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RESEARCH ARTICLE

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

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Abstract We estimate exchange rate pass-through (PT) into import, producer and consumer price indexes for nine OECD countries, using a method proposed by Uhlig (2005). In a Vector Autoregression (VAR) model, we identify the exchange rate shock by imposing restrictions on the signs of impulse responses for a small subset of variables. These restrictions are consistent with a large class of theoretical models and previous empirical findings. We find that exchange rate PT is less than one at both short and long horizons. Among three price indexes, exchange rate PT is greatest for import price index and smallest for consumer price index. In addition, greater exchange rate PT is found in an economy which has a smaller size, higher import share, more persistent exchange rate, more volatile monetary policy, higher inflation rate, and less volatile aggregate demand.

Keywords Exchange rate pass-through · Vector autoregression · Sign restrictions

JEL Classification F31 · F41

1 Introduction

Exchange rate pass-through (PT), the degree to which exchange rate changes are passed on into aggregate prices, has long piqued the interests of economists and policymakers. A thorough understanding of exchange rate PT to aggregate prices is of extreme importance for several reasons. First, the degree and timing of exchange

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rate PT is important for understanding inflation dynamics, which is a key issue for central banks. Second, the degree of exchange rate PT affects the strength of the expenditure-switching effect, which is an important channel for the international transmission of country-specific shocks.[1]

Given its importance, exchange rate PT has been widely studied in the literature during the last decade. A strand of the literature studies exchange rate PT to import price index (IMP), producer price index (PPI), and consumer price index (CPI) in a unified framework, using vector autoregression (VAR) models. For instance, see Hahn (2003), Ito et al. (2005), Choudhri and Hakura (2006), and McCarthy (2007), among others. These studies are based on the observation that a large fraction of imports are intermediate goods that are used to produce final consumption goods. Final goods must also go through distribution processes before they are consumed by households. IMP, PPI, and CPI partially reflect the prices of imports at different production and distribution stages. As a result, shocks to prices at an earlier stage of production and distribution may affect prices (with a lag) at a later state, but not the other way around. For instance, it is assumed that shocks to IMP can affect PPI and CPI with one or more lags, while PPI and CPI shocks do not affect IMP directly. The VAR model incorporating IMP, PPI, and CPI and this identification assumption are termed as "distribution chain of pricing model". The exchange rate shock in these studies is often identified from recursive restrictions of the Choleski decomposition. Exchange rate PT is then analyzed by examining the impulse responses of prices with respect to the exchange rate shock. There are several merits of using the VAR methodology with distribution chain of pricing. For instance, it avoids the endogeneity problem inherent in single-equation models and it incorporates the distribution chain of pricing in a unified framework.

However, a stationary VAR model with the Choleski decomposition inherently has two drawbacks. First, the standard recursive identification assumptions, in which some variables can or cannot respond to other variables in the first period of a shock, are very stringent and can have a great impact on results. Some assumptions may be developed over time in a "data-mining like manner" when researchers look for restrictions that can provide sensible results (see Rudebusch 1998). Indeed, 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 1999). Second, there are shortcomings associated with a differenced VAR system. Decision on which variables to difference is, to some extent, arbitrary because it is difficult to distinguish between trend- and difference-stationary variables in the data. The potential misspecification could impinge on the estimated dynamics of a differenced VAR model. With the 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 model in first difference are biased when estimating exchange rate PT, even when the VAR model is specified with a large number of lags. In 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.

[1] According to Obstfeld (2002), two conditions are required for a strong expenditure-switching effect: high exchange rate PT to import prices, but low exchange rate PT to consumer prices.

Based on the above drawbacks, we adopt a VAR model in levels with the sign restriction approach developed by Uhlig (2005) to estimate exchange rate PT. There are several advantages for the sign restriction approach. First, in the traditional structural VAR model, sign restrictions from conventional views are often used implicitly as criteria to check the validity of identifying assumptions. In the sign restriction approach, those restrictions are made more explicit by being imposed directly on impulse responses. Second, in estimating impulse responses, the sign restriction approach takes into account both data and identification uncertainty by simulation. Third, sign restrictions are weak in that they do not lead to exact identifications of the reduced form VAR. This is an important advantage because it circumvents "incredible" zero restrictions on the contemporaneous and long-run impact of shocks. Finally, the sign restriction method involves the Bayesian Monte Carlo procedure, which, according to Sims (1988), does not require differencing. Thus the sign restriction approach can avoid much of the subtle specification issues for observationally equivalent trend- and difference-stationary variables in VAR.

