance. The other variables are from the IFS website.

Name	Variable	Description of the data
Foreign exchange intervention	FEI	Monthly foreign exchange intervention against the U.S. dollar by the MoF. Net purchase (sale) of dollar is positive (negative).
Call money rate	CMR	The overnight interbank interest rate of Japan
Money demand	M	M1+quasi-money of Japan.
Federal funds rate	FFR	Federal funds rate of the U.S.
Industrial production	IP	Industrial production index of Japan
Consumer price index	CPI	Consumer price index of Japan
World oil price	WOP	The world oil price index
Exchange rate	E	The period average exchange rate of yen/USD

CMR, M, CPI and IP are well-known variables in monetary business cycle literature, they are essential in identifying monetary policy. Call money rate can be regarded as the best indicator of monetary policy in Japan, while monetary base may primarily reflect changes in money demand by private banks, firms and households (Miyao 2002).[7] IP is chosen as a commonly used measure of real economic activity. FEI is included to identify foreign exchange intervention; FFR and WOP are incorporated to isolate "exogenous" monetary policy changes. FFR is included to capture the notion that Japan's monetary policy reacts to the U.S. monetary policy shocks. As Grilli and Roubini(1995) shows, it is important to control the U.S. monetary policy in empirical models for non-U.S. G-7 countries. Also, the exchange rate depends upon the relative monetary policy of the two countries; FFR together with CMR can provide the measure for relative monetary policy. WOP is a proxy for negative and inflationary supply shocks, Kim (1999) shows that Japan's monetary policy is likely to respond to WOP. The exchange rate is defined in the yen price of a U.S. dollar; an increase in E is a depreciation of the yen.

The reduced form VAR equation is:

$$y_t = B_0 + B(L)y_{t-1} + u_t \qquad (2)$$

where B_0 is the matrix of constants, $B(L)$ is a matrix polynomial in lag operator L and $\text{var}(u_t) = \Sigma$.

Then the parameters in the structural form equation and those in the reduced form equation

[7] We implicitly assume call money rate targeting. If the actual policy were near-complete call rate targeting, the M shock would be almost fully accommodated by the BOJ's supply of money, and would not have a large effect on the call rate fluctuation. So the assumption is plausible given the result we find later that the contribution of M shock to the CMR variance decomposition is only 1.5%-2.8% over the 48-month horizon.

are related by:

$$B_0 = G_0^{-1} \Gamma_0 \qquad (3)$$

$$B(L) = G_0^{-1} \Gamma(L) \qquad (4)$$

In addition, the structural disturbances and the reduced form residuals are related by:

$$e_t = G_0 \mathrm{u_t}, \qquad (5)$$

which implies: $\Sigma = G_0^{-1} \Lambda \, G_0^{-1'}$ (6)

The estimates of Λ and G_0 can only be obtained through the sample estimates of Σ. The right-hand side of equation (6) has $n \times (n+1)$ free parameters, while Σ contains $\frac{n \times (n+1)}{2}$ parameters. So by normalizing n diagonal elements of G_0 to 1's, I still need at least $\frac{n \times (n-1)}{2}$ restrictions on G_0 to achieve identification.

Identification:

There are several approaches to recover the parameters in the structural form equation from the estimated parameters in the reduced form equation. One way is to use recursive approach by assuming Wold-chain ordering. However, there is no clean consensus about the ordering, and some ordering may not be justified by the economic structure. For example, many previous literatures usually put the exchange rate after the domestic interest rate to obtain impact effect of interest rate innovations, which implies that monetary policy cannot contemporaneously respond to exchange rate shocks. While this approach makes some sense for the U.S. economy because its economy is large and relatively closed and the monetary policy transmission mechanism is often viewed as operating primarily through the interest rate, situation is different in Japan. As Glick and Hutchison (1994) points out, efforts to influence the exchange rate have had an impact on domestic monetary control. Thus, it is essential to use identification scheme that allows a contemporaneous response of policy variables to the exchange rate shocks. Non-recursive contemporaneous structure is useful in that it allows a variety of possible contemporaneous simultaneity among the two types of policies and exchange rate.

The following are the restrictions on the contemporaneous structural parameters G_0, based on Equations (1). All the zero restrictions are on the contemporaneous structural parameters, and no restrictions are imposed on the lagged structural parameters. In addition, not imposing zero restrictions does not necessarily imply that the coefficients are non-zero.

$$\begin{bmatrix} 1 & g_{12} & 0 & 0 & 0 & 0 & 0 & g_{18} \\ 0 & 1 & g_{23} & 0 & 0 & g_{26} & g_{27} & g_{28} \\ 0 & g_{32} & 1 & g_{34} & g_{35} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & g_{45} & 0 & g_{47} & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & g_{57} & 0 \\ 0 & g_{62} & 0 & 0 & 0 & 1 & g_{67} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ g_{81} & g_{82} & g_{83} & g_{84} & g_{85} & g_{86} & g_{87} & 1 \end{bmatrix} \begin{bmatrix} FEI \\ CMR \\ M \\ CPI \\ IP \\ FFR \\ WOP \\ E \end{bmatrix} = \Gamma(L) \begin{bmatrix} FEI \\ CMR \\ M \\ CPI \\ IP \\ FFR \\ WOP \\ E \end{bmatrix} + \begin{bmatrix} e_{FEI} \\ e_{MP} \\ e_{MD} \\ e_{CPI} \\ e_{IP} \\ e_{FFR} \\ e_{WOP} \\ e_{E} \end{bmatrix} \quad (7)$$

$e_{FEI}, e_{MP}, e_{MD}, e_{CPI}, e_{IP}, e_{FFR}, e_{WOP}, e_E$ are structural disturbances. They are shocks on foreign exchange intervention, monetary policy, money demand, CPI, IP, FFR, world oil price and the exchange rate.

The explanations of the contemporaneous restrictions are as follows:

1. The first row in equation (7) represents foreign exchange intervention reaction function, the monetary authority implements intervention by selling and buying foreign currencies in reactions to current movements of exchange rate and the monetary policy.
2. The second row is monetary policy reaction function. World oil price is included in the monetary policy reaction function to control the systematic responses of monetary policy to the state of economy like inflationary shocks. And I also allow Japan's monetary policy to respond to the U.S. monetary policy contemporaneously by not imposing $g_{26} = 0$[8]. The monetary policy paying attention to the exchange rate movements implies a non-zero g_{28}. Since data on CPI and IP are not available within the same month, monetary authority is assumed not to contemporaneously react to the output and price level.

By examining the institution in Japan, I can impose $g_{21} = 0$. The MoF has responsibility for foreign exchange market policy in Japan, though the BoJ acts as its agent

[8] Kim and Roubini (1999) excludes the contemporaneous effect of FFR in the monetary policy reaction function for non-US G-7 countries even though the data is available within one month, their justification is that the U.S interest rate does not have additional information for non-U.S. monetary authorities after they consider their exchange rate against the U.S dollar. We do not exclude contemporaneous effect of FFR in this case because the U.S. is large enough to influence the world interest rate; what is more, in my system FFR is exogenous to all other variables except for world oil price and CMR, FFR shocks may reflect structural shocks such as the inflation shocks which are not reflected in world oil price. However, we still tried the identification system that restrict contemporaneous effect of FFR to zero, and it produce strange results.

in carrying out market operations by using an account of the government. Financing bills are issued by the MoF to the market to obtain the yen funds that in turn are used to purchase foreign currency denominated assets. The financing bills are issued domestically to obtain the yen funds before the foreign exchange purchase (yen sales), so in a technical sense the intervention is automatically sterilized, implying $g_{21} = 0$.

3. The third row is the money demand function, the demand for real money balances depends on real income and opportunity cost of holding money: the nominal interest rate, CMR.
4. The fourth and fifth rows represent the real sector. CPI is contemporaneously influenced by output but not the money supply, reflecting the sluggish of the real sector; and it responds to world oil price due to "mark-up" principle. In a similar vein, production is assumed to respond to the monetary policy and financial signals only with lags, but responds to the world oil price contemporaneously because oil is one of the main inputs in production.
5. The sixth row is the U.S monetary policy reaction function. It is assumed to react to the world oil price and Japan's monetary policy within the same period,Kim and Roubini (2000) find that Japan's CMR can influence FFR because Japan is a large and open economy.[9]
6. The seventh row simply assumes that world oil price is exogenous to all the other variables contemporaneously.
7. The eighth row is the arbitrage equation describing financial market equilibrium. I assume that all currently available information in the system affects the exchange rate instantaneously.

The model is estimated for the period from 1991:1 to 2004:7 using monthly data. All the variables are in logarithms except interest rate and foreign exchange intervention (multiplied by 0.001) data.

The structural shocks are composed of several blocks. The first three equations are foreign exchange intervention, monetary policy, money demand equations, which describe the money market equilibrium. The next two describe the domestic goods market equilibrium; the sixth and seventh equations represent the exogenous shocks originating from the world economy, the U.S. monetary policy shocks and the oil price shocks. The last is the arbitrage equation describing the exchange rate market.

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[9] We tried the identification scheme with g_{62}=0, we reject the over-identifying restrictions at 5% level of significance.

2.4. Empirical Findings

2.4.1 Contemporaneous Coefficients

The estimation results of the baseline specification are presented below. The number of lags included in the model is set at six as determined by the likelihood ratio test. Multivariate-Q test indicates no significant autocorrelation for the residuals at 24 lags.

$$G_0 = \begin{bmatrix} 1 & -0.286 & 0 & 0 & 0 & 0 & 0 & 9.289^{**} \\ 0 & 1 & -3.755^{*} & 0 & 0 & -0.697^{*} & -0.048 & -6.722^{**} \\ 0 & 0.0002 & 1 & -0.516^{*} & -0.034 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0.046^{**} & 0 & -0.0002 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0.0003 & 0 \\ 0 & 1.906 & 0 & 0 & 0 & 1 & 0.054 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ -0.0004 & 0.093 & -0.127 & 1.921^{*} & 1.039^{**} & -0.183^{**} & 0.108^{**} & 1 \end{bmatrix}$$

"**" denotes significance at the 5% level, "*" at the 10% level. If the model is just identified, there should be 28 zero restrictions, while I put 35 zero restrictions; the model is over-identified by 7 restrictions. The likelihood ratio test suggests that over-identifying restrictions are not rejected at any conventional significance level; the result is $\chi^2(7)$ =8.83 with the p-value 0.265.

The estimated signs of the parameters are consistent with the standard economic theory. g_{12}<0 measures the response of foreign exchange intervention to the monetary policy: an increase in CMR leads to an increase in FEI. As CMR increases, there will be yen appreciation, leading to a purchase of dollars to moderate the exchange rate change. $g_{18} > 0$ shows that yen depreciation leads to dollar sales (or yen purchases) by the Japanese authorities, possibly in an attempt to stem the exchange rate movement. These two coefficients can characterize the Japan's foreign exchange intervention as the "leaning-against-the-wind" type.

g_{23}<0 indicates that increases in the money demand lead to increases in CMR. Yen depreciation leads to an increase in CMR since $g_{28} < 0$. The BoJ increases CMR in response to a rise in FFR and a rise in WOP ($g_{26} < 0$, $g_{27} < 0$) to fight inflationary pressure.

Money demand increases when CPI or IP increases ($g_{34} < 0$, $g_{35} < 0$), and decreases when

CMR increases ($g_{32} > 0$); an output increase will lead to a price decrease ($g_{45} > 0$); CPI will increase and IP will decrease in response to a rise in WOP ($g_{47} < 0$, $g_{57} > 0$).

Foreign exchange intervention (net purchase of dollar) affects the exchange rate positively (yen depreciation) since $g_{81} < 0$, while CMR affects the exchange rate negatively (yen appreciation) since $g_{82} > 0$.

2.4.2 Impulse Responses

Figure 2.1 reports the impulse responses of each variable to positive FEI, CMR and exchange rate shocks over 48 months. The first column shows the responses of the variables to positive FEI shocks, the second to CMR shocks and the third to E shocks. The upper and lower dashed lines are one-standard-error bands.[10]

[Figure 2.1 about here]

Theoretical models predict the macroeconomic variables move in the following ways when monetary policy tightens. First, in a monetary contraction, interest rates rise and monetary aggregates fall initially. An initial rise in interest rates may be reversed in the very short run due to deflationary pressure from a monetary contraction. Second, the price level falls and the output level does not increase. Third, under flexible exchange rate regime, monetary contraction is expected to be followed by an exchange rate appreciation on impact.

However, vast empirical literature on the effects of monetary policy has been plagued by a number of puzzles. They can be summarized as follows:

1. The liquidity puzzle: When monetary policy shocks are identified as innovations in monetary aggregates, such innovations appear to be associated with increases rather than decreases in nominal interest rates. Or when monetary policy shocks are identified as interest rates, money demand rises when facing a positive interest rate shock (for example, Leeper and Gordon,1991).
2. The price puzzle: When monetary policy shocks are identified with innovations in interest rates, the price level increases rather than decreases in response to positive monetary shocks (for example, Sims, 1992).
3. The exchange rate puzzle: A positive innovation in interest rates is associated with the

[10] They were generated from 1000 draws by Monte Carlo Integration using importance sampling following Doan (2004).

currency deprecation on impact (for example, Grilli and Roubini, 1995).

4. Forward discount bias puzzle: If UIP holds, a positive innovation in interest rates should lead to a persistent depreciation of the currency over time after the impact appreciation. However, the empirical evidence suggests that positive interest rate shocks are associated with persistent appreciations of the currency for periods up to two years after the initial interest rate shock. (Eichenbaum and Evans 1995)

Those predictions by theoretical models and the absence of the puzzles can be taken as a supporting evidence for the identifying restrictions imposed on the model. Examining the impulse responses to a positive CMR shock (contractionary monetary policy), I find that the interest rate rise significantly at first, and then reverse in about 20 months. Money demand seems to increase a little bit, but the increase is quite noisy and not statistically significant. The price level decreases significantly over more than 30 months. Output increases a little bit for a brief period and return to the original level very soon; however, it should be observed that the initial increase is not statistically significant. The exchange rate appreciates for the first few months and soon depreciates to the original level. The estimated responses are broadly consistent with theoretical models regarding the effects of monetary contraction. In particular, there is no price puzzle, exchange rate puzzle and forward discount bias puzzle. While I can not say that the model is absent of liquidity puzzle, I do not find obvious evidence for it either. The overall results support the validity of the identifying restrictions.

I will next consider the interactions among conventional monetary policy, foreign exchange intervention and the exchange rate.

1. Relationship between the monetary policy and foreign exchange intervention

In response to a contractionary monetary policy, foreign exchange interventions increase (net purchase of the U.S. dollar) immediately, which is consistent with the "leaning-against-the-wind" intervention. As monetary contraction leads to exchange rate appreciation, the MoF will increase the purchase of the U.S. dollar to stem the yen from further appreciation. Although the probability bands are quite broad, the direction of the impulse response is correct and combined with the signs of the contemporaneous coefficients (g_{12} , g_{18}), I can interpret it as the "leaning-against-the-wind" policy.

In response to a positive FEI shock, CMR decreases immediately for several periods after the shock, which can be interpreted as future monetary expansion. The result is consistent with the “signaling” hypothesis. However, the decrease is not significant; the evidence for the “signaling” hypothesis is not obvious.

2. Relationship between foreign exchange intervention and the exchange rate

In response to a positive FEI shock, the exchange rate starts to appreciate for some time, but the appreciation is insignificant. The result suggests that interventions are ineffective if not counterproductive, which is consistent with Fatum and Hutchison (2004) and Ito (2003) to some extent. Fatum and Hutchison (2004) studies the most recent 5 years of daily intervention data, and find that the intervention was effective during the 1999—2002 sub-sample (characterized by infrequent interventions), while it had no significant impact on the yen/dollar exchange rate during 2003 sub-sample (characterized by frequent interventions). For the first quarter of 2004 (characterized by large scale interventions), the impact of intervention was significant, but systematically associated with the exchange rates moving in the opposite direction of what was intended by the intervening authority. Ito (2003) shows that the intervention during April 1991 to June 20, 1995 characterized by frequent intervention was ineffective, while the intervention during June 21, 1995 to March 2001 characterized by infrequent interventions was effective. Both studies revealed the interesting pattern that intervention tend to be effective during period of infrequent interventions but ineffective or even counter-effective during period of very frequent interventions. Specifically, the BoJ intervened on an average of 3% of business days over the 1999 to 2002, during which the study supported effectiveness; and when the intervention frequency is 35% of business days over the year 2003, the study found no significant impact of intervention. In contrast, the intervention frequency rose to 85% over the first quarter of 2004, and it appeared to be significantly counterproductive. Dominguez and Frankel (1993) states that unanticipated and coordinated interventions are most effective. When there is high frequency of intervention, the market had become too accustomed to the BoJ intervention, which tends to decrease the effectiveness of intervention on the exchange rates. Generally, Japan has been heavily intervening in the history, so interventions tend to be ineffective or even counterproductive as showed in the impulse response functions.

In response to a depreciation of the yen, FEI decreases (dollar sales) on impact to support the yen, which is the “leaning-against-the-wind” type of policy.

3. Relationship between the monetary policy and the exchange rate:

I now consider the correlation between monetary policy and the exchange rate. In response to the yen depreciation, the monetary authority increases the call money rate significantly to stabilize the exchange rate.

Consider next, the dynamic behavior of the exchange rate over time following a monetary contraction. Under the UIP, a positive innovation in domestic interest rates relative to foreign interest rates should be associated with a persistent depreciation of the domestic currency after the impact appreciation. However, the empirical results in Eichenbaum and Evans (1995) suggests that a positive interest rate differential in favor of domestic assets is associated with a persistent appreciation of the domestic currency, and the exchange rate effects peak after 2 years of the initial monetary policy shock, which is termed as "delayed overshooting". Grilli and Roubini (1995) find the same result for the G-7 countries. As seen in Figure 2.1, in response to contractionary monetary policy, both CMR and FFR increase. But the increase in CMR exceeds the corresponding increase in FFR, so a positive CMR shock leads to an increase in the interest rate differential between Japan and the U.S. The exchange rate appreciates for several months, and then is followed by depreciation to the original level. While the dynamic path of the exchange rate does not exactly follow the one implied by the UIP, the shape of the response is much closer to that suggested by the UIP than the previous work in that monetary contraction is associated with an initial appreciation followed by subsequent depreciation, and the maximal effect of the exchange rate comes within the first few months. So I prefer to interpret it as "overshooting".

Next, I can examine how the two types of monetary policies affect the output. The conventional monetary policy in Japan does not have much significant effect on output, while foreign exchange intervention does impact output significantly in short run: IP increases for some horizons in response to a positive FEI shock. The result validates the importance of including both foreign exchange intervention and the monetary policy in one model. Or else, the effects of conventional monetary policy on the aggregate activity might be biased upward.

2.4.3 Forecast Error Variance Decomposition

Table 2.1 reports the forecast error variance decomposition of the foreign exchange intervention, conventional monetary policy and the exchange rate for 6, 12, 24, and 48-month horizons. Estimated standard errors are shown in the parentheses.

[Table 2.1 about here]

Interestingly, the major contribution of foreign exchange intervention forecast error variance is coming from itself (46-66.2%) at all horizons. The result suggests that intervention tend to occur in a cluster: if there has been large intervention today, there is a good chance of another intervention the next day. Ramana and Ramaswamy (1995) finds the same result. They estimate a probit model to identify the triggers for intervention and they find that the lagged interventions have significant effect on the probability of intervention.

The largest contributor to call money rate fluctuation is monetary policy shocks. But the effects of the shock are quite transient, decreasing from 50.2% to 20.9% over the 48-month horizon. The exchange rate explains about 18.7-26.6% of the conventional monetary policy movement for 48-month horizon, which is in agreement with the fact that the monetary policy of Japan pays great attention to the exchange rate movements. The U.S. monetary policy (Federal funds rate) explains up to 12.3% of Japan's monetary policy for 48-month horizon. This is because the U.S. is a large country that can affect the world interest rate. The result validates the inclusion of FFR in the model.

Examining the variance decomposition for the exchange rate, I can see that intervention and monetary policy account for comparable fraction (8.4-10.0% for FEI, 7.4-9.4% for CMR) of the variance. The result is somewhat in contrast to Kim (2003) and common belief. Kim (2003) finds that foreign exchange intervention is a much more dominant source of the exchange rate fluctuation in the U.S. This is not surprising, as the U.S. monetary policy does not take exchange rate as an explicit goal and interventions are infrequent in the U.S. (frequency is negatively related to the effectiveness as mentioned above), so interventions are more effective than monetary policy in changing the exchange rate. In Japan, monetary policy is more likely to react to the exchange rate, while interventions are frequent (which tend to be ineffective), so the monetary policy can have as great effects on the exchange rate as the intervention. The result indicates that it is essential to incorporate both types of policies in one model to study their effects on the exchange rate. And the importance of the policies on exchange rate variability are country-specific, i.e. in some countries conventional monetary policy might affect the exchange rate to a similar degree as foreign exchange intervention, while in other countries the impact of interventions might be stronger . There is no uniform answer as to whether it is monetary policy or foreign exchange intervention more influential on exchange rates.

CPI, IP and FFR explain up to 12.2%, 15.8% and 15.1% of the exchange rate volatility respectively over the long run. This is in line with the exchange rate determination theory that price movement, supply shocks and foreign monetary policy are all important factors of exchange rate determination.

Next, I will examine the influence of FEI, CMR and E on CPI and IP fluctuation. The table 2.2 reports the forecast error variance decomposition of the CPI and IP for 6, 12, 24 48-month horizons.