In this paper, the sign restrictions on impulse responses are imposed such that a plausible identification of exchange rate shocks is achieved. The extent of exchange rate PT to prices along the distribution chain is then quantified by examining the impulse response functions. To the best of our knowledge, this is the first attempt of studying exchange rate PT with the sign-restriction strategy. Nine OECD countries are included in our study: Canada, Finland, Italy, Japan, South Korea, Spain, Sweden, the United Kingdom (UK), and the United States (US). We use monthly data and the sample period is from 1980:m1 to 2007:m8. Both the exchange rate and international trade behaved differently during the recent global financial crisis that started in the second half of 2007. We therefore choose the ending date of August 2007 in our sample to avoid the effect of the global financial crisis on our results. For instance, Levchenko et al. (2009) and Wang (2010) show that US trade dropped much more in this recession than in previous ones. The exchange rate during this period was also driven by factors that are not commonly observed during normal times. For instance, Engel and West (2010) document that the strength of the US dollar in 2008 and 2009 is mainly driven by the flight-to-safety effect.

To preview the results, our paper has the following findings. First, the empirical results are supportive of partial exchange rate PT for most countries, and the magnitudes of the PT estimates are broadly in line with previous literature. Second, the degree of PT declines along the distribution chain. The unweighted average PT ratios of IMP, PPI, and CPI are, respectively, 0.31–0.88, 0.16–0.27, and 0.02–0.10 for the first 16 horizons. Third, exchange rate PT varies across countries. By using the Spearman rank correlation, we explore macroeconomic factors that affect cross-country heterogeneity of exchange rate PT. We document that a greater PT coefficient is found in an economy with a smaller size, higher import share, more persistent exchange rate, more volatile monetary policy, higher inflation rate and more stable aggregate demand.

The rest of the paper is organized as follows. Section 2 provides the theoretical background and Section 3 describes our VAR model with sign restrictions. Section 4 reports our estimates of exchange rate PT with the sign restriction method. We also examine the factors determining exchange rate PT across countries in this section. Section 5 provides a robustness check and Section 6 concludes.

2 Theoretical Background

The extent of exchange rate PT into aggregate price indexes is found to vary across countries in empirical studies. This section provides a brief review of the theoretical background on the macroeconomic determinants of exchange rate PT to aggregate prices.

Mann (1986) and Taylor (2000), among others, have identified a list of macroeconomic variables affecting exchange rate PT to aggregate prices, notably, the size of a country, the openness of a country, exchange rate volatility, the persistence of exchange rate shocks, aggregate demand volatility, inflation and monetary policy environment.

In theory, the size of a country (measured by real GDP in US dollars in our empirical study) is inversely related to the extent of PT for two reasons. First, the inflationary effect of depreciation in a large economy will lower its demand for imports. When the economy is a large importer in the world market, the world price of the imports will decline, which reduces the measured PT. Second, foreign exporters have more incentives to maintain their market shares in a larger market. As a result, they are more likely to absorb some of exchange rate changes for exports to bigger countries by reducing their profit margins.

Openness, which is measured by the ratio of imports to GDP, may be a good proxy for the import penetration faced by firms. Greater import penetration may be an indicator of less competition from domestic producers. As a result, foreign companies may pass more exchange rate changes to importing countries. For instance, Feinberg (1986, 1989) find that exchange rate PT is larger in industries that face greater import penetration. It may be reasonable to expect that a country with a higher import share will also face larger exchange rate PT to its aggregate prices.

Using the pricing to market principle, Mann (1986) discusses why exchange rate volatility can negatively affect exchange rate PT. Suppose that prices are set in the importing country's currency. If exchange rate changes are volatile, but mainly transitory, foreign exporters will not change prices as frequently as the exchange rate to avoid the cost of adjusting prices.[2] In this case, they would rather adjust their profit margins, thus reducing exchange rate PT.