[Table 2.2 about here]

According to the table 2.2, CPI shocks explain most of its own movement, with IP as the second largest contributor of the fluctuation in the long run, while FEI and E explain smaller portion. Interestingly, the contribution of conventional monetary policy is larger at long horizons. Chinn and Dooley (1997) finds that Japan's monetary policy reacts to inflation over longer forecast horizons as compared to other central banks. The result seems to support his finding.

For IP, the contribution of FEI shocks is around 7.0-10.8%, the contribution of exchange rate is of 4.3-8.4% over 48-month horizon. Monetary policy shocks in Japan only contribute about 3.8-5.4% of output fluctuation, while monetary policy shocks in Japan and the U.S. together explain about 20% of the movement of the output. This result echoes for the strong influence of the U.S. monetary shocks on the Japanese economy. Shocks on IP, which are often interpreted as productivity/technology shocks in the literature is the most dominant source of the output fluctuation.

2.5. Robustness Check

Faust (1999) suggests that some results of the structural VAR models are sensitive to the chosen identification schemes. In this section I will check the robustness of the model with different identification schemes.

First, I experiment with different structures on the contemporaneous interactions of policies to the exchange rate. I consider the following alternative identifying assumptions on the different reactions of policies to the exchange rate: 1) ($g_{18} \neq 0,\ g_{28} = 0$) allowing non-zero contemporaneous reaction of foreign exchange intervention to the exchange rate, but restricting contemporaneous reaction of conventional monetary policy to the exchange rate to zero. Chinn and Dooley (1997) recover monetary policy reaction function for Japan, and find that exchange rate target does not affect significantly in either economic or statistical sense. 2) ($g_{28} \neq 0,\ g_{18} = 0$) allowing non-zero contemporaneous reaction of monetary policy to exchange rate, but restricting contemporaneous reaction of intervention to the exchange rate to zero. Because I find that the exchange rate is not the main motivation for intervention in my baseline model. 3) ($g_{28} = 0,\ g_{18} = 0$) restricting the contemporaneous reaction of both conventional monetary policy and foreign exchange intervention to the exchange rate to zero.

In the first and third models, it is difficult to identify conventional monetary policy shocks. In response to a monetary contraction, the yen depreciates (exchange rate puzzle), money demand increases (liquidity puzzle), and IP increases instead of decreases. So the models seem to be mis-specified. The results from the second model are much similar to the baseline model; there is no exchange rate puzzle, price puzzle, or liquidity puzzle. The identifying assumptions of "$g_{28} \neq 0,\ g_{18} = 0$" yielding reasonable results suggests that the BoJ use monetary policy to influence the exchange rate direction, while using intervention to stabilize the exchange rate ex. ante when it is volatile.

Second, I examine alternative identifying assumptions on the interactions between the two policies. I consider the following identifying assumptions: 1) ($g_{12} = 0,\ g_{21} \neq 0$) allowing conventional monetary policy reaction to foreign exchange intervention only. 2) ($g_{12} \neq 0,\ g_{21} \neq 0$) allowing contemporaneous interaction between the two policies. 3) ($g_{12} = 0,\ g_{21} = 0$) restricting contemporaneous interactions between the two policies.

The first and the third models produce similar results to my baseline case. The second model produces some strange results, the sign of g_{12} is positive, which means as CMR increases, the yen appreciates, but the BoJ will still sell dollars to make the yen appreciate further. $g_{18} < 0$ implies that foreign exchange intervention systematically destabilize the exchange rate by buying dollars in reaction to the exchange rate depreciation.

Third, I examine different types of monetary policy. The baseline model assumes the monetary policy is backward looking. Since information on output and price are not available in the current period, monetary policy does not react to CPI and IP contemporaneously. However, Clarida, Gali and Gertler (1997) finds that the G-3 central banks are forward looking: they respond to anticipated inflation as opposed to lagged inflation. So I allow non-zero g_{24}, g_{25} to capture the forward-looking monetary policy. However, the model produces some strange results. It is hard to identify both types of policies, there are liquidity puzzle and exchange rate puzzle in response to contractionary monetary policy shocks, and foreign exchange intervention destabilize the exchange rate by selling dollars in reaction to the exchange rate appreciation ($g_{18} < 0$).

To summarize, various models with alternative identifying assumptions are examined. Some models produce puzzling results, while other models produce similar results to the original model. Overall, the baseline model is preferred.

2.6. Policy implications

Japan has long been in economic recession in 1990s which is characterized by a combination of economic stagnation and a strong currency. While real growth of Japanese GDP during the 1990s was extremely slow, the yen has been surprisingly strong. And the inter-bank interest rate in Japan has been virtually zero since early 1999, which indicates that Japan may be in a "liquidity trap" so that monetary policy is ineffective in stimulating aggregate demand. Would sterilized foreign exchange market intervention, by depreciating the exchange rate and inducing export-led growth, be an effective alternative to monetary policy under these circumstances? Actually many researchers have proposed to revive the Japanese economy by more aggressive foreign exchange interventions, for example Svensson (2003), Spiegel (2001), etc. They argue that the feasible approach to escape from a liquidity trap involves generating expectations of a higher future price level, which will reduce the real interest rate and stimulate the economy, even if initial short term nominal interest rates are near or at zero. And depreciating the exchange rate is more effective in signaling to the market participants about the central bank's determination to generate inflation, because the exchange rate can be observed instantaneously while inflation rate or price level is available only with a lag. But those proposals rely on the effectiveness of foreign exchange intervention to affect the exchange rate. The results reported in this paper suggest that foreign exchange intervention on the yen/dollar rate may be ineffective or even counterproductive. Intervention alone may not be sufficient to escape the liquidity trap. However, given the result that foreign exchange intervention has some expansionary effects on the real economy, there is some possibility of using intervention in conjunction with other measures, such as monetary quantitative easing, to depreciate the yen and inflate the economy. For example, the BoJ may initiate "money rain" together with intervention. Though foreign exchange intervention might not be effective, it can at least signal the determination and intention of depreciating the currency; coupled with the "money rain", the determination of generating higher price level become credible. The households are rational and know the structure of the monetary policy rule; they can accurately expect that the "money rain" will ultimately drive the price level to its targeted level. The injection of money will relax the representative household's budget constraint and thereby stimulate aggregate demand.

2.7. Conclusion

This paper develops a structural VAR model in which foreign exchange intervention, conventional monetary policy and the exchange rate are analyzed in a unifying model. The model is applied to Japan from 1991:01 to 2004:07, for which the intervention data was made available recently. My analyses start from a set of sensible identifying assumptions which are consistent with Japan's economic structure. The resulting predictions support the identifying assumptions in that the estimated dynamic responses are close to the expected movements of macroeconomic variables. Then I study the relationship among monetary policy, intervention and the exchange rate.

First, the results indicate that increase in call money rate will increase the dollar purchase, which supports the "leaning-against-the-wind" manner of foreign exchange intervention to monetary policy. There is some evidence for the "signaling" hypothesis, but the evidence is not obvious.

Second, in Japan the conventional monetary policy is comparable source of the exchange rate fluctuation as foreign exchange intervention. In contrast, Kim (2003) finds that foreign exchange interventions have much greater effects on the exchange rate in the U.S. The result suggests that there is no uniform answer as to whether it is monetary policy or intervention the major source for the exchange rate fluctuation. And the response of the yen/dollar rate seems to support the "overshooting" hypothesis.

Third, foreign exchange intervention is not effective, and sometimes may even be counter-effective in Japan, so escaping liquidity trap by interventions alone may not be a feasible approach. Initiating foreign exchange intervention together with "money rain" might be a method to generate inflationary pressure.

There are some other interesting finds: monetary policy in Japan does not have significant effect on the real economy, while monetary policies in Japan and the U.S. together can explain some fluctuation of the real output.

However, those results should be read with a caveat. It is known that interventions are conducted sporadically with several interventions over the course of a few days or weeks. Such sporadic intervention means that it has an unusual distribution. The low frequency monthly macro data can hardly capture the characteristic of the distribution and will miss the important high frequency interactions, thus complicates the task of sorting out the interaction between intervention and the exchange rate. So structural VAR models considering the unusual distribution of intervention could be more successful in identifying the policies, which might be the direction of future research.

Table 2.1: Variance Decomposition of FEI, CMR and E

Forecast Error Variance Decomposition of FEI								
Horizon	FEI	CMR	M	CPI	IP	FFR	WOP	E
6 month	66.2	4.0	2.4	4.1	6.3	4.6	4.5	8.0
	(7.8)	(2.1)	(1.2)	(2.6)	(3.4)	(2.6)	(2.6)	(5.0)
12month	57.5	4.7	3.3	5.6	7.1	5.6	7.1	9.1
	(8.0)	(2.4)	(1.5)	(3.0)	(3.3)	(2.5)	(3.0)	(4.9)
24month	50.7	5.3	3.6	6.4	8.8	8.1	7.7	9.4
	(8.1)	(2.4)	(1.6)	(2.7)	(4.0)	(3.9)	(3.2)	(5.2)
48month	46.0	5.7	4.0	7.3	9.9	9.2	8.3	9.7
	(8.9)	(2.2)	(1.8)	(2.9)	(4.5)	(4.3)	(3.4)	(4.7)
Forecast Error Variance Decomposition of CMR								
Horizon	FEI	CMR	M	CPI	IP	FFR	WOP	E
6 month	3.2	50.2	7.1	2.8	4.4	9.8	3.9	18.7
	(2.5)	(16.5)	(6.1)	(2.3)	(2.8)	(8.4)	(3.0)	(14.9)
12month	5.4	36.5	6.9	3.7	4.8	11.5	6.1	25.0
	(4.7)	(16.4)	(6.0)	(2.8)	(3.3)	(11.6)	(4.8)	(15.9)
24month	6.5	26.8	6.3	5.7	8.4	10.7	9.0	26.6
	(4.7)	(13.7)	(5.4)	(4.4)	(7.0)	(9.8)	(7.0)	(14.9)
48month	6.4	20.9	5.3	7.5	11.9	12.3	12.9	22.7
	(4.4)	(11.7)	(3.3)	(5.0)	(9.0)	(7.8)	(10.3)	(13.0)
Forecast Error Variance Decomposition of E								
Horizon	FEI	CMR	M	CPI	IP	FFR	WOP	E
6 month	8.4	7.5	2.8	7.3	3.2	6.9	6.5	57.4
	(8.5)	(6.1)	(2.5)	(4.7)	(1.4)	(4.2)	(4.4)	(12.5)
12month	10.0	9.4	2.9	9.8	4.4	8.4	8.5	46.4
	(8.7)	(6.9)	(2.2)	(5.3)	(2.2)	(6.1)	(4.9)	(11.8)
24month	9.9	7.5	2.5	10.9	13.6	12.1	8.7	34.9
	(7.0)	(5.8)	(1.5)	(6.9)	(9.2)	(6.8)	(4.5)	(10.6)
48month	9.7	7.4	2.7	12.2	15.8	15.1	10.0	27.2
	(5.5)	(5.0)	(1.8)	(8.8)	(10.2)	(9.0)	(6.0)	(9.0)

Note: values in parenthesis are the standard errors from a Monte-Carlo simulation with 1000 draws.

Table 2.2: Forecast Error Variance Decomposition of CPI and IP

Forecast Error Variance Decomposition of CPI								
Horizon	FEI	CMR	M	CPI	IP	FFR	WOP	E
6 month	4.4	4.1	4.9	59.5	5.4	12.4	4.8	4.4
	(3.4)	(2.9)	(3.0)	(8.7)	(3.1)	(6.8)	(2.9)	(2.4)
12month	6.1	6.4	5.4	41.5	13.6	12.2	8.5	6.3
	(3.1)	(3.8)	(2.5)	(8.3)	(5.4)	(7.1)	(5.3)	(3.2)
24month	6.4	10.3	5.2	25.7	24.9	10.6	10.1	6.6
	(3.6)	(5.5)	(2.8)	(7.9)	(10.9)	(6.4)	(7.1)	(3.2)
48month	7.1	10.4	5.1	20.9	26.1	11.1	11.1	8.3
	(3.7)	(5.0)	(3.1)	(7.8)	(11.5)	(5.7)	(6.6)	(4.2)
Forecast Error Variance Decomposition of IP								
Horizon	FEI	CMR	M	CPI	IP	FFR	WOP	E
6 month	7.0	3.8	1.4	1.8	62.3	16.1	3.2	4.3
	(4.8)	(2.8)	(0.8)	(1.5)	(9.4)	(8.4)	(2.3)	(3.7)
12month	11.0	3.9	1.4	4.0	52.5	17.6	4.9	4.7
	(9.4)	(2.3)	(0.9)	(3.3)	(13.0)	(10.4)	(3.1)	(3.8)
24month	11.2	4.5	1.8	6.9	42.4	15.8	9.9	7.3
	(9.0)	(2.4)	(1.3)	(4.9)	(13.3)	(9.3)	(6.6)	(4.1)
48month	10.8	5.4	2.1	8.9	37.9	16.0	10.5	8.4
	(8.0)	(2.7)	(1.3)	(7.5)	(13.6)	(8.3)	(6.3)	(4.5)

Note: values in parenthesis are the standard errors from a Monte-Carlo simulation with 1000 draws.

Figure 2.1: Impulse Responses to Positive FEI, CMR and Exchange Rate Shocks

Response of FEI to FEI shock | Response of FEI to CMR shock | Response of FEI to E shock

response of CMR to FEI shock | Response of CMR to CMR shock | Response of CMR to E shock

Response of M to FEI shock | Response of M to CMR shock | Response of M to E shock

Response of CPI to FEI shock | Response of CPI to CMR shock | Response of CPI to E shock

Response of IP to FEI shock | Response of IP to CMR shock | Response of IP to E shock

Response of FFR to FEI shock | Response of FFR to CMR shock | Response of FFR to E shock

Response of WOP to FEI shock | Response of WOP to CMR shock | Response of WOP to E shock

Response of E to FEI shock | Response of E to CMR shock | Response of E to E shock

Chapter Three:
Sources of Exchange Rate Movements in Japan:
Is the Exchange Rate a Shock-absorber or a Source of Shock?

3.1. Introduction

Measuring the relative importance of various sources of exchange rate movements is important for a variety of reasons. First, it is essential for exchange rate modeling. "Disequilibrium" models of exchange rate determination by Dornbusch (1976) and others generally focus on the importance of nominal disturbances in explaining the real and nominal exchange rate movements, whereas "equilibrium" models offered by Stockman (1987) rely on permanent real shocks to explain variations in exchange rates. Understanding the sources of exchange rate fluctuation would be a useful key in selecting the right model of exchange rate determination. Second, understanding the sources of exchange rate volatility can help us gauge the role of exchange rates in macroeconomic adjustment and evaluate whether exchange rates act as shock-absorbers or sources of shocks. No doubt, this is one of fundamental issues in choosing an appropriate exchange rate regime for a country.

In this paper, I develop a structural VAR model to investigate the relative roles of real and nominal shocks in the determination of the yen-dollar exchange rate in the post-Bretton Woods period. By imposing a mixture of short and long-run zero restrictions, I identify five sources of exchange rate fluctuation: oil price shocks, relative productivity shocks, relative demand shocks, exchange rate shocks and relative monetary policy shocks. The role of exchange rate in the Japanese economy is then examined by the impulse response functions of the exchange rate to various shocks and the forecast error variance decompositions of the exchange rates. If the exchange rate appreciates (depreciates) significantly to a positive asymmetric demand (supply) shock and the asymmetric demand (supply) shocks contribute to a large portion of the total variation in the exchange rate, then exchange rate flexibility helps stabilize the economy. But if the exchange rate is mainly driven by shocks in the foreign exchange market and these shocks have the potential to strongly affect output, then the exchange rate is likely to be a source of shock.

I am interested in the role of exchange rate adjustment in Japan for two reasons. First, whether the exchange rate behaves as a shock-absorber is of primary interest to an economy like Japan's, which is typically viewed as heavily dependent on international trade. Second, Japan's economic distress in the past 10 years or so is unprecedented among the industrial economies in the postwar period. Faced with the zero constraint on nominal interest rates, the Bank of Japan has substantially relied on the policy of quantitative easing but failed to achieve the objective of sustained economic growth. Many researchers propose to utilize the exchange rate policy to revitalize the economy. So identifying the sources of exchange rate variation and its role in macroeconomic stabilization can assist policymakers in determining the extent of excess variability in the exchange rate.

The rest of the paper is organized as follows: section 3.2 provides a literature review. Section 3.3 presents the econometric methodology of structural VAR modeling. The data and the empirical results are presented in Section 3.4. The paper concludes with a brief summary in Section 3.5.

3.2. Literature Review

Given the general failure of existing models to explain exchange rate movements and also considering a multiplicity of variables and shocks to be considered in exchange rate modeling, it is not surprising that VAR models are a popular tool in empirical studies. Following the pioneering work of Blanchard and Quah (1989), there has been a growing body of literature in which some long-run relationship from theory is used to identify structural shocks in an open economy setting. A number of studies including Lastrapes (1992) and Enders and Lee (1997), Chen and Wu (1997), and Kutan and Dibooglu (1998) adopted a bivariate model of real and nominal exchange rates, imposing a long-run neutrality restriction of nominal shocks on the real exchange rate. Lastrapes (1992) and Enders and Lee (1997) find that fluctuations in both the real and nominal exchange rates are due primarily to real shocks. Chen and Wu (1997) find that real shocks are important in Japan and Korea while less so in the Philippines and Taiwan. Kutan and Dibooglu (1998) find markedly different results in that nominal shocks play a significant role in the nominal and real exchange rate movements in Poland and Hungary.

While exchange rates are subject to multiple nominal and real shocks, the above papers only identify aggregate real and nominal shocks.[11] Clarida and Gali (1994) constructed a

[11] Though Blanchard and Quah (1989) derive several reasonable conditions under which the existence of multiple shocks does not vitiate the identification of nominal and real shocks. For example, if the variance of one type of real disturbance grows “arbitrarily” small relative to the other, then the two shocks can be aggregated. However, there is no neat way to test these conditions.

three-variable—relative output, relative prices, and the real exchange rate----structural VAR model, and identify three types of macro economic shocks: supply, demand and nominal shocks. Numerous literatures later on use the same model to study sources of exchange rate movements for different countries, such as Thomas (1997), Funke (2000), Wang (2004) and etc.[12]

Compared to these literatures addressing only sources of exchange rate movements, literature studying the role of exchange rate is more diverse. Thomas (1997) and Funke (2000) use a structural VAR representation of the Mundell-Fleming model to analyze the role of exchange rates. They identify supply, demand and nominal shocks. Thomas (1997) finds that demand shocks account for a higher fraction of the real shocks in Sweden. And he concludes that if real demand shocks result from controllable macroeconomic policies, the role of exchange rate as a shock-absorber is not high. The empirical results in Funke (2004) indicate that most of the variation in relative output is caused by supply shocks while the shocks driving the real ECU exchange rate are mainly nonmonetary demand shocks in nature. Therefore, the exchange rate does not act much as a shock-absorber.

Artis and Ehrmann (2002) studies the UK, Canada, Sweden and Denmark using a five-variable structural VAR model which includes output, price level, foreign short-term nominal interest rate, domestic short-term nominal interest rate and the nominal exchange rate. What distinguish their work from many of the previous literature is that they estimate the VAR in levels instead of relative variables, so that their study can reveal the information on the comparative frequency of symmetric and asymmetric shocks.[13] Exchange rate can act as shock-absorber if an economy is hit by an asymmetric shock with respect to its trading partner. Whether the exchange rate is an important tool to stabilize an economy can only be judged when I know how frequently this economy is hit by shocks that necessitate exchange rate adjustment. They find that in all countries but the UK, real shocks are predominantly symmetric relative to the neighbor, such that there is little need for the exchange rate to act as shock-absorber.

Farrent and Peersman (2004) analyze the role of the real exchange rate in a structural VAR framework for the United Kingdom, Euro area, Japan and Canada vis-à-vis the United States.

[12] They have also analyzed the sources of fluctuation in output and inflation, not only the sources of exchange rate movements.

[13] However, as Farrant and Peersman (2004) point out, though they do not need to assume that the dynamics of the system are similar across the two countries, estimating the model in levels can lead to a substantial bias in the results, in particular when there is an important role for symmetric shocks across countries. The existence of the latter will result in a more important role for pure exchange rate shocks when the VAR is estimated in levels.

They use sign restrictions to identify relative supply, relative demand, monetary policy and exchange rate shocks. Their results are compared to the benchmark conventional approach of Clarida and Gali (1994) based on long-run zero restrictions. The results are strikingly different despite the fact that both sets of restrictions are derived from the same theoretical model. They find an important role for nominal shocks in explaining real exchange rate fluctuations, hence, the exchange rate can rather be considered as a source of shock.

Bjornland (2004) analyses the interactions between the real exchange rate and the business cycle in Norway. He has specified a structural VAR model in the real wage, the GDP, the real exchange rate and the unemployment rate that is identified through triangular long run restrictions on the dynamic multipliers in the model. The four structural shocks identified are: productivity, labor supply, nominal demand, and real demand shocks. He finds that the main shocks determining output variation (labor supply and nominal demand shocks) are not the same shocks as explaining most of the real exchange rate variation (real demand shocks). Only productivity shocks are common to both real output and real exchange rate variation. So the exchange rate does not act much as a shock-absorber in Norway.

Borghijs and Kuijs (2004) estimates two sets of structural VAR model for the Czech Republic, Hungary, Poland, the Slovak Republic and Slovenia. The first model incorporates only nominal exchange rate and relative industrial production, and the identified shocks are neutral shocks and non-neutral shocks.[14] The result from this model suggests that the nominal exchange rate does not respond to the shocks that cause the large fluctuation in output. In the second model, they incorporate the real exchange rate, the nominal exchange rate and relative output, which is in a similar vein to Clarida and Gali (1994). They find that the real exchange rate is also predominantly driven by LM and IS shocks as the nominal exchange rate. The result suggests that the exchange rates appears on average to have served as much or more as an unhelpful propagator of LM shocks than as a useful absorber of IS shocks.

Alexius and Post (2005) studies Sweden, Canada, Australia, New Zealand and the United Kingdom. By using country-specific trade-weighted GDP, domestic GDP, trade-weighted CPI, domestic CPI and nominal exchange rate, they are able to identify world-wide symmetric supply shocks, domestic asymmetric supply shocks, world-wide symmetric demand shocks, domestic

[14] In terms of Mundell-Fleming model, neutral shocks include monetary or financial market (LM) shocks and real demand (IS) shocks. Non-neutral shocks can be identified as supply shocks.

asymmetric demand shocks, and exchange rate shocks. Their results indicate that supply shocks are more important than demand shocks for nominal exchange rate behavior but the overwhelmingly most important determinant is speculative shocks from the exchange rate market. However, the contribution of exchange rate shock to inflation and output growth is small, which is consistent with the "exchange rate disconnect" puzzle that the exchange rate movements are weakly related to the rest of the economy.

3.3. The Model

This section presents the model which differs from those employed in the previous studies in several important ways. First, I separate the supply shocks into "oil supply" and "productivity" shocks; nominal shocks into "monetary policy" and "exchange rate policy" shocks.[15] As Faust and Leeper (1994) argue, the aggregation of multiple shocks into one shock is appropriate only if the underlying shocks affect the variable of interest in precisely the same fashion. Thus, it is important to distinguish among those shocks because their effects are likely to be substantially different. Second, I use a combination of short-run and long-run restrictions, which I believe will provide more credible estimates of structural shocks than using solely short-run or long-run restrictions. Third, I let the real exchange rate to capture real demand shocks, rather than the relative price as in many previous studies. And I include both the real and the nominal exchange rates in the VAR system since the two may respond very differently against shocks.[16]

Consider the following specification for a vector of endogenous variables Y_t :

$$CY_t = \Gamma_0 + \sum_{i=1}^{n} \Gamma_1(i) L^i Y_t + \varepsilon_t \qquad (1)$$

where C is a 5×5 contemporaneous matrix, Γ_0 is a vector of constants, $\sum_{i=1}^{n} \Gamma_1(i)$ is a 5×5 matrix of autoregressive coefficients. L is the lag operator. The endogenous variables, Y_t , consists of the first difference of oil price ($\Delta Poil$), the relative industrial production between Japan and the US (ΔIP), the real yen/dollar rate (ΔRER), the nominal yen/dollar rate (ΔNER), and the interest rate differential between Japan and the US (ΔInt).[17] All variables except the

[15] Farrant and Peersman (2004) and Artis and Ehrmann (2002) also differentiate between monetary policy shocks and exchange rate policy shocks.
[16] Borghijs and Kuijs (2004) also include both nominal exchange rate and real exchange rate.
[17] Industrial production covers only part of economic output, and GDP has the coverage which is more preferable.

interest rate differential are in logarithm. ε_t are the corresponding structural shocks: oil supply shock, relative productivity shock, relative demand shock, exchange rate shock and relative monetary policy shock, i.e. $\varepsilon_t = \left[\varepsilon_t^{oil}, \varepsilon_t^{s}, \varepsilon_t^{d}, \varepsilon_t^{e}, \varepsilon_t^{m}\right]'$.[18][19]

Rearranging Eq (1) yields:

$$Y_t = C^{-1}\Gamma_0 + C^{-1}\sum_{i=1}^{n}\Gamma_1(i)L^iY_t + C^{-1}\varepsilon_t \tag{2}$$

Rewriting Eq (2), I obtain the reduced-form model:

$$Y_t = G_0 + \sum_{i=1}^{n} Z(i)L^iY_t + B\varepsilon_t \tag{3}$$

where $G_0 = C^{-1}\Gamma_0$, $Z(i) = C^{-1}\Gamma_1(i)$, and $B = C^{-1}$. $B\varepsilon_t$ is the reduced form residuals, where B can be interpreted as the contemporaneous reaction of the variables to the structural innovations.

Rewrite Eq (3) as

$$\left[I - G_0 - \sum_{i=1}^{n} Z(i)L^i\right]Y_t = B\varepsilon_t \tag{4}$$

and inverting, I obtain:

$$Y_t = \left[I - G_0 - \sum_{i=1}^{n} Z(i)L^i\right]^{-1} B\varepsilon_t = A(L)B\varepsilon_t \tag{5}$$

where $A(L) = \left[I - G_0 - \sum_{i=1}^{n} Z(i)L^i\right]^{-1}$. Eq (5) can be expressed in an extended form,

$$\begin{bmatrix} \Delta Poil \\ \Delta IP \\ \Delta RER \\ \Delta NER \\ \Delta i \end{bmatrix} = \begin{bmatrix} A_{11}(L) & A_{12}(L) & A_{13}(L) & A_{14}(L) & A_{15}(L) \\ A_{21}(L) & A_{22}(L) & A_{23}(L) & A_{24}(L) & A_{25}(L) \\ A_{31}(L) & A_{32}(L) & A_{33}(L) & A_{34}(L) & A_{35}(L) \\ A_{41}(L) & A_{42}(L) & A_{43}(L) & A_{44}(L) & A_{45}(L) \\ A_{51}(L) & A_{52}(L) & A_{53}(L) & A_{54}(L) & A_{55}(L) \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{oil} \\ \varepsilon_t^{s} \\ \varepsilon_t^{d} \\ \varepsilon_t^{e} \\ \varepsilon_t^{m} \end{bmatrix}$$

The reduced-form model, Eq (3), is estimable. However, the structural shocks, ε_t, are not

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However, GDP data is only available on a quarterly basis, which would reduce the number of observations too much by using GDP.

[18] In this analysis, we are only interested in relative or asymmetric shocks because common shocks do not require any adjustment in the real exchange rate. Oil price shock might be considered as world symmetric shock at the first glance, but Japan is much more dependent on the world oil supply than the US, so the world oil price can capture the asymmetric oil supply shock to the two countries.

[19] We will use "demand shock", "supply shock", "monetary policy shock" interchangeably with "relative demand shock", "relative supply shock" and "relative monetary policy shock".

identified. To recover the structural model, Eq (1), from the estimated coefficients of Eq (3), 25 identification assumptions need to be imposed. Fifteen of these come from the standard assumption that the structural errors have unit variance and are uncorrelated, i.e. $\mathrm{cov}(\varepsilon) = I$. The remaining restrictions are imposed as follows.

I assume that there is a contemporaneous impact of an oil price shock on all other variables in the system, but no immediate impact of the other shocks on the oil prices. This corresponds to $b_{12} = b_{13} = b_{14} = b_{15} = 0$. The assumption of exogenous contemporaneous oil price movements is common. Following Blanchard and Quah (1989), I also assume a vertical long-run Philips curve, that is, demand and nominal shocks have no long-run impact on the level of real output. But in the short run, due to nominal and real rigidities, they can influence production. Thus, oil price shocks and productivity shocks are the only shocks that have permanent effects on the output. These long-run assumptions provide three additional restrictions:

$$A_{21}(1)b_{13} + A_{22}(1)b_{23} + A_{23}(1)b_{33} + A_{24}(1)b_{43} + A_{25}(1)b_{53} = 0$$

$$A_{21}(1)b_{14} + A_{22}(1)b_{24} + A_{23}(1)b_{34} + A_{24}(1)b_{44} + A_{25}(1)b_{54} = 0$$

$$A_{21}(1)b_{15} + A_{22}(1)b_{25} + A_{23}(1)b_{35} + A_{24}(1)b_{45} + A_{25}(1)b_{55} = 0$$

Another popular identifying assumption is the short-run restriction that nominal shocks do not affect output contemporaneously, that is, $b_{24} = b_{25} = 0$. But I consider this assumption too restrictive. There is no solid theoretical reason to justify a zero contemporaneous impact of nominal shocks on output, and it is inconsistent with a large class of general equilibrium models.[20] (Canova and Pina, 1999)

Following Clarida and Gali (1994), I assume nominal shocks have no long-run effects on the real exchange rate, while they may on the nominal exchange rate. The long-run restriction on the nominal shock is consistent with the models that explain exchange rate volatility with sticky prices and monetary disturbances as in Dornbusch (1976), but allows for long-run real exchange rate variations due to real shocks. The two restrictions are:

$$A_{31}(1)b_{14} + A_{32}(1)b_{24} + A_{33}(1)b_{34} + A_{34}(1)b_{44} + A_{35}(1)b_{54} = 0$$

$$A_{31}(1)b_{15} + A_{32}(1)b_{25} + A_{33}(1)b_{35} + A_{34}(1)b_{45} + A_{35}(1)b_{55} = 0$$

[20] The second reason we do not restrict the two parameters is that the model would be over-identified with the two restrictions. If the model is over-identified, the long-run restrictions end up constraining the lag-coefficients, not just the covariance matrix, so the Maximum likelihood would require estimating the entire VAR, lags and all. There is no neat way to estimate the over-identified SVAR in the context of mixture of short and long run restrictions.

I am left with the task of differentiating the two nominal shocks, the exchange rate and monetary policy shocks. I impose a restriction that monetary policy does not respond contemporaneously to nominal exchange rate movements, that is, $b_{54} = 0$. Given the anti-inflation reputation, the monetary authority of either Japan or the US is more likely to respond contemporaneously to price movements, not to exchange rate movements.

The restrictions can be summarized as the following matrix form:

$$\begin{bmatrix} D_{11}(L) & D_{12}(L) & D_{13}(L) & D_{14}(L) & D_{15}(L) \\ D_{21}(L) & D_{22}(L) & 0 & 0 & 0 \\ D_{31}(L) & D_{32}(L) & D_{33}(L) & 0 & 0 \\ D_{41}(L) & D_{42}(L) & D_{43}(L) & D_{44}(L) & D_{45}(L) \\ D_{51}(L) & D_{52}(L) & D_{53}(L) & D_{54}(L) & D_{55}(L) \end{bmatrix} = A(L) \begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & 0 & b_{55} \end{bmatrix}$$

where $D(L)$ is the long-run vector moving average impact matrix of the structural shocks, and $D(L) = A(L)B$.

3.4. Empirical Results

This section provides the estimation results of the above model. Section 4.1 presents the preliminary data analysis. Section 4.2 reports the results for impulse response functions, forecast error variance decompositions.

3.4.1 Preliminary Data Analysis

Before estimating the model, the data need to be examined for nonstationarity and possible cointegration features. The stationarity of the variables is first checked by the Augmented Dickey-Fuller (ADF) test and the results are reported in Table 3.1. Only for the series of interest rate differential I can reject the null hypothesis of unit root two out of four cases at the 5 percent significant level. All other series appear nonstationary.

[Table 3.1 about here]

In performing the ADF unit root test, special care must be taken if it is suspected that a structural change has occurred. When there are structural breaks, the test statistic is biased towards non-rejection of a unit root. To take this problem into account, I employ the Perron (1997) test, which allows for a break in the deterministic trend function and endogenous determination of the date of possible break in the intercept or the slope. The results are presented in Table 3.2.

[Table 3.2 about here]

I fail to reject the null hypothesis of unit root for all the series at the 5 percent significant level, indicating all the series are nonstationary. Both the ADF and Perron tests are based on a null hypothesis of a unit root. The failure to reject a unit root may be simply due to the low power of the tests against stable autoregressive alternative with roots near unity. As a consequence, it is important to carry out unit root tests with the null hypothesis of stationarity, and then draw conclusions based on the combined results. For this purpose, I apply the test of Kwiatkowski, Phillips, Schmidt, and Shin (KPSS). The results are in Table 3.3.

[Table 3.3 about here]

The KPSS test rejects the null hypothesis of stationarity for all series at the 5 percent significance level. Combining the results from the three tests, I conclude that all series are integrated of order one. Table 3.4, 3.5 and 3.6 report the results of the ADF, Perron and KPSS test to the series in first differences. All transformed series are stationary.

[Tables 3.4, 3.5, 3.6 about here]

Since all variables are integrated of the same order, it is crucial to check for cointegration. I use the Engle-Granger cointegration test. In the first step, relative output is regressed on all the other variables and a constant. Then, the residuals are tested for the presence of a unit root. I fail to reject the null hypothesis of a unit root at the 10 percent significant level in ADF test and reject the null of stationarity in the KPSS test at the one percent significant level.[21] I thus proceed with the assumption that all variables have a unit root but not cointegrated. A structural VAR model in first difference is therefore the correct specification.

The data are monthly for the period 1973:01 through 2005:04. The lag length is chosen so that the residuals are white noise.

3.4.2 Impulse Response Functions and Forecast Error Variance Decomposition

This section presents results from the structural VAR analysis developed in the previous section. I examine the impulse responses of each variable to a positive innovation in each of the fundamental shocks and present variance decompositions of the forecast errors based on the VAR

[21] The test statistic in ADF test is -1.66, the 10 percent critical value is -2.571; the test statistic in KPSS test is 1.47, and the 1 percent critical value is 0.739.

analysis. The accumulated impulse responses are reported in Figure 3.1. The impulse responses are shown with one standard deviation confidence bounds using Monte Carlo simulation with 10000 draws.[22]

[Figure 3.1 about here]

In response to an increase in the oil price, the real and nominal exchange rates significantly depreciate. The interest rate differential also decreases significantly for the first 10 months, indicating that the central bank uses expansionary monetary policy to stimulate the economy. It is surprising, however, that industrial production increases in response to an oil price shock, though not significantly. It may be due to the significant depreciation of the real and nominal rates, which stimulates exports and thus aggregate demand. This finding indicates that exchange rates act as shock-absorber in the presence of oil supply shocks.

According to Mundell-Fleming model, a positive demand shock creates excess demand for home output resulting in an appreciation of the real exchange rate and a short-run increase in output. A positive productivity shock creates an excess supply of home goods resulting in a depreciation of the real exchange rate. Over time, output increases to a higher long-run level and the real exchange rate remains depreciated. However, many past literatures report that the real exchange rate appreciated rather than depreciated in response to a positive productivity shock, which is documented by Detken et al (2002) as "perverse supply effect".[23] They explained that such a shock is accompanied by an upward shift in the aggregate demand curve as there is a rise in domestic real wealth and consumers have a home bias in consumption. In my case, I do not find such perverse effect of the real exchange rate. From the Figure 1, the real exchange rate depreciates in the long run while the nominal exchange rate remains appreciated, though not significantly, which implies that the relative price between Japan and the US decreases in response to a positive productivity shock. As expected, the shock has significantly positive effects on relative output over the whole horizon.

In response to a negative demand shock, the relative output decreases for the first five months and soon returns to the original level. Though the decrease is small, it is still marginally significant. The real and nominal exchange rates depreciate significantly on impact and remain depreciated in the long-run. All these are consistent with the prediction of the model. The finding

[22] To compute the factorization of a covariance matrix with a combination of short and long run restrictions, we use "shortandlong.src" on estima website, which operate by Newton's method to solve for exact factorization.

[23] Such as Clarida and Gali (1994), Katie and Farrent (2004), etc.

suggests that negative (positive) real demand shocks have little output effect as the exchange rate may have depreciated (appreciated) to such an extent that the trade balance improves (deteriorates), making the output revert to the original level in just a few months. Interest rate differential first decreases for a short horizon and then increases significantly over the long run. This is not strange. As the negative demand shock hit the economy, the monetary authority decreases the interest rate to offset the negative impact of the demand shock. But as the exchange rates depreciate in the long time, interest rate differential increases to reverse the depreciation.

It is also important to note that the magnitudes of the real and nominal exchange rate movements in response to oil supply and real demand shocks are virtually identical. This suggests that permanent changes in the real exchange rate due to oil supply and real demand shocks mainly occur through the nominal exchange rate changes, not through relative price levels.

In response to a positive exchange rate shock, output increases significantly on impact, and the increase lasts for about 20 months, which dies out in the long run. The substantial contemporaneous effect of pure exchange rate shocks on relative output validates my identifying assumptions in which nominal shocks are allowed to affect output on impact. The real exchange rate and nominal exchange rate both depreciate significantly facing positive exchange rate shocks. It is noteworthy that the exchange rate shocks affect the real exchange rate and the nominal exchange rate in similar way in the short-run, which indicates the commodity price inertia. Over time, however, the shock has no long-run effect on the value of the real exchange rate due to the identifying assumption, but has permanent effects on the nominal exchange rate. This is consistent with the notion that nominal shocks can have permanent effects on the nominal exchange rate. The interest rate differential increases significantly in the long run to support the exchange rate, which is the same as my expectation.

In response to a contractionary monetary policy shock, the relative output increases for a very brief period. Though it is in contradiction to theory, it is not rare in the empirical monetary literature. For example, Uhlig (2005) identifies the effects of monetary policy shocks by imposing sign restrictions on the impulse responses. He finds that “contractionary monetary policy shocks do not necessarily seem to have contractionary effects on real GDP” and “the reaction of real GDP can as easily be positive as negative following a ‘contractionary’ shock.”

In general, the monetary policy shock seems not to have much effect on the economy.

Except for the interest rate differential itself, all the variables change for a very small magnitude. This echoes the fact that monetary policy in Japan is not effective. Although the call money rate has almost reached to the zero bound since 1995, the economy remains in recession and not stimulated by the expansionary monetary policy until recently.

[Table 3.7 about here]

While the impulse response functions reveal the dynamic effects of a one-time shock, variance decompositions are a convenient measure of the relative importance of such shocks to the system. This is essential for evaluating the role of exchange rates since the usefulness of flexible exchange rates as shock-absorbers depends largely on the types of shocks that exchange rates are responsive to. In response to real asymmetric supply and demand shocks, flexible exchange rates can generate more rapid adjustment in international relative prices when domestic prices adjust slowly, which makes them useful absorbers of real shocks. For instance, a sudden drop in demand would, under flexible exchange rates, cause a depreciation and will "crowds in" extra demand. On the other hand, exchange rates adjustment in response to monetary and financial shocks leads to undesired changes in relative prices. For example, in response to negative financial shocks that increase interest rates, exchange rates would appreciate, which amplify rather than dampen the negative impact on output. So the more exchange rates respond to real shocks and the less to the monetary or financial shocks, the more useful are exchange rates as shock-absorbers. Table 3.7 reports the forecast error variance decomposition of the variables in first difference for 6, 12, 24, 48-month horizons. Estimated standard errors are shown in the parentheses. In this case, real shocks, which are oil supply, productivity and demand shocks, play a dominant role in explaining the movements in the relative production, accounting for around 60 percent of the forecast error variance. Among the three sources of real shocks, productivity shock is the largest contributor, explaining about 46-48.4 percent for the 48-month horizon. Demand shocks explain a relatively smaller portion especially in the short run. The result contradicts Neo-Keynesian theory which emphasizes the role of demand shocks in the short-run fluctuations of output. It should be noted that, nominal shocks also play an important role (more than 40 percent in total) in output fluctuation, thought not as large as real shocks. The effects of nominal shocks on relative output are much larger than that found in previous studies. For example, Thomas (1997) and Artis and Ehrmann (2002) find that the effect of the nominal shocks is negligible on output. Exchange rate shocks are important in affecting the relative output, contributing for 32.8-35.8 percent of its variance over the whole horizon. This may reflect Japan's heavy reliance on the international trade. The effect of monetary policy on the relative output is quite negligible, which is line with the impulse response function.

For the real and nominal exchange rates, demand shocks always play the largest role over the whole horizon, explaining 66.6-76.7 percent of the real exchange rate volatility, 60.4-69.0 percent of the nominal exchange rate volatility. The dominance of real demand shock is evident from the impulse response functions in Figure 3.1. The importance of demand shocks in accounting for real exchange rate movements is also found in many of the previous work, such as Clarida and Gali (1994) and Enders and Lee (1997). However, in the case of Japan in Clarida and Gali (1994), they also find an important role of nominal shocks, which I do not find. The fact that demands shocks are important in exchange rate movements implies that exchange rate models which ignore aggregate demand factors are likely to have poor in-sample fit and out-of-sample forecasts, thus it is important to incorporate real demand-side factors into the theory of exchange rate determination. In the case of the relative productivity shock, it is a little more important for the nominal rate fluctuations than for the real rate fluctuations, accounting for 6.2-8.2 percent of the real exchange rate movements and 10.1-11.1 percent of the nominal exchange rate movements.

In general, I find that real shocks dominate nominal shocks in explaining exchange rate variability at all horizons. In my model, the two nominal shocks account for only 18.6-21.4 percent of the nominal exchange rate volatility, and 14.9-18.5 percent of the real exchange rate volatility. In contrast, Canzoneri et al. (1996) and Farrent and Peersman (2004) find a more important role for nominal shocks than for real shocks. In Canzoneri et al. (1996), real shocks account for only 25 percent of the forecast error variance of the real exchange rates, with demand shocks accounting for less than 20 percent in the EMU countries. And Farrent and Peersman (2004), using sign restrictions, finds that in Japan only 27-31 percent of exchange rate movements is driven by real shocks while nominal shocks explain 57-67 percent of the portion. If exchange rates are dominated by nominal shocks, then the "disequilibrium approach" of Dornbusch is appropriate in analyzing the behavior of exchange rates. Conversely, if the evidence suggests the contrary, then the "equilibrium approach" offered by Stockman should be considered as an alternative. While results of Farrent and Peersman (2004) suggest "disequilibrium approach", my results render some support to the "equilibrium approach"

It is important to note that the nominal shocks play a larger role in explaining the forecast error variance for the nominal rate than they do for the real rate. The same finding is also documented by Lastrapes (1992) and Enders and Lee (1997). The result suggests that models including the real exchange rate only will systematically underestimate the importance of the nominal shocks, thus overestimate the shock-absorber role of the exchange rates.

For the interest rate differential, relative monetary policy shocks explain the majority of its own forecast error variance, ranging from 69.1-82 percent. The second largest contributor is demand shocks, which explains 11.9-15.2 percent over the long horizon. It might be because that the monetary authority of Japan places emphasis on controlling inflation. Whenever demand shocks are likely to affect inflation rate, monetary policy responds to such shocks.

In sum, the impulse responses and variance decompositions indicate a stabilizing role for the exchange rate in the presence of asymmetric real shock. The real exchange rate depreciates significantly to a negative demand shock, oil supply shock and positive productivity shock. In addition, it is real shocks that dominate the variations in the real and nominal exchange rates. The results support the shock-absorber role of the exchange rates.

A word of caution is in order. In my results, variance decompositions reveal that the exchange rate and output are responsive to different real shocks, i.e., supply shocks dominate the output movements while demand shocks mainly drive the exchange rate movements. In many previous studies, when it is found that different shocks dominate exchange rate and output fluctuations, they conclude with a weak shock-absorbing role of exchange rates. For example, Funke (2000) states that "the fact that only 20 percent of the real exchange rate variance is accounted for by supply shocks, while 90 percent of the variance of relative output is accounted for by supply shocks seems to suggest that the real ECU exchange rate has not played the shock-absorber role." However, I think differently. As long as real exchange rate appreciates (depreciates) to a positive demand (supply) shock and the demand (supply) shock dominates the exchange rate movements, the exchange rates are exerting the shock-absorber role. The fact that the larger part of the relative output fluctuation is driven by supply shocks while the larger part of the exchange rate movements are determined by demand shocks just indicates that the exchange rates have absorbed the demand shocks that output is shielded from most of them, so these demand shocks are not transmitted to the real economy to a great extent.

A related question to the role of exchange rate is to check whether the exchange rate market creates its own shocks. To answer this question, I first see whether the exchange rate is mainly driven by its own shocks, and second, if this is the case, whether these shocks affect output, and as such have the potential to distort the economy.

The exchange rate shock explains 8.7-10.3 percent of the real exchange rate movements and 13.1-13.8 percent of the nominal exchange rate, which indicates that the exchange market creates some shocks but the shocks are not likely to be major. In contrast, Artis and Ehrmann (2002) find that, with exchange rate shocks explaining 50-90 percent and more of the variance of the exchange rates, they look more like a source of shocks rather than a shock-absorber. However, it should be noted that, in my case, those exchange rate shocks, once created, do explain 32.8-35.8 percent of the output variability for the 48-months horizon. Thus, the shocks have the potential to distort the real economy, which contradicts the "exchange rate disconnect puzzle" discussed by Obstfeld and Rogoff (2000). And there is rich policy implication for this result: while the authority should monitor the exchange market development, and provide the financial market stability, the authority can use exchange rate policy to stimulate the economy.

3.5. Conclusion

The aim of this paper is to study the sources of the exchange rate movements in Japan, understanding which would allow us to determine whether the exchange rate functions as a shock-absorber or a source of shocks in the economy.

In contrast to several earlier studies, I choose to segregate the supply shock into oil supply and relative productivity shock, nominal shock into exchange rate and relative monetary policy shock. I include both the nominal and the real exchange rate to calibrate the shock-absorbing capacity of the exchange rates. Mixture of short-run and long-run restrictions is employed. To ensure the validity of the model, I impose as parsimonious restrictions as possible, for example, I let free the zero restrictions of contemporaneous response of output to the nominal shocks that is prevalent in previous literatures. Other restrictions involved here are largely conventional in that they are standard assumptions typical in many textbook macroeconomic models, and have been adopted in earlier studies. Impulse response functions validate my identification schemes. The real and nominal exchange rates depreciate significantly in response to negative oil supply shocks, negative demand shocks and positive exchange rate shocks; the real exchange rate depreciates in response to positive supply shocks, while the nominal exchange rate appreciates, which imply decreases in the relative price. Relative output increases in response to positive relative productivity shocks, positive exchange rate shocks, and decreases in the short run facing negative relative demand shocks. Interest rate differential also behaves as expected in response to various shocks.

From variance decompositions, I find that real shocks dominate the nominal shocks in the exchange rate movements, with demand shocks being the most important contributor. This supports the role of the exchange rate as a shock-absorber. Also the fact that real shocks preponderate the exchange rate volatility indicates that the "equilibrium approach" of Stockman may be appropriate in analyzing the behavior of exchange rate.

The fact that nominal exchange rate shocks only explain around 13 percent of the nominal exchange rate variance and 10 percent of the real exchange rate variance suggests that exchange rate market creates few shocks. However, once created, these shocks explain about 35 percent of the relative output volatility, which is in contradiction to the "exchange rate disconnect" puzzle. With regard to the exchange rate policy, the results imply that variation in the nominal exchange rate might be an efficient way of achieving necessary changes in relative prices across national borders, thus allows Japan to recover from the recent recession more rapidly.

Table 3.1: Augmented Dick-Fuller Test

Test statistic	With intercept	With intercept and trend
Series Poil		
ADF(15)[a]	-2.19	-2.23
ADF(15)[b]	-2.19	-2.23
Series IP		
ADF (4)[a]	-0.84	-1.20
ADF(3)[b]	-0.65	-1.06
Series RER		
ADF(1)[a]	-2.23	-.2.22
ADF(1)[b]	-2.23	-2.22
Series NER		
ADF (13)[a]	-1.42	-2.42
ADF(1)[b]	-1.18	-2.23
Series Int		
ADF(13)[a]	-2.87	-2.83
ADF(1)[b]	-3.76*	-3.88*

Notes: 1. ADF(k) is the augmented Dickey-Fuller t-statistic calculated with truncation lag k. k is determined by "ADFautoSelect.src" available on www.estima.com, which is designed to select the optimal lag length for an ADF unit root test. 'a' denotes that the lag length is selected by AIC criterion, and b denotes that the lag length is selected by BIC criterion.
2. * denotes for rejection of the unit root null at the 5 percent level of significance.

Table 3.2: Perron (1997) Test

Series	Model	K	t-statistic
Poil	M1	1	-3.80
	M2	15	-3.80
IP	M1	8	-3.95
	M2	13	-2.83
RER	M1	11	-4.38
	M2	11	-4.39
NER	M1	11	-4.73
	M2	11	-4.71
Int	M1	16	-4.46
	M2	16	-4.04

Notes: 1.M1 is the model in which an innovational outlier with a change in the intercept and the slope are allowed. In M2, only an innovational outlier with a change in the intercept is allowed.
2. The truncation lag parameter k is chosen using a general to specific recursive procedure based on the t-statistic of the coefficient associated with the last lag in the estimated autoregression.
3. The simulated 5 percent critical values for the first model and second model are -5.08 and -4.8 respectively.

Table 3.3: KPSS Test

	Test statistic	
Variables	η_μ	η_τ
Poil	1.21*	0.64*
IP	2.23*	1.75*
RER	3.78*	0.74*
NER	6.83*	0.79*
INT	0.75*	0.35*

Notes: 1. η_μ and η_τ are the KPSS statistics based on residuals from regressions with a constant term only, and with a constant term and a time trend, respectively.
2. The KPSS test statistics are obtained based on a Newey-West adjustment with four lags and there is no notable change in the decision when I lengthen the lags.
3. *denotes significance at the 5 percent level.

Table 3.4: ADF Test to the First Differenced Series

Test statistic	With intercept	With intercept and trend
Series dPoil		
ADF(16)[a]	-5.98*	-5.89*
ADF(14)[b]	-6.94*	-6.85*
Series dIP		
ADF (3)[a]	-7.86*	-7.94*
ADF(3)[b]	-7.86*	-7.94*
Series dRER		
ADF(1)[a]	-14.42*	-14.43*
ADF(1)[b]	-14.42*	-14.43*
Series dNER		
ADF (12)[a]	-4.76*	-4.77*
ADF(1)[b]	-14.18*	-14.16
Series dInt		
ADF(12)[a]	-5.76*	-5.77*
ADF(0)[b]	-12.53*	-12.52*

Table 3.5: Perron (97) Test to the First Differenced Series

Series	Model	K	t-statistic
Poil	M1	14	-7.78*
	M2	14	-7.78*
IP	M1	3	-8.29*
	M2	3	-8.19*
RER	M1	10	-5.69*
	M2	1	-14.33*
NER	M1	10	-5.49*
	M2	0	-197.26*
Int	M1	12	-6.41*
	M2	12	-7.09*

Table 3.6: KPSS Test to the First Differenced Series

	Test statistic	
Variables	η_μ	η_τ
POIL	0.31	0.18*
IP	0.55*	0.09
RER	0.30	0.13
NER	0.33	0.14
INT	0.03	0.02

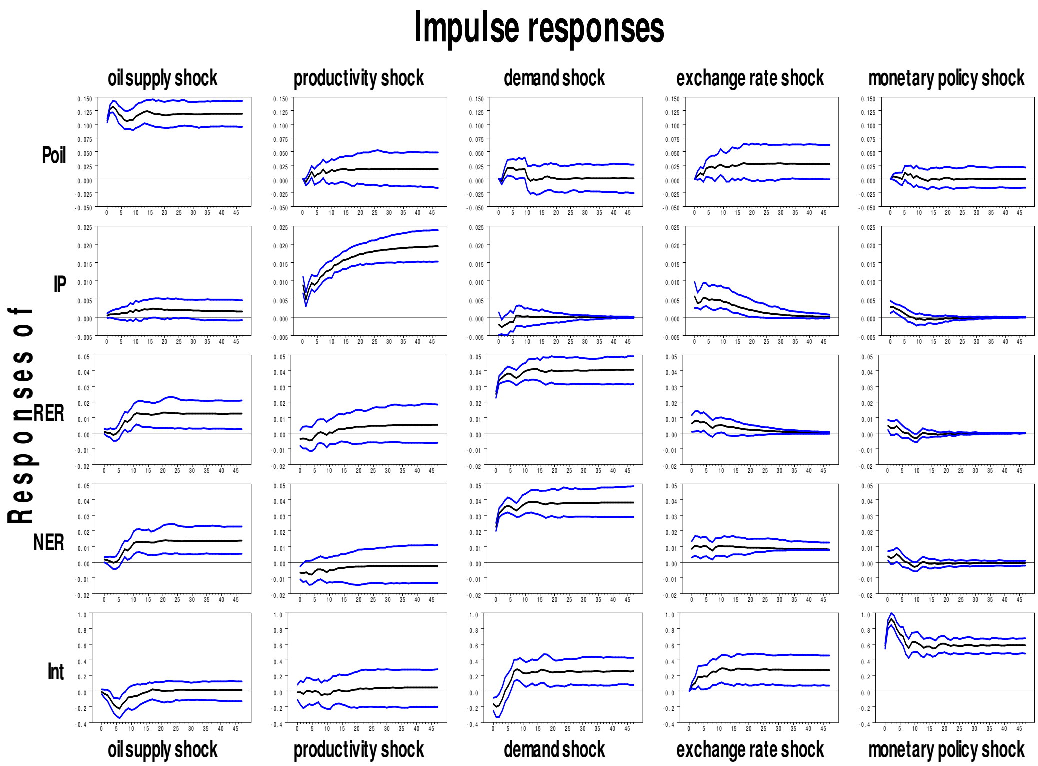
Note: * denotes significant at the 5 percent level.

Table 3.7: Forecast Error Variance Decomposition

Forecast Error Variance Decomposition of	$\Delta Poil$				
Horizon	ε^{oil}	ε^{s}	ε^{d}	ε^{e}	ε^{m}
6 month	86.1 (3.2)	3.6 (1.6)	3.9 (1.7)	4.0 (1.6)	2.4 (1.4)
12 month	78.1 (3.4)	5.2 (1.7)	6.9 (2.3)	5.6 (2.0)	4.2 (1.8)
24 month	75.7 (3.3)	5.7 (1.7)	7.6 (2.5)	6.2 (1.8)	4.9 (1.9)
48 month	75.3 (3.3)	5.7 (1.7)	7.7 (2.7)	6.3 (1.9)	4.9 (1.9)
Forecast Error Variance Decomposition of	ΔIP				
Horizon	ε^{oil}	ε^{s}	ε^{d}	ε^{e}	ε^{m}
6 month	1.8 (0.9)	48.4 (16.7)	7.6 (4.4)	35.8 (17.2)	6.4 (3.7)
12 month	3.4 (1.7)	46.6 (16.1)	9.3 (3.8)	33.4 (15.0)	7.4 (3.7)
24 month	3.8 (1.7)	46.1 (15.8)	9.5 (3.7)	32.9 (14.3)	7.7 (3.6)
48 month	3.9 (1.7)	46.0 (15.7)	9.5 (3.8)	32.8 (14.1)	7.8 (3.6)
Forecast Error Variance Decomposition of	ΔRER				
Horizon	ε^{oil}	ε^{s}	ε^{d}	ε^{e}	ε^{m}
6 month	2.2 (1.0)	6.2 (4.1)	76.7 (10.5)	8.7 (5.8)	6.2 (3.7)
12 month	6.3 (2.2)	7.5 (4.1)	68.8 (9.0)	10.0 (6.3)	7.4 (3.5)
24 month	6.7 (2.1)	8.1 (3.7)	66.9 (9.4)	10.2 (5.8)	8.1 (3.3)
48 month	6.8 (2.1)	8.2 (3.6)	66.6 (9.4)	10.3 (5.8)	8.2 (3.4)
Forecast Error Variance Decomposition of	ΔNER				
Horizon	ε^{oil}	ε^{s}	ε^{d}	ε^{e}	ε^{m}
6 month	2.2 (1.3)	10.1 (5.5)	69.0 (12.0)	13.1 (8.0)	5.5 (3.7)
12 month	6.5 (2.3)	10.7 (5.0)	62.2 (11.4)	13.6 (9.4)	6.9 (3.7)
24 month	7.0 (2.5)	11.0 (5.0)	60.7 (11.3)	13.8 (9.2)	7.5 (3.7)
48 month	7.1 (2.4)	11.1 (5.0)	60.4 (11.1)	13.8 (9.2)	7.6 (3.6)
Forecast Error Variance Decomposition of	ΔInt				
Horizon	ε^{oil}	ε^{s}	ε^{d}	ε^{e}	ε^{m}
6 month	3.0 (1.9)	4.0 (2.6)	11.9 (6.1)	4.5 (2.5)	76.6 (6.7)
12 month	5.1 (2.0)	4.9 (2.7)	14.8 (7.0)	5.9 (2.3)	69.3 (6.9)
24 month	5.8 (2.1)	5.5 (2.6)	15.0 (6.4)	6.4 (2.4)	67.3 (6.4)
48 month	5.9 (2.1)	5.6 (2.6)	15.2 (6.3)	6.5 (2.3)	66.9 (6.6)

Note: values in parentheses are the standard errors from a Monte-Carlo simulation with 10000 draws.

Figure 3.1 Impulse Response Functions



Chapter Four
Exchange Rate Pass-Through:
Evidence Based on Vector Autoregression with Sign Restrictions

4.1. Introduction

The relationship between exchange rate movement and price adjustments of traded goods, which is termed as "exchange rate pass-through", has long been debated in academic and policy circles. When exchange rates changes, foreign firms can choose to pass exchange rate changes fully to their selling prices in export markets (complete pass-through), to bear exchange rate changes to keep selling prices unchanged (zero pass-through), or some combination of these (partial pass-through). It has been widely recognized that exchange rate pass-through is a time-consuming process, and it appears to vary a great deal across countries and time as well as across industries within a country. The total effects of exchange rate pass-through are dependent on microeconomic factors such as market structure, the pricing behavior of firms, as well as macroeconomic conditions.

Thorough understanding of exchange rate pass-through is of extreme importance for several reasons: first, the knowledge of the degree and timing of pass-through are essential for the proper assessment of monetary policy transmission on prices as well as for inflation forecasting. Second, the adoption of inflation targeting requires knowledge of the size and speed of exchange rate pass-through to inflations. Finally, the degree of exchange rate pass-through has important implication for "expenditure-switching" effects from the exchange rate. A low degree of exchange rate pass-through would make it possible for trade flows to remain relatively insensitive to changes in exchange rates, though demand might be highly elastic. If prices respond sluggishly to changes in exchange rates and if trade flows respond slowly to relative price changes, then the overall balance of payments adjustment process would be severely stalled, which will produce a certain degree of "exchange rate disconnect".

Given the importance of the pass-through issue, a sizeable literature has developed over recent years, and basically I can divide them into two strands. The first strand literature have drawn heavily on models of industrial organization and focused on the impact of market structure and foreign firms' pricing behavior. They analyze pass-through to disaggregate import prices of different products or industries at the micro level, such as Yang (1998), Kardasz and

Stollery (2001), Campa and Goldberg (2005), etc.[24] While the finding of the nature of pass-through of the disaggregate studies are very interesting in themselves, the result should not be adduced as evidence that carries over to the broader macro economy (see Kenny and McGettigan (1998)). Therefore, the second strand studies the effects of exchange rate pass-through at the macro level using aggregate price measures. And they pay more attention to the impact of macroeconomic conditions on exchange rate pass-through. As they aim at providing evidence that is more relevant for macroeconomic policy, pass-through of exchange rate changes to import, producer and consumer price are all of interest.[25] So many studies follow the broad definition of pass-through and measure the pass-through rates of exchange rate changes to not only import prices, but also producer and consumer prices.[26] This paper falls into this category.

One dominant branch of this strand assumes the "distribution chain of pricing" to study exchange rate pass-through to prices at different stages of the distribution chain, that is, import price index, PPI and CPI. They typically use a vector autoregression (VAR) model for an analysis of pass-through of exchange rate shocks to domestic inflation by examining the impulse response and variance decomposition. Recent contributions include McCarthy (2000), Hahn (2003), and Faruqee (2004).

It is conventional in this type of empirical studies using VAR models to assume recursive ordering procedures in which some variables can or cannot respond to other variables in the first period of a shock. The assumptions regarding the short-run behavior of money, prices and other variables, which are very stringent but needed for statistical identification of the shocks, have a substantial impact on results. Those standard recursive identifying assumptions may be over-identifying restrictions that have been developed over time in a data-mining like manner as researchers looked for restrictions that can provide sensible results (See Rudebush (1998)). Also, the zero restrictions on the contemporaneous impact of shocks might not be consistent with a large class of general equilibrium models (see Canova and Pina (1998)). Although there are occasionally some studies resorting to long-run restrictions or combination of short and long-run

[24] Some also analyze the pass-through to import price at aggregate level as well as the disaggregate level, for example, Campa and Goldberg (2005).

[25] For example, Obstfeld (2002) argues that for a strong expenditure-switching effect, a high exchange rate pass-through to import price and a low pass-through to consumer price must be satisfied.

[26] The textbook definition of exchange rate pass-through is "the percentage change in local currency import prices resulting from a one percent change in the exchange rate". Changes in import prices are, nevertheless, to some extent passed on to producer and consumer prices. Therefore, they are using a broader definition of exchange rate pass-through, which is seen as the change in domestic prices (import prices, producer prices and consumer prices) that can be attributed to changes in nominal exchange rates.

restrictions, such as Shambaugh (2003) and Hahn (2004), those assumptions are hard to justify and should vary across countries depending on the specific economic structure. From an empirical point of view, Faust and Leeper (1997) show that substantial distortions in the estimations are possible due to small sample biases and measurement errors when using zero restrictions in long run effects.

As an alternative, I pursue the more recent sign restriction approach proposed by Uhlig (2005) to identify exchange rate shocks. There are several advantages in using the sign restriction approach. First, compared to the traditional structural VAR model, restrictions which are often used implicitly, consistent with the conventional view, are made more explicit in the sign restriction approach. Second, in estimating impulse responses, it takes into account of both data and identification uncertainty by simulation, drawing from the posterior distribution of the reduced form VAR covariance matrix and coefficients and from the set of structural matrices consistent with the assumed sign restrictions. Third, sign restrictions are weak in the sense that they do not lead to exact identifications of the reduced form VAR. I regard this as an important advantage, since it circumvents "incredible" zero restrictions on the contemporaneous and long-run impact of shocks. Peersman (2004) finds impulse responses based on traditional zero restrictions can be considered as a single solution of a whole distribution of possible responses that are consistent with the imposed sign constraints. He also shows that a number of impulse responses based on zero restrictions are located in the tails of the distributions of all possible impulse responses. As such, results from the sign restriction approach are more convincing and at least can serve as a robustness check for the past empirical works.

In this paper, by imposing the sign restrictions on impulse responses, I successfully identify the exchange rate shock. I then quantify the extent and speed of exchange rate pass-through to prices along the distribution chain by examining the impulse response functions. I study eight major industrial countries: United States, Japan, Canada, Italy, UK, Finland, Sweden and Spain.[27] I then explore the macroeconomic factors that affect the exchange rate pass-through to explain the cross country differences using Spearman rank correlation. To the best of my knowledge, this is the first attempt to study exchange rate pass-through with this alternative strategy. The main conclusions are the following: first, for most countries, I find partial pass-through to be the most common phenomenon, though complete pass-through is

[27] Germany is a large country, I should have included it. However, due to the lack of data for more than 200 observations compared to other countries, I have to exclude it from my study.

observed occasionally. Second, the extent of pass-through declines and the speed slows along the distribution chain. Third, I find that a greater pass-through coefficient is associated with an economy that is smaller in size with higher import shares, more persistent and less volatile exchange rate shocks, more volatile monetary shocks, higher inflation rate and less volatile GDP.

The rest of the paper is organized as follows. In section 4.2, a comprehensive theoretical background and literature review is provided. In section 4.3, a VAR model based on microeconomic import price determination and macroeconomic factors are constructed. Methodology of the sign restrictions is discussed. Section 4.4 reports the results of estimation and examines the determinants of exchange rate pass-through. Section 4.5 is for robustness check and section 4.6 concludes.

4.2 Theoretical Background and Literature Review

There has been growing body of literature on this topic. This section aims to provide a brief yet comprehensive review of the literatures. I first provide some theoretical background about the determinants of exchange rate pass-through in section 2.1; in section 2.2, I discuss the main empirical studies, summarizing the salient features of these works and explaining how my research fits into the literature.

4.2.1. Theoretical Background

There are many factors - both microeconomic and macroeconomic - affecting exchange rate pass-through. At the micro level, well-known factors are: the responsiveness of mark-ups, the degree of returns to scale in production and the demand elasticity of the imported goods.

In a hypothetical monopoly market, where a foreign firm is able to maintain a constant mark-up, the exchange rate pass-through would be complete. However, this is not the case in reality. Mark-ups will adjust in order to keep prices in destination markets constant, which is termed as “pricing to market”. Foreign firms usually sustain substantial shifts in profit margins as exchange rate changes, because they want to keep constant the market share, thus, exchange rate pass-through is dampened. The mark-up response is often interpreted as an indicator of changes in competitive conditions confronting foreign exporters in the destination market. Several studies, such as Dornbusch (1987) and Hooper and Mann (1989), observed that the adjustment of mark-up to exchange rate movements is dependent on the extent of product homogeneity and substitutability, the relative market shares of domestic and foreign firms, the market concentration and the extent of price discrimination. A general result in the literature is that a more differentiated (or the less substitutable) products in an industry, a larger share of foreign exporters relative to domestic producers, a higher degree of price discrimination or a higher concentrated market will lead to greater ability to maintain mark-up, thus higher pass-through rates.

The degree of returns to scale also affects the pass-through. According to Olivei (2002), if a typical foreign firm sets the price of an export good as a constant mark-up over marginal costs (with price and marginal costs measured in domestic currency), then complete pass-through will occur when returns to scale are constant. In this scenario, a m percent domestic currency appreciation lowers the foreign firm's marginal costs measured in domestic currency by m percent. In the case of decreasing returns to scale, pass-through will be less than full. The increase in domestic demand for the imported good brought by the domestic currency appreciation will put upward pressure on the foreign firm's marginal costs. Thus, marginal costs decline by less than m percent in response to a m percent domestic currency appreciation, which leads to incomplete pass-through. In a similar vein, Yang (1997) reports that exchange rate pass-through is negatively related to the elasticity of marginal cost with respect to output.

Demand elasticity affects exchange rate pass-through as well. An exporting firm's pricing reaction to an exchange rate change depends on the curvature of its perceived demand elasticity. If demand becomes more elastic as price goes up, it is to firms' benefit to refrain from fully passing through the exchange rate shock to purchasers' prices (see Yang (1997)).

Several studies, such as Mann (1986) and Taylor (2002), have identified factors affecting exchange rate pass-through at the macro level. They are: the size of a country, the openness of a country, exchange rate shock volatility and persistence, aggregate demand volatility, inflation environment and monetary policy environment.

In a large country, the inflationary effect of a currency depreciation on domestic prices is counteracted by a decline in the world price (because of lower world demand), reducing the measured pass-through. For a small country, currency depreciation would have no effect on world prices, and pass-through would be complete (See McCarthy (2000)).

Openness can be linked to the "ratio of importers to domestic producer" at the micro level, which can be measured by trade share (or import share) in total production. It is intuitive that the more open the country (or the higher the import share of total production), the greater the exchange rate pass-through.

Using the pricing to market principle, Mann (1986) discusses that exchange rate shock volatility is negatively related to pass-through. There is cost involved in adjusting prices.[28] If exporters perceive a shock to be transitory, they would refrain from changing prices by shifting the mark-up and adopt the “wait and see” approach, thus reducing the pass-through. On the other hand, if firms expect exchange rate shocks to be persistent, they are more likely to change prices rather than adjust profit margins.

Another economic variable put forward by Mann (1986) is aggregate demand uncertainty. Exporters will alter profit margins when aggregate demand shifts in tandem to exchange rate fluctuations in an imperfectly competitive environment, thus reduce measured pass-through. So pass-through should be less in countries where aggregate demand is more volatile.

A further determinant of pass-through - inflation environment - is brought forward by Taylor (2000). According to Taylor (2000), perceived persistence of cost changes is likely to be positively related to the persistence of aggregate inflation, which also tends to be positively correlated with inflation rate.[29] So in a macroeconomic environment with a great deal of price stability, an increase in (nominal) marginal cost will have less persistence than in an environment with little aggregate price stability. While firms adjust their prices (pass-through) to a lesser extent to cost and price developments that are expected to be less persistent, a low inflation environment may entail a lower pass-through of (exchange rate) shocks to prices via a reduction in the expected persistence of shocks.

A related factor to inflation environment is relative stability of monetary policy. Deverux, Engel and Stogaard (2003) develop a model of endogenous exchange rate pass-through within an open economy macroeconomics framework. They find that countries with relatively low volatility of money growth will have relatively low rates of exchange rate pass-through. When two countries have differences in the volatility of monetary growth, exporting firms of both countries will tend to pre-set their prices in the currency of the country with stable monetary policy, thereby reducing the impact of exchange rate changes on the country’s prices.

Besides these theoretical underpinnings of exchange rate pass-through in general, a more

[28] The cost includes re-tagging goods, revising and reprinting catalogues and advertising.
[29] Exchange rate changes are usually perceived as cost shocks for a foreign firm producing in its home country and selling in its export market. (see Yang (1997))

differentiated analysis regarding exchange rate pass-through at different stages of the distribution chain is of great interest. Exchange rate shocks may affect prices at different stages both directly and indirectly through previous price stages. To be more specific, exchange rate movements are transmitted to PPI and CPI through three channels: (i) through prices of imported intermediate goods, which are reflected by the share of imports in PPI; (ii) through prices of imported consumption goods, which are reflected by the share of imports in the CPI baskets; (iii) through prices of domestically produced goods. The extent of pass-through to PPI and CPI will therefore depend on the rate of pass-through to import price, the share of imports in PPI and CPI, and responses of prices of domestically produced goods to movements in exchange rates.

Assuming for a moment that prices of domestically produced goods do not respond to exchange rate changes, then the degree of exchange rate pass-through is declining along the distribution chain. There are two reasons. First, the share of imported goods seems to decrease along the distribution chain, pointing to a declining pass-through (see Clark (1999)). Second, given incomplete pass-through at individual stages, accumulation over different stages also implies a decline in the pass-through along the distribution chain. However, it is worth emphasizing that prices of domestically produced goods typically do respond to movements in exchange rates. For example, if depreciation results in higher prices for imported goods, production costs of domestically produced goods increase via increased prices of imported intermediate. In addition, demand for domestic goods that compete with imports will increase. As a result, there will be upward pressure on domestic prices.

With regards to the adjustment speed, adjustment lags at different stages of the distribution chain might accumulate in the presence of price stickiness, which imply a decline in the adjustment speed along the distribution chain (see Blanchard (1987)).

4.2.2. Previous Findings

While I can broadly characterize the empirical works into two strands - the micro or macro level - according to their perspective, the data and methodology vary a lot even in the same strand. As Menon (1995) points out “the significant differences in the estimate of pass-through obtained by different researchers studying the same country, commodity and time period highlight the importance of choice of data and methodology”. For ease of reference, the data, methodology and key findings are summarized in tabular form in Table 4.1. These studies are listed in chronological order.

[Table 4.1 about here]

In summarizing the findings of previous studies, I concentrate on the following two issues: (i) the degree and dynamics of pass-through; (ii) pass-through across countries and products;

(i) Pass-through degree and dynamics: It is clear from Table 4.1 that incomplete pass-through is a prevalent phenomenon across a broad range of countries and industries, but still a number of studies have found full pass-through for certain countries and industries, such as Faruqee (2004), Kenny and McGettigan (1998), etc. Majority of the studies find adjustment lags in exchange rate pass-through, which vary across the countries and industries. They even vary among different studies for the same country and industry. In addition, most studies find that the degree and speed of exchange rate pass-through is greatest and fastest on import price, then on PPI and smallest on CPI.

(ii) Pass-through across products and countries: At the micro level, there are significant differences in the rate of pass-through across industries. This is quite clear from the multi-industry study, such as Yang (1997) and Camp and Goldberg (2005). At the macro level, pass-through rates also vary a lot from country to country. For example, Choudhri, Faruqee and Hakura (2004) finds that pass-through ranges from a low 0.47 for Czech Republic to full pass-through in Slovenia. In addition, results from some of the multi-country studies provide conflicting signals with regard to some theoretically widely-accepted relationship. For example, Jonathan (1998) finds that pass-through tends to be inversely correlated with the size of the country, while Hung, Kim and Ohno (1993) and Campa and Goldberg (2005) hardly find any relationship between pass-through and the country size.

As Table 4.1 reveals, empirical literature on pass-through has mainly adopted three approaches, namely, standard single-equation regression techniques, stationary VAR and cointegration. The earliest researchers have employed OLS to estimate pass-through, with polynomial distributed lags used to capture the dynamic response of traded good prices to exchange rate changes. However, those researchers have not paid attention to the time series properties of the data. A considerable body of literature suggests that a large number of macroeconomic series and asset prices such as exchange rates are non-stationary. Hence, the assumptions of OLS estimation are violated, creating the problems of spurious regression. By employing first differences of the variables, this problem can most probably be avoided, but information in levels is lost. What is more, estimates of pass-through obtained from a single-equation model are based on a ceteris paribus interpretation of coefficients. It assumes that there is no endogenous adjustment in prices accompanying changes in exchange rates. Thus, the estimation suffers from inconsistency problems due to endogenous determination of exchange rates and prices.

McCarthy (2000) pioneers the stationary VAR framework that incorporates a recursive distribution chain of pricing. Using differenced VAR models has several advantages compared to previous single-equation-based methods. First, it solves the endogeniety problem inherent in the single-equation-based methods. Second, it allows us to incorporate prices along the distribution chain in a unifying model. By investigating exchange rate pass-through to a set of prices along the distribution chain, the VAR analysis characterizes not only absolute but relative pass-through in up-streaming and down-streaming prices. Third, estimated impulse response functions trace the effects of a shock to one endogenous variable on other variables through the structure of VAR, which allows me to assess not only pass-through within a specific time period, but also its dynamics through time.

However, there are shortcomings associated with a differenced VAR system. Differencing throws information away while produces no gains, which may cause the results, such as impulse response functions, to lack statistical significance (See Fuller (1976) and RATS User's Guide (2004)). With data generated from a dynamic stochastic general equilibrium model and Monte Carlo techniques for statistical inferences, Bache (2005) finds that impulse response functions from a VAR in first difference are biased, even when the VAR is specified with a large number of lags. By contrast, a low order vector cointegration model is a good approximation to the data generating process, and cointegration can capture the equilibrium relationships among the variables. However, he doubts whether an econometrician would be able to infer the correct rank or identify the true cointegration relations.

Based on these, I estimate the VAR in levels with sign restrictions. The sign restriction method involves Bayesian Monte Carlo procedure. According to Sims (1988), the Bayesian method does not require differencing, which justifies adopting VAR in levels. What is more, using sign restrictions can avoid the zero restrictions of Choleski decomposition that is used in most previous studies.

As my work is from a macroeconomic standpoint, I follow the broad definition of exchange rate pass-through and measure the exchange rate pass-through to the three aggregate price indices, i.e. import price, producer price and consumer price.

4.3. A Simple VAR Model with Sign Restrictions

The model draws on the "distribution chain" model introduced by McCarthy (2000), but differs from his model in several aspects. Firstly, I include one important variable omitted by him, the foreign price level. Secondly, instead of oil price in local currency, I use oil price in the US dollar. Since fluctuations of oil prices in local currency largely reflect not oil price fluctuation per se but the variability of bilateral exchange rate vis-à-vis the US dollar. Thirdly, to make the model as simple as possible, I include only the short-term interest rate to capture monetary policy shock, instead of including both the interest rate and money supply as he does. Lastly, while I incorporate the distribution chain, I do not make recursive assumptions in the distribution chain.

This section comprises two parts. The first part of the section refers to the setup of the baseline model. The second part illustrates the implementation of the sign restriction approach.

4.3.1. The VAR Model

The VAR model consists of eight endogenous variables: oil price (P_{oil}), short-term interest rate (S), output gap (Gap), nominal effective exchange rate (NER), foreign export price index (FP), import price index (IMP), PPI and CPI.

Output gap is included to capture demand shocks, while oil price is to balance the model with supply shocks. Following McCarthy (2000), output gaps are calculated as the residuals from a regression of the log of industrial production indices on a constant plus linear and quadratic time trends.[30] A positive (negative) deviation indicates that the country is growing faster (slower) than the trend. This variable acts as a proxy for the business cycle, which can capture the notion that pass-through of increases in costs to final prices is affected by aggregate demand. For example, large depreciations sometimes do not imply large price increases when the economy is in recession and firms do not adjust their prices proportionally to increases in costs.

The short-term interest rate is included in the model to allow for the effects of monetary

[8] I employ the industrial production index because I want to use monthly series for the empirical analysis.

policy. These countries' monetary policies are usually assigned to keep domestic inflation within the target ranges, thus their monetary authorities are likely to try to offset the effects of exchange rate fluctuation on domestic prices. As such, the underlying relationship between changes of exchange rates and domestic prices may be masked if monetary policy is excluded from the analysis (see Hahn (2003)). Neglecting the short-term interest rate may result in the omitted variables problem.

The majority of previous studies, including McCarthy (2000), Hahn (2003) and Ito, Sasaki and Sato (2005), fail to include foreign export price level. The microfoundations of export pricing behavior suggest that the variable is essential in modeling exchange rate pass-through.

The import price for any country i, $P^{m,i}$, is a transformation of the export prices of that country's trading partners, $P^{x,i}$, using the bilateral exchange rate, ER, which is expressed in domestic currency per unit of foreign currency.

$$P^{m,i} = ER^{i} P^{x,i} \qquad (1)$$

The export prices, in turn, are a mark-up ($markup^{x}$) over the exporter's marginal costs MC^{x}. Using lower letters to reflect logarithms, equation (1) can be rewritten as:

$$p^{m,i} = er + markup^{x} + mc^{x} \qquad (2)$$

While exchange rate changes may have direct effect on import prices, they can also affect mark-up and marginal costs of exporting firms. Kim (1990) shows that in the presence of short-run cost price rigidity, mark-ups will fall with exporting firms' currency appreciation and rise with a depreciation. Also marginal costs tend to increase with exporting firms' currency depreciation because of more expensive imported inputs. Therefore, it is essential to include foreign export price index to control the indirect transmission of exchange rate changes to domestic prices through mark-up and marginal costs of trading partners.

Exchange rate, import price, PPI and CPI are the center of the analysis, they are included naturally.[31]

I choose to use effective nominal exchange rates and effective foreign export price indices, as I think effective exchange rates will better reflect the situation of a country that is trading with many other countries. So it remains to choose the weighting scheme for effective exchange rates and effective export price indices of trading partners. Different weighting schemes generate very

[31] I have used import price index or unit value of import, whichever is available.

different time series of effective exchange rates. Although indices based on multilateral shares of major industrial countries are often used to measure the extent of real appreciation or depreciation of the currency, they are not ideal for this case (see Kim (1990)). Pauls and Helkie (1987) reports that an index based on bilateral import shares of developing countries as well as industrial countries forecasts import prices better than indices based on multilateral trade shares or excluding developing countries in weighting. As such, the nominal effective exchange rates are constructed by the weighted average of bilateral exchange rates vis-à-vis trading partners, according to the formula:

$$NER = \Pi_{i=1}^{q}\left(\frac{ER_d}{ER_i}\right)^{\omega_i}$$

where ER_i is the nominal exchange rate of currency *i*, expressed as units of currency *i* per US dollar, ER_d is the nominal exchange rate of domestic currency, expressed as units of domestic currency per US dollar. The weight, ω_i, is the share of import from country *i* in domestic country's total import with its q largest trading partners, q is large enough to capture 80% of total import in a country.[32] The exchange rate is constructed in such a way that an increase in the index implies a depreciation of the domestic currency. The foreign export price index is the weighted average of foreign producers' prices using the same weighting scheme as the nominal exchange rate.[33]

The model is summarized in the reduced-form VAR:

$$Y_t = \Gamma_0 + \sum_{i=1}^{n} B_i Y_{t-i} + u_t \qquad (3)$$

where Y_t is an 8×1 vector of variables $[Poil, S, GAP, NER, FP, IMP, PPI, CPI]'$, B_i are 8×8 coefficient matrices and u_t is the one-step ahead prediction error with variance-covariance matrix Σ, Γ_0 is the intercept. All variables are in logarithms except the short-term interest rate. The number of lags in the VAR is set at 6 for all countries except the US, the shortest lag that can

[32] The trading pattern is quite spread out for some countries while concentrated for other countries, so I do not use the same number of trading partners for all the countries. Instead, I include enough number of trading partners for each country to ensure at least 80% of the total imports is captured. The weights are calculated based on the average of 1989-1998 year trade data available from DOTS. Although Taiwan China, mainland China are important exporters to many countries, they are not included due to the absence of some data in International Finance Statistics.

[33] I will use export price index or unit value of export, whichever is available. If they are not complete or not available, I will use producer price index or consumer price index instead.

produce white noise residuals.[34] The model is estimated over the period 1976:01 to 2005:08.

4.3.2. Implementation of the Sign Restrictions

Disagreement starts when researchers discuss how to decompose the prediction error u_t in equation (3) into economically meaningful fundamental innovations. Most works rely on Choleski decomposition assuming different orderings among the variables, about which disputes exist. Here I employ the sign restriction approach, which will make use of some weak restrictions that have achieved agreement among most researchers. For example, a depreciation of domestic currency will lead to an increase in import price, PPI and CPI.

There are two branches of sign restrictions. Canova and De Nicolo (2002) imposes sign restrictions on cross-correlations of variables in response to shocks, adding restrictions until the maximum number of shocks is uniquely identified. Uhlig (2005) imposes sign restrictions on impulse responses directly. He does not aim at a complete decomposition of the one-step ahead prediction errors into all components due to underlying structural shocks, but rather concentrate on identifying only one shock. His intention is to be minimalistic and to impose not much more than the sign restrictions themselves, as they can be reasonably agreed upon across many economists. In this paper, my primary interest is to obtain evidence on how exchange rate shocks affect different prices over time. Instead of identifying all structural disturbances, I use minimal restrictions that are sufficient to identify the exchange rate shock and quantify the extent of price changes to exchange rate changes. So the method of Uhlig (2005) suits best here.

The method involves a rejection based Bayesian Monte Carlo procedure, which consists of "outer-loop draws" and "inner-loop draws".

To identify the exchange rate shock, I must identify the impulse vector corresponding to the exchange rate shock, er, which is a column of A, and $AA' = \Sigma$.[35] A can be any factor of permissible decomposition of Σ, such as those based on Choleski decomposition, Eigen decomposition or structural decompositions. The products of the factors with identity matrices are also permissible factors.

The impulse vector corresponding to exchange rate shock, er, can be characterized as

[34] I choose lag 5 for the US, since lag 5 is the shortest lag length that can produce white noise residuals.

[35] According to Uhlig (2005), a vector a is called an impulse vector, iff there is some matrix A, so that a is a column of A and $AA' = \Sigma$.

follows. Let $\tilde{A}\tilde{A}=\Sigma$ be the Choleski decomposition of Σ, Then er is the impulse vector if and only if there is an eight-dimensional vector α of unit length, so that

$$er=\tilde{A}\alpha$$

Given the impulse vector for exchange rate shocks, the appropriate impulse response is calculated as follows. Let $r_i(k)$ be the vector response at horizon k to the exchange rate shock in a Choleski decomposition of Σ. The impulse response of the variables to an exchange rate shock at horizon k, $r_{er}(k)$ is then given by:

$$r_{er}(k)=\sum_{i=1}^{8}\alpha_i r_i(k) \qquad (4)$$

And the fraction $\phi_{er,j,k}$ of the variance of this forecast error for variable j explained by exchange rate shock at horizon k is given by:

$$\phi_{er,j,k}=\frac{(r_{er,j}(k))^2}{\sum_{i=1}^{8}(r_{i,j(k)})^2} \qquad (5)$$

So as the first step of the simulation, which is "outer-loop draws", I take n_1 random draws from the posterior distribution of the reduced form VAR coefficients, B_i, and the covariance matrix of disturbance, Σ.[36] For each draw from the posterior distribution of the VAR parameters, I decompose it with Choleski decomposition and get the Choleski factor $\tilde{A}$. In the second step, n_2 draws are randomly taken from the unit sphere assuming a flat prior, getting an eight-dimensional vector of unit length, α, which is the "inner-loop draws".[37] The impulse vector is constructed according to: $er=\tilde{A}\alpha$. The corresponding impulse response and forecast error variance are obtained according to equation (4) and (5).

I generate $n_1\times n_2$ draws, thus $n_1\times n_2$ exchange rate impulse vectors and $n_1\times n_2$

[36] The posterior distribution is derived under the assumption of a diffuse Jeffries prior over the parameters of the VAR. Following Zellner (1971), if the joint distribution of the VAR disturbances is $i.i.d$ normal and the elements of B_i are independent of elements of Σ, then a Jeffries prior implies B_i has a normal conditional posterior distribution and Σ has an Inverse Wishart conditional posterior distribution (See RATS User's Guide (2004)).

[37] Drawing from flat prior on the unit sphere is appealing, because the results will be independent of the chosen decomposition of Σ. So reordering the variables and choosing different Choleski decomposition in order to parameterize the impulse vectors will not yield different results.

corresponding sets of impulse responses and forecast error variance decompositions.[38] Only the impulse responses, whose ranges are compatible with the sign restrictions, are kept and used to calculate the median impulse response and probability bands.

The sign restrictions I impose on impulse responses are:

1. The output gap does not decrease (≥ 0) in response to a positive exchange rate shock, i.e. exchange rate depreciation. As the domestic currency depreciate, exported goods become cheaper relative to imported goods, increasing demands for domestic goods and the output gap.
2. The short-term interest rate does not decrease (≥ 0) to a positive exchange rate shock, as monetary policy will tighten to back up the exchange rate.
3. The exchange rate will not decrease (≥ 0) in response to its own positive shock.
4. The foreign export price index does not increase (≤ 0) in response to a positive exchange rate shock. As the mark-up and marginal cost decrease when foreign firms' currency appreciates.
5. The import price, PPI and CPI do not decrease (≥ 0) in response to a depreciation of the domestic currency.

These restrictions seem reasonable as they only make use of a priori appealing and consensual views about the effects of exchange rate shock on demand, monetary policy and various prices. However, there remains one degree of the choice here: the horizon K for the sign restrictions. I follow the convention of setting K=5. And leave other possible values of K for robustness check.

4.4. Results

In this section, I first report the impulse responses of import price index, PPI and CPI to an exchange rate shock, and the pass-through ratios of price indices are calculated. Secondly, I explain the cross-country differences by calculating the Spearman rank correlation between the pass-through ratios and the macroeconomic factors discussed in section 4.2.1. Thirdly, I present variance decompositions, which are assessments of the importance of exchange rate shocks in explaining movements of price measures.

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[38] I make $n_1 = n_2$=500, so there are 250000 draws in total.

4.4.1. Impulse Responses and Pass-Through Ratios

[Figure 4.1, 4.2, 4.3, 4.4 about here]

Figures 4.1-4.4 display the impulse responses of the nominal exchange rate, import price index, PPI and CPI to a positive exchange rate shock. The solid line in each graph is the estimated response while the dashed lines denote the one standard error confidence band around the estimate. It is interesting to note that the error bands are typically symmetric around the median. The results can be described as follows:

1. The nominal exchange rates increase instantly and significantly in response to their own shocks in all countries, and remain significant for a while, with those in Japan, Spain and Finland reverse the sign at some late horizons.
2. The import price indices in all countries react largely and positively immediately following the shock. Most of the impulse response functions remain significantly positive for 8 to 15 months, with those of the US, Italy and the UK remaining significant almost for all horizons. However, the impulse response of Japan reverses the course in about one year.
3. The PPI and CPI react similarly as the import price index, but with smaller magnitudes. The import price index and PPI in Japan reverse the course in two years, but not significantly. For the CPI, the responses in all countries remain significant for almost all horizons except for Spain.

[Table 4.2 about here]

It is unclear to compare the pass-through ratios of import price index, PPI and CPI by just examining the impulse response functions because the initial exchange rate shocks in the countries are not of equal size. For easy comparison, I calculate the pass-through ratios defined as $PT_{t,t+i} = \frac{P_{t,t+i}}{E_0}$, where $P_{t,t+i}$ is the change of price indices in the period i, E_0 is the impact change of exchange rates to their own shocks. Table 4.2 displays the pass-through ratios for horizons 0, 3, 6, 9, 12 and 15. Several main characteristics emerge:

1. Incomplete pass-through seems to be a universal phenomenon across the countries and horizons. But I do find complete pass-through in some countries at some horizons, such as import price of Canada at horizons 0, 3 and 6. Yet, those estimates are within the ranges of previous works in Table 4.1.

There are some cases where the pass-through ratios are greater than one, indicating that foreign exporters are overreacting to exchange rate shocks. Many previous studies, such as Campa and Goldberg (2005), have similar findings. Although such rates are unlikely to be observed, it is possible to justify. There are mainly two reasons. First, as discussed in section 4.2, the degree of returns to scale affects pass-through, in the case of increasing returns to scale, changes in exchange rates are more than fully passed through to import prices. Second, demand elasticity affects exchange rate pass-through as well. If demand curve becomes less elastic, pass-through ratios become greater than one (Yang (1998)). In addition, the results should be interpreted with caution since the error bands are wide in some cases, rendering the estimates less accurate.

2. It is also interesting to note that, in several countries, such as Canada and Spain, I find pass-through overshoots. The pass-through rates decline after reaching the maximum. Choudhri, Faruqee and Hakura (2005) also finds similar overshooting patterns in exchange rate pass-through.
3. In most countries, the pass-through ratios are largest for the import price index, followed by the PPI, and smallest for the CPI, confirming the previous finding that the pass-through ratios decline along the distribution chain. The main exceptions are the UK and Sweden, in which the pass-through to the CPI is larger than that to the PPI. In addition, exchange rate pass-through to the CPI is modest in most countries except Sweden, Since CPI is usually the principal price index for monetary policy, the result suggests that monetary policy may not need to be over sensitive to exchange rate fluctuations resulting from turmoil in emerging markets.
4. As to the speed of pass-through adjustment, it appears that pass-through to the import price index reaches the maximum (or complete) first, then for the PPI and last for the CPI. The results are in line with the previous finding that the speed of pass-through declines along the distribution chain.

4.4.2. Spearman Rank Correlation

Though the pass-through ratios of all countries share some common characteristics, there are noticeable differences across countries. To explain the differences, I calculate the Spearman rank correlation between the pass-through ratios at various horizons and the factors that are expected to influence them. McCarthy (2000) also calculates the Spearman rank correlation, but I choose slightly different factors. From discussion in section 4.2, the factors at the macro level are: (1) the size of a country, represented by the average nominal GDP value in national currency deflated by CPI and converted into U.S. dollar at the year 2000 average nominal exchange rate. (2) The openness of a country, approximated by the mean import share of GDP in the sample period. (3) Exchange rate shock volatility measured by the variance of the residuals from the exchange rate equation in the VAR system. (4) Exchange rate shock persistence measured by the impulse response at the 12-month horizon of the exchange rate to its own initial shock.[39] (5) Aggregated demand volatility measured by the variance of real GDP during the sample period. (6) Inflation environment, measured by the average annualized inflation rate based on the CPI in the sample period. (7) Monetary policy environment, measured by monetary shock volatility. I use the variance of the residuals from the short-term interest rate equation as the approximation. Tables 4.3-4.5 present the Spearman rank correlations between pass-through ratios at the horizons 0, 3, 6 and 12 and the above factors.

[Table 4.3, 4.4, 4.5 about here]

The rank correlations are generally in accord with theory discussed in section 4.2. Country size is inversely related with pass-through. Because foreign exporters are more willing to maintain market share in a large market, they are more likely to exercise pricing-to-market to a large country and thus reduce the pass-through. The correlations between pass-through ratios and country size are all correctly signed and significant at the 10% level in half of the cases. The more open the country (the higher import share), the higher is the pass-through, with the only exception being the import price index at the horizon 12. The more volatile the exchange rate shocks, the less the exchange rate pass-through, as foreign exporters hesitate to change prices if exchange rate changes are perceived to be transient. The more persistent an exchange rate shock, the higher is the pass-through ratio, except for import price index at the horizons 0, 3, 6. Aggregate demand volatility, which is approximated by the real GDP volatility, is negatively correlated with pass-through ratios in most cases, which is in line with the notion that the more volatile the aggregate demand, the lower the pass-through. Inflation rate is positively correlated with pass-through in most cases, though the relationship is not strong. The results give some support to Taylor (2000). Also, more volatile monetary policy shocks lead to higher pass-through,

[39] I follow McCarthy (2000) to measure the exchange rate shock volatility and exchange rate shock persistence.

and the signs of the correlation coefficients are all correct and quite significant in several cases, which give strong support to the finding of Deverux, Engel and Stogaard (2003).

In summary, higher import shares, more persistent exchange rate shocks, higher inflation rate, more volatile monetary shocks are related with higher pass-through. While a larger economy, more volatile exchange rate shocks and aggregate demand (GDP) are correlated with lower pass-through.

4.4.3. Variance Decompositions

While impulse response functions provide information on the extent of exchange rate pass-through to domestic prices, they yield no information about how important exchange rate shocks have been for movements of the price indices. In the case that pass-through is large, but exchange rate shocks are small, exchange rate shocks will not have much impact on domestic prices. Therefore, it is necessary to investigate the importance of exchange rate shocks. For this purpose, I examine the variance decompositions of the price indices.[40] Table 4.6 presents the percentage of forecast error variance for the price indices attributed to exchange rate shocks at the horizons 0, 3, 6, 12, 15. The numbers in parentheses are the standard errors.

[Table 4.6 about here]

For the import price index, exchange rate shocks are most important in Canada and Japan, where their share ranges from 24-30% and 20-35%, respectively. In other countries, exchange rate explains 12-28% of forecast error variance. For the PPI and CPI, similar patterns can be observed as for the import prices. The share of exchange rate shocks in the three price indices is usually comparable within each country and the percentage is quite stable across horizons.

In sum, the variance decompositions indicate that exchange rate shocks explain non negligible - though not dominant - proportion of the forecast error variance of the price indices, thus establishing exchange rate shocks an important source of fluctuations in domestic prices.

[40] It should be noted that it is harder to interpret the results of forecast error variance decomposition in sign restrictions, because the percentage often have a much skewed distribution. One cannot interpret the results without also considering the significance of the impulse responses. The results of variance decomposition are more meaningful for steps that have well-defined strict positive or negative responses. In my case, most steps I reported have significant impulse responses, so the results are quite plausible.

4.5. Robustness Check

In this section, I consider some variation of the baseline model for robustness check. I first present the results obtained by an alternative method to calculate the pass-through ratios. I also investigate the sensitivity of the results to the choice of the restriction horizon, K.

4.5.1. Alternative Measure of Defining Pass-Through Ratio

In the VAR literature, two measures are widely used in defining the pass-through ratio. The first is what I adopted in getting the baseline results, defined as $PT_{t,t+i} = \frac{P_{t,t+i}}{E_0}$, where $P_{t,t+i}$ is the change of price indices in the period i, E_0 is the impact change of exchange rates to their own shocks. The second is defined as $PT_{t,t+i} = \frac{P_{t,t+i}}{E_{t,t+i}}$, where $E_{t,t+i}$ is the change of exchange rate in the period i to initial exchange rate shocks. Those who propose the second measure of defining pass-through ratios argue that this way will account for the secondary exchange rate dynamics generated by initial shocks. However, I think this way of measurement mixes in a systematic way changes in exchange rates from other variables with the pure exchange rate shocks. As I regard pass-through as the effect of a pure exchange rate change rather than changes from other sources, I prefer the first measure of defining exchange rate pass-through ratios. Yet, it would be interesting to use the second measure as a robustness check.

[Table 4.7, 4.8. 4.9, 4.10 about here]

Table 4.7 presents the pass-through ratios obtained using the alternative measure. Tables 4.8- 4.10 present the Spearman rank correlations between the pass-through ratios and the determinants. The basic characteristics as to the speed and magnitude of pass-through along the distribution chain tend to hold though not as clear as in the baseline results. But strange results emerge with this alternative definition, such as implausible pass-through ratios of -956.924, 483.27 in Japan. As to the Spearman rank correlation, most results are in agreement with those from baseline measure except for the exchange rate persistence. In most cases, exchange rate persistence is negatively correlated with pass-through ratios, which is in contradiction to theory.

In general, the first measure of defining exchange rate pass-through ratio is preferred.

4.5.2. Different Restriction Horizon K

How sensitive are the results to the changes in horizon K for the sign restrictions? In this part, I present the results for 3-month (K =2) and 12-month (K =11) horizon restriction.

[Figure 4.5, 4.6 about here]

Figures 4.5 and 4.6 show the impulse response functions of the import price to a positive exchange rate shock for K =2 and K =11, respectively.[41] The results are quite similar to that of the baseline setup, especially for K =2. Only for Sweden with K =11, the accepted draw from sign restrictions is 1, which does not allow the impulse responses to generate the error bands. This is not unreasonable, the restriction horizon is quite long for K =11, and the actual data pattern of Sweden may not generate enough draws that are compatible with the sign restrictions for such long horizon. Table 4.11 shows the forecast error variance decompositions for the import price with K =2 and K =11. Still, there is not much difference between these results and that from my baseline setup.

[Table 4.1, 4.12, 4.13 about here]

Tables 4.12 and 4.13 present the pass-through ratios of the price indices. The main results remain the same as in the baseline set-up, with only a slight difference in the magnitudes.

In general, the results are quite robust to different horizons. The sign restriction approach appears to produce results that are stable and sensible given the reasonable choice of K .

4.6. Conclusion

This paper examined the pass-through of exchange rate changes to domestic prices for several industrialized economies. Using a VAR model with sign restrictions, I successfully identify the exchange rate shock. Information on the size and the speed of exchange rate pass-through is then derived from impulse response functions. According to the results, pass-through is incomplete in many horizons, though there is occasionally complete pass-through. The degree of pass-through decreases and the time needed for complete pass-through lengthens along the distribution chain. These results seem to be broadly in line with previous findings. I also find that a greater pass-through coefficient is associated with an economy that is smaller in size with higher import shares, more persistent and less volatile exchange rate shocks, more volatile monetary shocks, higher inflation rate and less volatile GDP.

[41] For the sake of brevity, I do not present the impulse response functions of PPI and CPI. But the same conclusion can be drawn as that of the import price. The results are available upon request.

Robustness was tested in two ways. First, estimates of the pass-through using an alternative measure are generated and compared to the baseline model. I give preference to the definition in the baseline setup. Second, I change the restriction horizon of K and find that the outcomes remain stable across different restriction horizons.

In summary, the sign restrictions approach appears to produce sensible and stable results, which can further be used as inputs for making monetary policies. Nevertheless, the sample period is quite long, several financial and economic crises have happened, which has effects on the global prices of some goods. A natural extension is to model the time variation in the parameters in the context of the sign restrictions, and I leave this for future research.

Table 4.1: The Empirical Literature on Exchange Rate Pass-through

Study	Data	Method	Findings
Kim (1990)	Quarterly import unit values of the US.	Varying parameter approach in the form of the Kalman filter	Sensitivity of the import prices to exchange rate changes reduced in the 1980s, with significant 'pricing to market' behavior.
Hung, Kim and Ohno (1993)	Quaterly export unit values of 16 countries.	Cointegration and error correction model	The export prices increase significantly only in Belgium, the Netherlands, Japan and Taiwan China. Other countries' export prices are little affected. There is hardly any correlation between the size of country and the extent of export price adjustment.
Menon (1995)	Import prices of the Australian manufactured imports.	Johansen Maximum Likelihood procedure	The pass-through is incomplete, around 66%.
Yang (1997)	Quarterly import price indices of the three- and four-digit SIC industries in the manufacturing sector in the US.	Two stage single equation method	The short run exchange rate pass-through elasticities range from 16.25-42.85% across the industries, while the long run elasticities range from 21.23-75.59%. The pass-through is positively correlated to product differentiation, and negatively to the elasticity of marginal cost.
Yang (1998)	Import and export price indices covering 2-,3-,4-digit industries in the manufacturing sector in the US.	Two stage single equation method	Pass-through is incomplete, and is larger for the U.S. exports than for the U.S. imports.

Table 4.1 (continued)

Study	Data	Method	Findings
Kenny and McGettigan (1998)	Import unit values and domestic manufacturing output price indices of Ireland.	Vector error correction mechanism	Pass-through to the import unit values and domestic competing prices are close to full.
McCarthy (2000)	Quarterly import price, PPI and CPI of nine developed countries	Stationary VAR model	Pass-through is very small, and largest on the import price, second on the PPI and then on the CPI. Pass-through is larger in countries with a larger import share and more persistent exchange rate shocks.
Kardasz and Stollery (2001)	Import prices of 33 Canadian manufacturing industries at L-level of aggregation	Two-stage single equation estimation procedure	First, pass-through is small, averaging 25.5%. Second, pass-through elasticities vary a lot across industries.
Toh and Ho (2001)	Quarterly export prices on several different main products of 4 newly industrialized countries	Vector error correction model	The aggregate pass-through elasticities for Malaysia, Thailand, Singapore and Taiwan are 0.63, 0.997, 0.807 and 0.127, respectively.
Choudhri and Hakura (2001)	Monthly CPI of 71 countries	Single equation model	For high inflation regimes, exchange rate pass-through is higher.
Hufner and Schroder (2002)	Monthly CPI of the Euro area.	Vector error correction model	In response to a 10% depreciation of euro exchange rate, the CPI tends to increase by 0.4% and complete after three years.
Olivei (2002)	Quarterly import prices that the BLS produces using the Standard International Trade Classification structure in the US.	Single equation model	Pass-through estimates are usually less than full and the hypothesis that pass-through is full in the long-run is rejected in all but three industries.

Table 4.1 (Continued)

Study	Data	Method	Findings
Kikuchi and Sumner (2002)	Quarterly export prices of total manufactured goods in Japan.	Vector error correction model	In the long-run exchange-rate pass-through is complete.
Gueorguiev (2003)	Monthly PPI and CPI of Romania	Stationary VAR model	Pass-through to both the CPI and PPI has been large and fast, ranging from 60-70% for the PPI and 30-40% for the CPI.
Hahn (2003)	Quarterly import price index, PPI and CPI of the Euro area	Stationary VAR model	Pass-through of exchange rate to the import price index, PPI and CPI are 50%, 28% and 8% for one year horizon, respectively. The speed of pass-through slows along the distribution chain.
Rowland (2003)	Monthly import prices, PPI and CPI in Colombia	Stationary VAR model and vector error correction model	The pass-through coefficient of the import price is 0.48 after three months and 0.80 after one year. The pass-through rates of the PPI and CPI are 0.28 and 0.15, respectively.
Billmeier and Bonato (2004)	Monthly manufacturing price index (MPI) and retail price index (RPI) of Croatia	Stationary VAR model and cointegrated VAR	For stationary VAR model, the MPI responds to exchange rate significantly but not the RPI. For cointegrated VAR, the authors find the pass-through coefficient of 0.3 for the RPI in the long run.

Table 4.1 (Continued)

Study	Data	Method	Findings
Berben (2004)	Monthly CPI-inflation differential between Netherlands, Germany, UK and the US.	Stationary VAR model	The response of the price differential between the Netherlands and Germany is larger compared to Netherlands with the US and the UK.
Faruqee (2004)	Monthly import and export unit value, PPI and CPI of the Euro area.	Stationary VAR model	After 18 months, pass-through rates of the export and import prices are about 0.5 and 1, respectively. Pass through to the PPI and CPI are nearly 0.2 and 0.02, respectively.
Doyle (2004)	Quarterly bilateral import unit values between Irish and the UK at five-digit level.	Cointegration and error-correction model	Full pass-through from the Pound-Sterling exchange rate could not be rejected for total and sectoral import unit values.
Ito, Sasaki and Sato (2005)	Monthly import prices, PPI and CPI of the crisis-hit east Asian countries	Single equation method and stationary VAR model	The degree of exchange rate pass-through to the import prices is quite high, ranging from 23-127% in the short-run, but is generally low to the CPI with the exception of Indonesia.

Table 4.1(Continued)

Study	Data	Method	Findings
Kara and Ogunc (2005)	Monthly core CPI measure	Stationary VAR model	74% pass-through to the core CPI in 6 months for pre-float period, and 50% pass-through in 15 months for after-float period. Pass-through slows down and decreases after floating exchange rate regime.
Kiptui, Ndolo and Kaminchia (2005)	Monthly import price index and CPI of Kenya	Vector error correction model	1% depreciation of the exchange rate results in 0.71% increase in import price. The CPI also increases sharply, but the increase dissipates by the end of the fourth quarter.
Campa, Goldberg and Gonzalez-Minguez (2005)	Monthly import unit values across industries and countries in the Euro area	Single equation model	The unweighted average pass-through rates by country and by industry within one month are 0.66 and 0.56 respectively; In the long run, the average rate is 0.8 across countries.
Campa and Goldberg (2005)	Quarterly import price indices of 23 OECD countries.	Single equation model	The unweighted average pass-through rate across countries is 0.46 in the short run and 0.64 in the long run, but the pass-through rates vary a lot among those countries.
Choudhri, Faruqee and Hakura (2005)	Monthly CPI of the four acceding countries in EMU	Vector error correction model	The CPI pass-through rates of Slovenia, Hungary, Poland and Czech Republic are 1, 0.97, 0.8 and 0.47, respectively.

Table 4.2. Pass-through Ratios of the Import Price Index, PPI and CPI

		Horizons					
Country	Price indices	0	3	6	9	12	15
US	IMP	0.40	0.74	0.77	0.82	0.97	1.04
	PPI	0.32	0.46	0.57	0.64	0.75	0.82
	CPI	0.13	0.24	0.29	0.37	0.44	0.50
Canada	IMP	1.26	1.26	1.09	0.84	0.70	0.55
	PPI	0.36	0.40	0.34	0.34	0.34	0.35
	CPI	0.15	0.23	0.28	0.34	0.38	0.42
Finland	IMP	0.71	0.93	0.89	0.85	0.78	0.58
	PPI	0.43	0.43	0.55	0.55	0.56	0.50
	CPI	0.25	0.24	0.36	0.39	0.37	0.37
Italy	IMP	0.55	0.88	0.67	0.74	0.87	0.84
	PPI	0.12	0.29	0.30	0.23	0.23	0.22
	CPI	0.09	0.16	0.16	0.16	0.16	0.17
Japan	IMP	0.73	0.95	0.85	0.44	0.20	-0.38
	PPI	0.10	0.22	0.30	0.30	0.26	0.20
	CPI	0.11	0.09	0.16	0.18	0.20	0.19
Spain	IMP	1.41	1.54	1.22	1.07	0.96	0.98
	PPI	0.30	0.53	0.45	0.47	0.51	0.53
	CPI	0.20	0.29	0.15	0.15	0.11	0.09
Sweden	IMP	0.46	0.84	0.60	0.53	0.52	0.51
	PPI	0.32	0.47	0.40	0.39	0.40	0.40
	CPI	0.41	0.53	0.87	0.95	0.95	0.97
UK	IMP	0.29	0.31	0.31	0.18	0.21	0.19
	PPI	0.09	0.09	0.16	0.18	0.20	0.21
	CPI	0.12	0.13	0.17	0.21	0.22	0.23

Note: IMP denotes “import price index”.

Table 4.3. Spearman Rank Correlation Between Import Price Pass-Through Rates and Factors Influencing Pass-Through

Horizons / Factors	0	3	6	12
Country size	-0.36	-0.53*	-0.71**	-0.07
Country openness	0.10	0.31	0.45	-0.14
ER shock volatility	-0.30	-0.21	-0.21	-0.57*
ER persistence	-0.67**	-0.29	-0.24	0.54*
AD volatility	0.21	-0.07	-0.02	0.33
Inflation rate	0.05	0.38	0.23	0.45
MSvolatility	0.12	0.54*	0.64**	0.04

Table 4.4. Spearman Rank Correlation Between PPI Pass-Through Rates and Factors Influencing Pass-Through

Horizons / Factors	0	3	6	12
Country size	-0.64**	-0.50*	-0.40	-0.28
Country openness	0.62**	0.29	0.17	0.17
ER shock volatility	-0.59**	-0.21	-0.28	-0.28
ER persistence	0.43	0.45	0.73**	0.71**
AD volatility	-0.12	-0.05	-0.07	-0.09
Inflation rate	-0.19	0.16	0.02	-0.14
MSvolatility	0.38	0.62**	0.36	0.33

Table 4.5. Spearman Rank Correlation Between CPI Pass-Through Rates and Factors Influencing Pass-Through

Horizons / Factors	0	3	6	12
Country size	-0.83**	-0.52*	-0.36	-0.07
Country openness	0.67**	0.38	0.54**	0.45
ER shock volatility	-0.43	-0.24	-0.14	0.13
ER persistence	0.45	0.52**	0.81**	0.69**
AD volatility	0.00	0.00	-0.45	-0.71**
Inflation rate	0.26	0.29	-0.29	-0.5*
MSvolatility	0.74**	0.71**	0.31	0.31

Notes: (1) ER denotes “exchange rate”, AD denotes “aggregate demand”, MS denotes “monetary shocks”.
(2) *Significant at the 10% level (critical value=0.467)
** Significant at the 5% level (critical value=0.583)

Table 4.6. Percentage of Forecast Error Variance Attributed to Exchange Rate Shocks

Country	Horizons	Import Price	Producer Price	Consumer Price
US	0	0.17 (0.14)	0.16 (0.15)	0.20 (0.17)
	3	0.18 (0.09)	0.19 (0.18)	0.20 (0.13)
	6	0.17 (0.09)	0.19 (0.11)	0.18 (0.11)
	12	0.17 (0.09)	0.20 (0.10)	0.20 (0.09)
	15	0.18 (0.09)	0.21 (0.10)	0.20 (0.10)
Canada	0	0.29 (0.19)	0.20 (0.15)	0.20 (0.17)
	3	0.30 (0.13)	0.19 (0.11)	0.19 (0.13)
	6	0.30 (0.11)	0.17 (0.09)	0.19 (0.12)
	12	0.26 (0.10)	0.16 (0.08)	0.18 (0.11)
	15	0.24 (0.09)	0.16 (0.08)	0.18 (0.10)
Finland	0	0.17 (0.12)	0.20 (0.16)	0.25 (0.17)
	3	0.20 (0.08)	0.17 (0.08)	0.19 (0.12)
	6	0.18 (0.08)	0.13 (0.07)	0.17 (0.11)
	12	0.16 (0.09)	0.11 (0.07)	0.15 (0.09)
	15	0.16 (0.09)	0.11 (0.08)	0.14 (0.09)
Italy	0	0.12 (0.21)	0.11 (0.09)	0.13 (0.09)
	3	0.18 (0.09)	0.14 (0.08)	0.14 (0.06)
	6	0.18 (0.05)	0.15 (0.09)	0.15 (0.07)
	12	0.19 (0.05)	0.16 (0.07)	0.15 (0.06)
	15	0.14 (0.07)	0.16 (0.07)	0.15 (0.07)
Japan	0	0.35 (0.14)	0.26 (0.21)	0.28 (0.19)
	3	0.28 (0.11)	0.25 (0.13)	0.26 (0.15)
	6	0.27 (0.11)	0.25 (0.11)	0.26 (0.11)
	12	0.22 (0.10)	0.25 (0.10)	0.27 (0.08)
	15	0.20 (0.11)	0.25 (0.10)	0.28 (0.08)
Spain	0	0.26 (0.20)	0.24 (0.19)	0.24 (0.16)
	3	0.23 (0.13)	0.20 (0.10)	0.26 (0.11)
	6	0.20 (0.10)	0.18 (0.09)	0.25 (0.10)
	12	0.15 (0.09)	0.15 (0.08)	0.22 (0.11)
	15	0.14 (0.09)	0.15 (0.09)	0.21 (0.11)
Sweden	0	0.14 (0.09)	0.12 (0.05)	0.17 (0.15)
	3	0.20 (0.06)	0.15 (0.04)	0.18 (0.14)
	6	0.19 (0.04)	0.13 (0.05)	0.20 (0.11)
	12	0.18 (0.05)	0.12 (0.07)	0.25 (0.08)
	15	0.18 (0.07)	0.12 (0.06)	0.26 (0.07)
UK	0	0.19 (0.11)	0.26 (0.13)	0.21 (0.19)
	3	0.26 (0.09)	0.19 (0.09)	0.19 (0.09)
	6	0.27 (0.09)	0.16 (0.08)	0.16 (0.06)
	12	0.27 (0.10)	0.17 (0.07)	0.15 (0.06)
	15	0.28 (0.10)	0.18 (0.07)	0.15 (0.06)

The numbers in parentheses are the standard errors

Table 4.7. Pass-through Ratios of the Import Price Index, PPI and CPI using Alternative Measure

		Horizons					
Country	Price indices	0	3	6	9	12	15
US	IMP	0.40	0.47	0.53	0.66	0.82	1.00
	PPI	0.32	0.29	0.39	0.52	0.64	0.79
	CPI	0.13	0.15	0.20	0.30	0.38	0.48
Canada	IMP	1.26	1.69	1.85	1.72	1.88	2.10
	PPI	0.36	0.54	0.58	0.71	0.93	1.32
	CPI	0.15	0.32	0.48	0.70	1.01	1.59
Finland	IMP	0.71	0.78	0.69	1.04	1.22	1.62
	PPI	0.43	0.37	0.43	0.68	0.87	1.38
	CPI	0.25	0.20	0.28	0.47	0.58	1.04
Italy	IMP	0.69	0.94	0.76	0.99	1.93	2.37
	PPI	0.14	0.30	0.32	0.26	0.48	0.66
	CPI	0.13	0.18	0.16	0.18	0.33	0.50
Japan	IMP	0.73	0.94	1.08	1.00	0.09	-956.90
	PPI	0.10	0.22	0.37	0.70	1.23	483.27
	CPI	0.11	0.09	0.21	0.41	0.94	485.67
Spain	IMP	1.41	1.19	1.21	1.69	3.80	44.65
	PPI	0.30	0.41	0.45	0.75	2.01	24.26
	CPI	0.20	0.22	0.15	0.23	0.42	3.94
Sweden	IMP	0.67	0.77	0.77	0.78	0.95	1.03
	PPI	0.33	0.39	0.43	0.48	0.62	0.68
	CPI	0.40	0.36	0.76	0.99	1.28	1.45
UK	IMP	0.29	0.34	0.60	0.42	0.46	0.53
	PPI	0.09	0.09	0.32	0.42	0.45	0.58
	CPI	0.12	0.14	0.33	0.48	0.49	0.63

Note: IMP denotes “import price index”.

Table 4.8. Spearman Rank Correlation Between Import Price Pass-Through Rates and Factors Influencing Pass-Through Using Alternative Measure

Factors \ Horizons	0	3	6	12
Country size	-0.36	-0.26	-0.33	-0.55*
Country openness	0.1	0.14	0.31	0.33
ER shock volatility	-0.3	-0.4	-0.06	-0.79**
ER persistence	-0.67**	-0.62**	-0.69	-0.05
AD volatility	0.21	0.083	-0.19	0.48
Inflation rate	0.05	0.07	0.07	0.67**
MSvolatility	0.11	0.06	0.33	0.38

Table 4.9. Spearman Rank Correlation Between PPI Pass-Through Rates and Factors Influencing Pass-Through Using Alternative Measure

Factors \ Horizons	0	3	6	12
Country size	-0.64**	-0.67**	-0.55*	-0.14
Country openness	0.62**	0.64**	0.58**	-0.12
ER shock volatility	-0.59**	-0.54*	-0.29	-0.01
ER persistence	0.43	-0.05	-0.09	-0.57*
AD volatility	-0.12	-0.05	-0.11	0.14
Inflation rate	-0.19	0.24	-0.04	-0.23
MSvolatility	0.38	0.64**	0.63**	0.05

Table 4.10. Spearman Rank Correlation Between CPI Pass-Through Rates and Factors Influencing Pass-Through Using Alternative Measure

Factors \ Horizons	0	3	6	12
Country size	-0.87**	-0.76**	-0.29	-0.33
Country openness	0.67**	0.78*	0.71**	0.43
ER shock volatility	-0.48*	-0.45	0.25	0.46
ER persistence	0.42	0.24	0.21	-0.19
AD volatility	0.02	-0.19	-0.73**	-0.67**
Inflation rate	0.32	0.33	-0.31	-0.43
MSvolatility	0.73**	0.81**	0.41	0.33

Notes: (1) ER denotes “exchange rate”, AD denotes “aggregate demand”, MS denotes “monetary shocks”. (2) *Significant at the 10% level (critical value=0.467), ** Significant at the 5% level (critical value=0.583)

Table 4.11. Percentage of Error Variance Attributed to Exchange Rate Shocks with $K=2$ and $K=11$

Country	Horizons	Import Price ($K=2$)	Import price ($K=11$)
US	0	0.21 (0.17)	0.14 (0.12)
	3	0.20 (0.10)	0.16 (0.07)
	6	0.20 (0.10)	0.14 (0.06)
	12	0.19 (0.09)	0.14 (0.06)
	15	0.20 (0.10)	0.14 (0.06)
Canada	0	0.26 (0.21)	0.32 (0.19)
	3	0.26 (0.13)	0.31 (0.13)
	6	0.26 (0.10)	0.31 (0.11)
	12	0.24 (0.09)	0.28 (0.09)
	15	0.23 (0.09)	0.27 (0.09)
Finland	0	0.17 (0.13)	0.14 (0.08)
	3	0.20 (0.09)	0.20 (0.08)
	6	0.18 (0.09)	0.18 (0.07)
	12	0.17 (0.10)	0.16 (0.07)
	15	0.17 (0.11)	0.16 (0.08)
Italy	0	0.21 (0.16)	0.13 (0.09)
	3	0.16 (0.07)	0.21 (0.04)
	6	0.14 (0.07)	0.18 (0.04)
	12	0.15 (0.08)	0.17 (0.04)
	15	0.16 (0.08)	0.17 (0.05)
Japan	0	0.31 (0.14)	0.36 (0.13)
	3	0.25 (0.12)	0.31 (0.11)
	6	0.23 (0.12)	0.30 (0.11)
	12	0.19 (0.12)	0.26 (0.10)
	15	0.17 (0.12)	0.22 (0.10)
Spain	0	0.23 (0.19)	0.25 (0.18)
	3	0.20 (0.13)	0.23 (0.12)
	6	0.16 (0.11)	0.18 (0.12)
	12	0.12 (0.11)	0.14 (0.09)
	15	0.11 (0.11)	0.12 (0.08)
Sweden	0	0.15 (0.09)	0.17 (n.a.)
	3	0.20 (0.08)	0.23 (n.a.)
	6	0.19 (0.08)	0.14 (n.a.)
	12	0.18 (0.10)	0.11 (n.a.)
	15	0.18 (0.11)	0.12 (n.a.)
UK	0	0.20 (0.14)	0.20 (0.10)
	3	0.21 (0.08)	0.28 (0.08)
	6	0.22 (0.09)	0.29 (0.07)
	12	0.22 (0.09)	0.28 (0.08)
	15	0.22 (0.10)	0.28 (0.08)

The numbers in parentheses are the standard errors

Table 4.12. Pass-Through Ratios of the Import Price Index, PPI and CPI with $K=2$

		Horizons					
Country	Price indices	0	3	6	9	12	15
US	IMP	0.58	0.98	1.07	1.11	1.26	1.30
	PPI	0.44	0.62	0.76	0.82	0.93	0.99
	CPI	0.17	0.33	0.38	0.47	0.54	0.59
Canada	IMP	1.28	1.22	0.97	0.72	0.56	0.41
	PPI	0.37	0.38	0.29	0.29	0.28	0.27
	CPI	0.17	0.26	0.31	0.37	0.41	0.45
Finland	IMP	0.80	1.00	1.00	0.96	0.85	0.64
	PPI	0.56	0.54	0.69	0.69	0.68	0.61
	CPI	0.28	0.27	0.40	0.43	0.42	0.42
Italy	IMP	0.92	0.99	0.96	1.27	1.48	1.42
	PPI	0.21	0.40	0.39	0.33	0.39	0.41
	CPI	0.14	0.24	0.20	0.20	0.23	0.26
Japan	IMP	0.77	0.93	0.74	0.26	-0.20	-0.50
	PPI	0.11	0.24	0.31	0.31	0.26	0.20
	CPI	0.13	0.10	0.18	0.19	0.22	0.20
Spain	IMP	1.46	1.40	0.99	0.84	0.74	0.78
	PPI	0.29	0.51	0.40	0.43	0.46	0.48
	CPI	0.24	0.29	0.15	0.15	0.10	0.09
Sweden	IMP	0.57	0.90	0.63	0.56	0.57	0.57
	PPI	0.40	0.56	0.45	0.42	0.42	0.41
	CPI	0.44	0.60	0.87	0.89	0.87	0.87
UK	IMP	0.35	0.24	0.18	0.03	0.07	0.06
	PPI	0.12	0.11	0.18	0.19	0.20	0.21
	CPI	0.15	0.18	0.22	0.27	0.27	0.29

Note: IMP denotes “import price index”.

Table 4.13. Pass-Through Ratios of the Import Price Index, PPI and CPI with $K = 11$

		Horizons					
Country	Price indices	0	3	6	9	12	15
US	IMP	0.34	0.59	0.63	0.67	0.82	0.91
	PPI	0.33	0.45	0.56	0.63	0.74	0.83
	CPI	0.12	0.22	0.27	0.36	0.43	0.49
Canada	IMP	1.34	1.29	1.23	1.00	0.88	0.73
	PPI	0.33	0.37	0.33	0.34	0.35	0.36
	CPI	0.14	0.21	0.25	0.29	0.32	0.35
Finland	IMP	0.60	0.86	0.82	0.81	0.71	0.52
	PPI	0.36	0.36	0.47	0.47	0.45	0.38
	CPI	0.24	0.24	0.35	0.38	0.36	0.36
Italy	IMP	0.55	0.82	0.67	0.75	0.87	0.84
	PPI	0.12	0.30	0.30	0.23	0.23	0.22
	CPI	0.09	0.16	0.16	0.16	0.16	0.17
Japan	IMP	0.63	0.88	0.99	0.78	0.47	0.13
	PPI	0.09	0.20	0.28	0.32	0.31	0.27
	CPI	0.09	0.08	0.14	0.16	0.19	0.19
Spain	IMP	1.23	1.38	1.16	0.91	0.76	0.72
	PPI	0.30	0.51	0.45	0.45	0.48	0.50
	CPI	0.19	0.26	0.16	0.15	0.11	0.08
Sweden	IMP	0.39	0.64	0.00	0.13	0.23	0.14
	PPI	0.30	0.45	0.16	0.21	0.30	0.26
	CPI	0.12	0.38	0.59	0.62	0.69	0.72
UK	IMP	0.26	0.30	0.32	0.24	0.25	0.25
	PPI	0.08	0.07	0.14	0.16	0.17	0.19
	CPI	0.07	0.10	0.13	0.16	0.16	0.18

Note: IMP denotes “import price index”.

Figure 4.1. Impulse Responses of Exchange Rates to a Positive Exchange Rate Shock

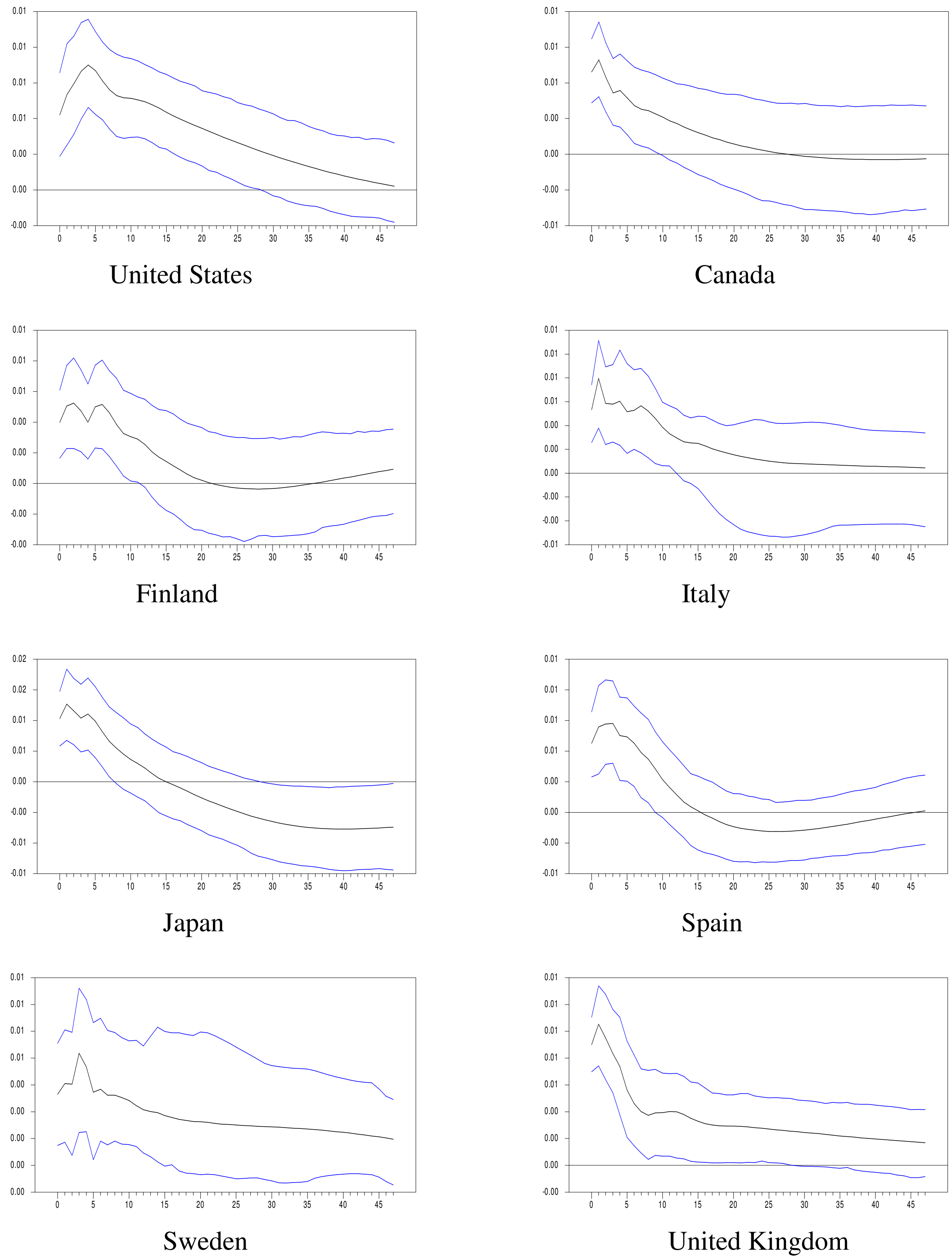
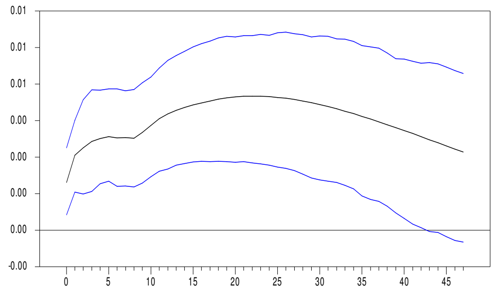
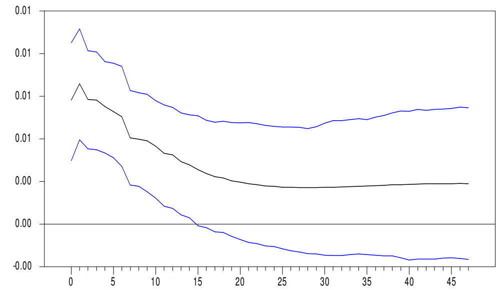


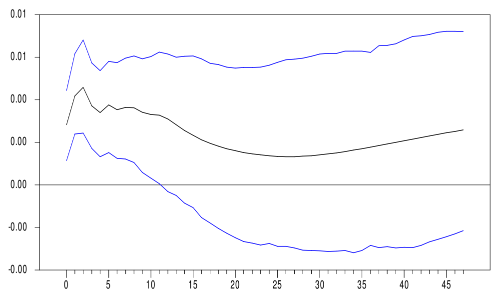
Figure 4.2. Impulse Responses of the Import Price to a Positive Exchange Rate Shock



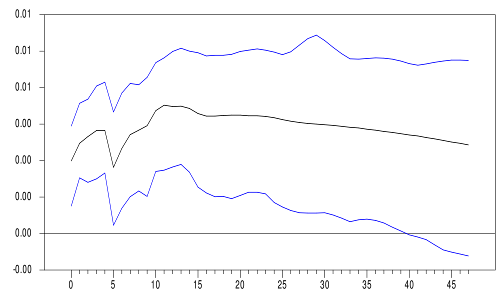
United States



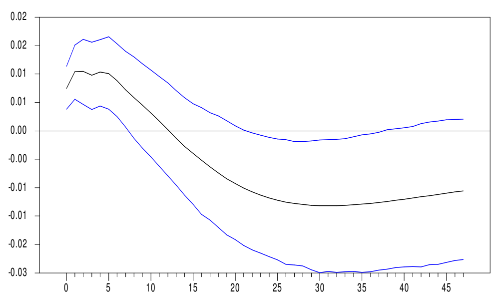
Canada



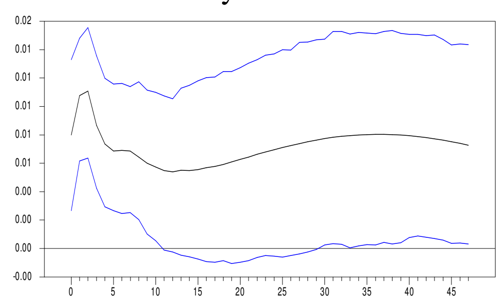
Finland



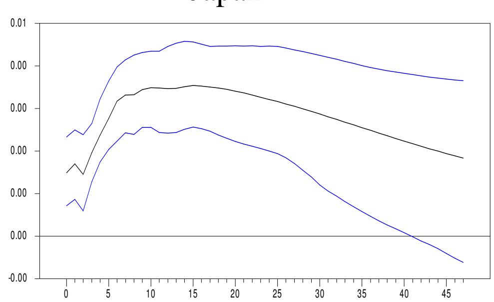
Italy



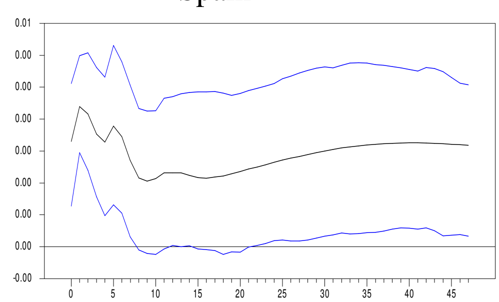
Japan



Spain



Sweden



United Kingdom

Figure 4.3. Impulse Responses of the PPI to a Positive Exchange Rate Shock

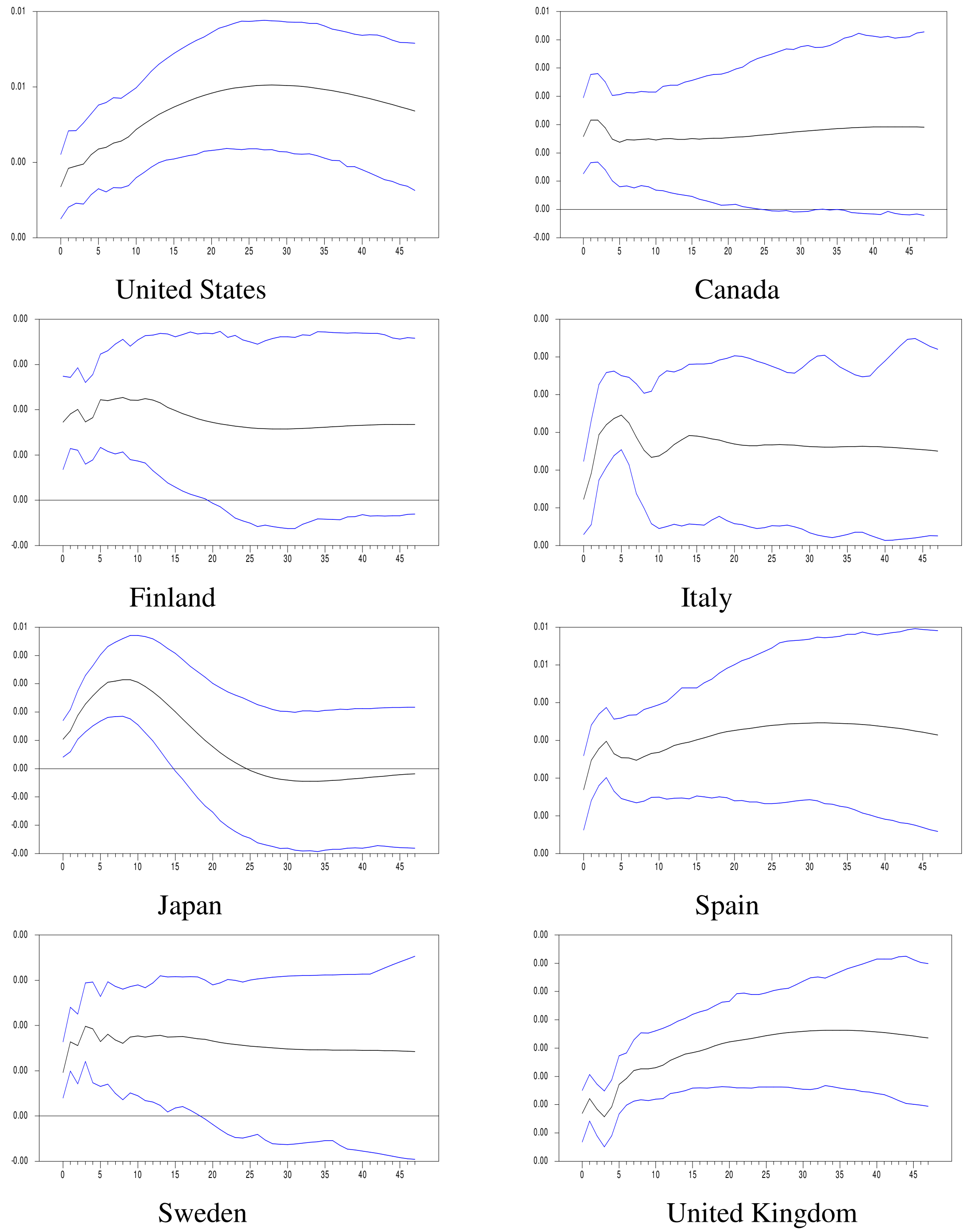
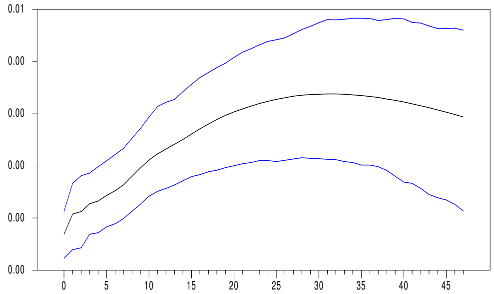
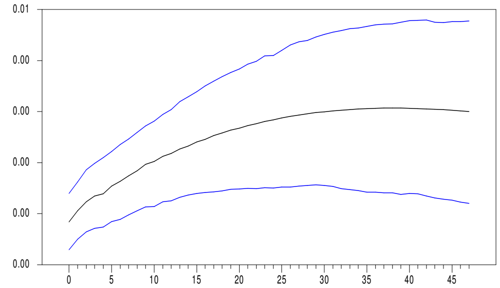


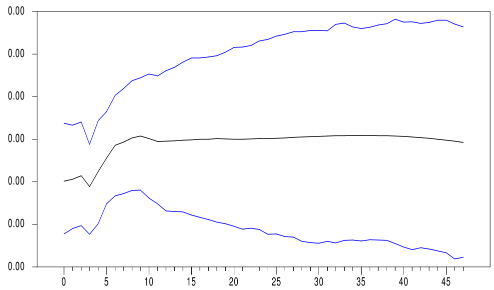
Figure 4.4. Impulse Responses of the CPI to a Positive Exchange Rate Shock



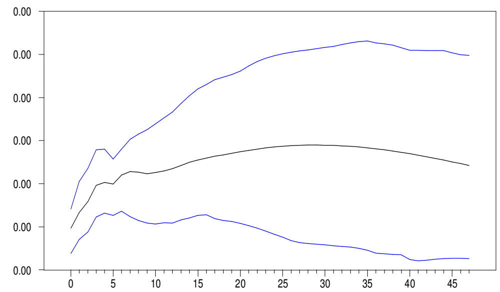
United States



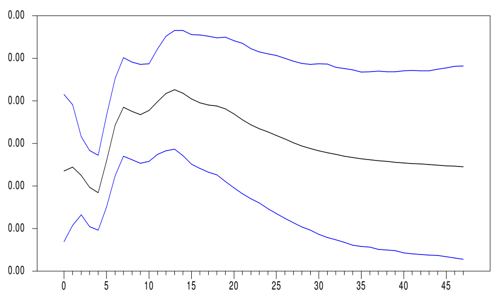
Canada



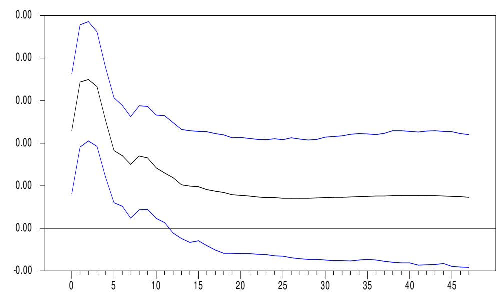
Finland



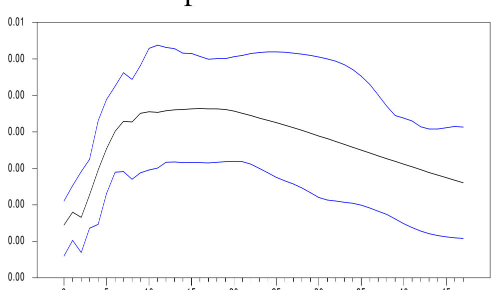
Italy



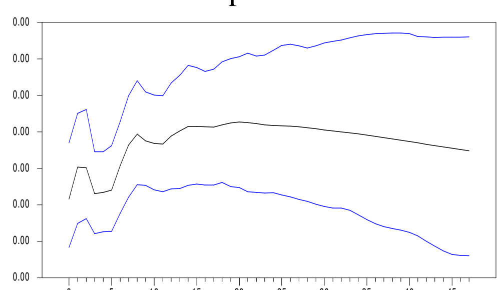
Japan



Spain



Sweden



United Kingdom

Figure 4.5. Impulse Responses of the Import Price to a Positive Exchange Rate Shock with $K=2$

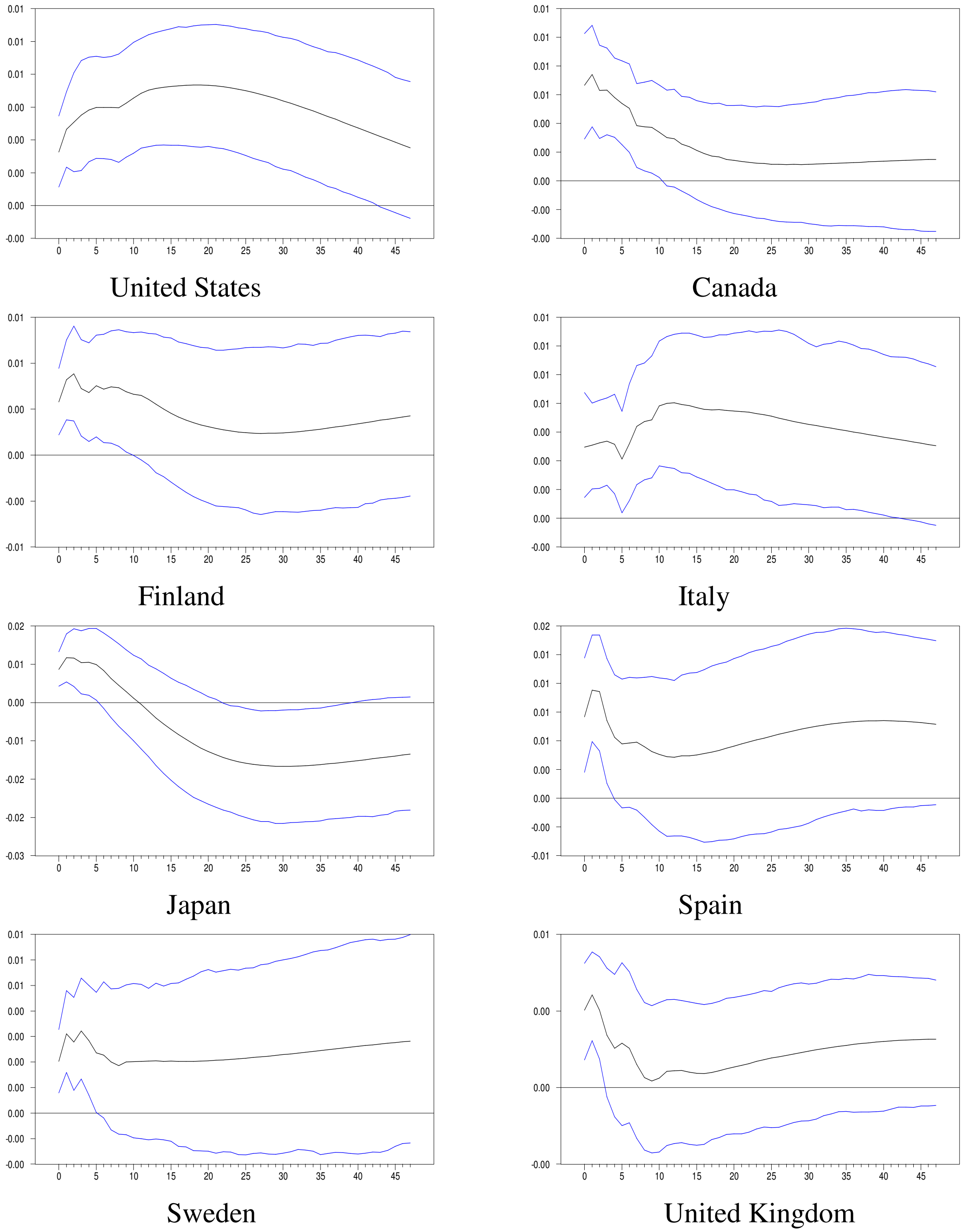
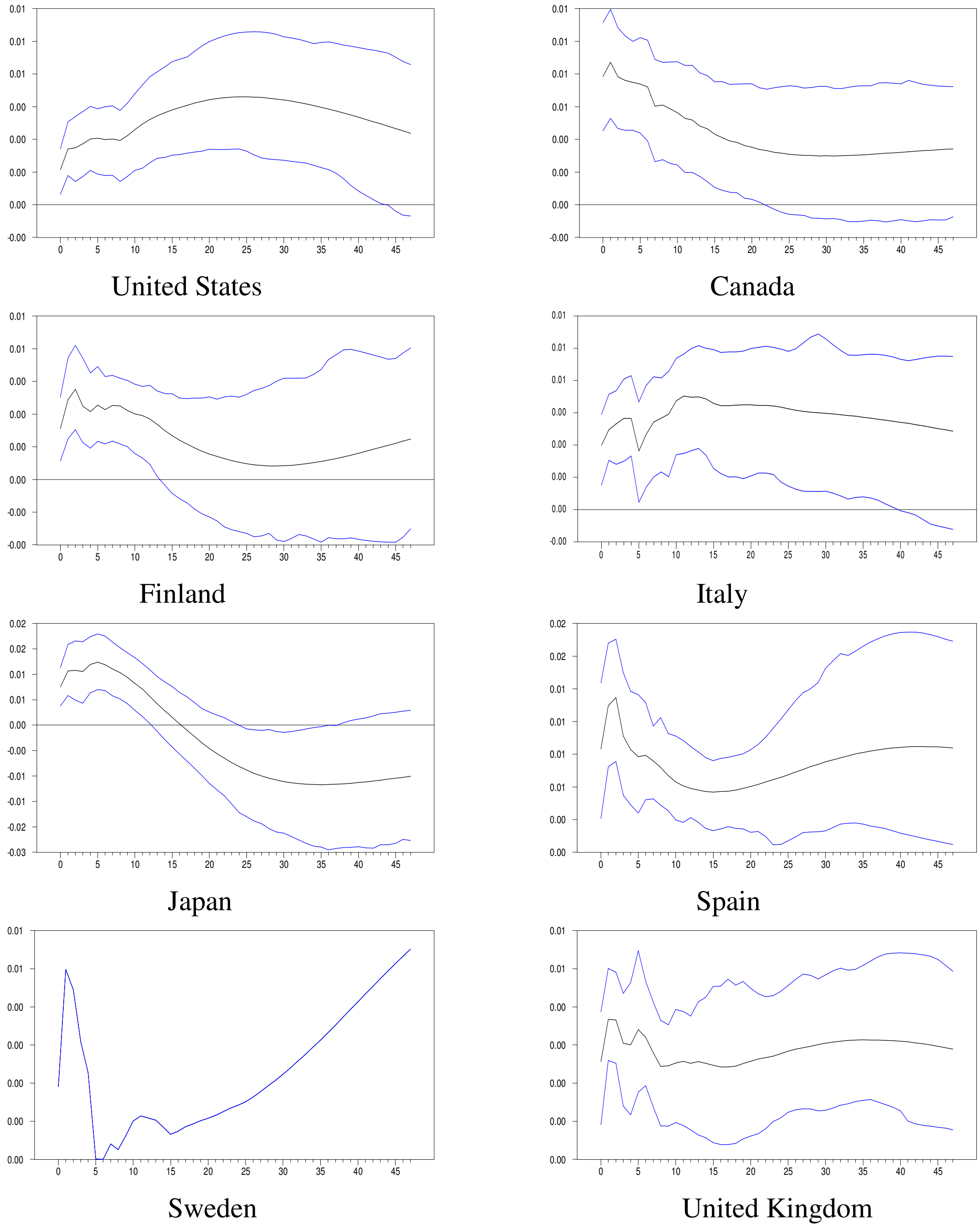


Figure 4.6. Impulse Responses of the Import Price to a Positive Exchange Rate Shock with $K = 11$



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[2] "Exchange Rate Pass-Through: Evidence Based on Vector Autoregression with Sign Restrictions," Kentucky Graduate Workshop, University of Kentucky, March, 2006
[3] "Monetary Policy, Foreign Exchange Intervention and the Exchange Rate," Western Economic Association Conference, San Diego, CA, July, 2006
[4] Discussant, Western Economic Association Conference, San Diego, CA, July, 2006
[5] "Exchange Rate Pass-Through: Evidence Based on Vector Autoregression with Sign Restrictions," Kentucky Economic Association Conference, Lexington, KY, October, 2006
[6] "Exchange Rate Pass-Through: Evidence Based on Vector Autoregression with Sign Restrictions," University of Kentucky Macroeconomics Workshop, Lexington, KY, November, 2006
[7] "Is the Exchange Rate a Shock-Absorber or a Source of Shock? The Case of Japan," Southern Economic Association Conference, Charleston, SC, November, 2006
[8] Discussant, Southern Economic Association Conference, Charleston, SC, November, 2006
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Excellent Academic Achievement Awards, Hubei University, 1999-2001

University Fellowship, Hubei University, 1998-2002

Professional Membership
American Economic Association
Western Economic Association
Southern Economic Association
Kentucky Economic Association
CFA Institute

Lian An
February 7, 2007