In similar spirit, the persistence of exchange rate movements can positively affect exchange rate PT. If firms expect that an appreciation/depreciation will last for a long period into the future, they are more likely to pass exchange rate changes to prices.

Another economic variable put forward by Mann (1986) is aggregate demand uncertainty. When aggregate demand is unstable, foreign exporters are wary of losing market share should they increase prices in response to exchange rate movements. Therefore, they will alter profit margins when aggregate demand fluctuates significantly in an imperfectly competitive environment, reducing measured PT.

A further determinant of exchange rate PT is inflation environment, which was brought forward by Taylor (2000). According to Taylor (2000), perceived persistence of cost changes is likely to be positively correlated to the persistence

[2] The cost includes re-tagging goods, revising and reprinting catalogues, and advertising.

of aggregate inflation, which is usually positively correlated with the level of the inflation rate.[3] So in a macroeconomic environment with a low inflation rate, an increase in (nominal) marginal cost will be less persistent than in an environment with a high inflation rate. Firms usually adjust their prices to a less extent in response to a cost change when the cost change is expected to be less persistent. As a result, low inflation environment may entail low PT of exchange rate shocks to prices via a reduction in the expected persistence of shocks.

A factor related to inflation environment is the stability of the monetary policy environment. Devereux et al. (2003) develop a model of endogenous exchange rate PT when prices are sticky and exporting firms can choose which currency to set their prices. They find that countries with stable monetary policy will have relatively low exchange rate PT because exporting firms will set prices in importer's currency when the importing country's monetary policy is more stable than that in the exporting country. In an extreme case that all import prices are set in the importing country's currency, import prices do not respond to exchange rate changes at all in the short run under sticky prices.

Besides cross-country difference in exchange rate PT, the variation in exchange rate PT at different stages of the distribution chain is also 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 two channels: (i) through changes in the prices of imported intermediate goods, and (ii) through changes in the prices of domestically produced goods in response to price changes of imported goods. The extent of PT to PPI and CPI will therefore depend on exchange rate PT to IMP, the share of imports in PPI and CPI, and responses of prices of domestically produced goods to exchange rate movements.

If prices of domestically produced goods respond less to exchange rate changes than prices of imported goods, the degree of exchange rate PT declines along the distribution chain for two reasons. First, the share of imported goods usually decreases along the distribution chain, leading to declining PT (see Clark 1999). Second, since PT is incomplete at each stage, accumulation over different stages also implies a decline in exchange rate PT along the distribution chain.

3 A Simple VAR Model with the Sign Restrictions

This section consists of two parts. The first part sets up the baseline model and the second part describes the sign restriction approach.

3.1 The VAR Model

Our VAR model draws on the "distribution chain" model in the literature and consists of eight endogenous variables: oil price (P_{oil}), the short-term interest rate (S), output gap (GAP), the nominal effective exchange rate (NER), foreign export price index (FP), IMP, PPI, and CPI. Our sample includes monthly data for nine

[3] Exchange rate changes are usually perceived as cost shocks for an exporter (see Yang 1997).

OECD countries over the period 1980:m1 to 2007:m8: Canada, Finland, Italy, Japan, South Korea, Spain, Sweden, the UK, and the US.

Oil price is measured by the Brent spot price of petroleum obtained from International Financial Statistics (IFS). It is used to capture supply shocks. Output gap is used to capture demand shocks and is measured by industrial production detrended by linear and quadratic time trends.[4] Industrial production data are obtained from IFS. Output gap acts as a proxy for demand fluctuations over business cycles where a positive (negative) number indicates that the economy is growing faster (slower) than the trend. This variable is important because exchange rate PT is affected by macroeconomic conditions (i.e., aggregate demand). For example, when the economy is in recession, firms usually refrain from increasing prices in response to currency depreciations as they are wary of losing market share when aggregate demand is low.

The short-term (three-month) interest rate is included to allow for potential effects of monetary policy and the data are obtained from IFS. Empirical evidence shows that some central banks respond to exchange rate changes when setting the policy rate. For instance, Clarida, et al. (1998) find that the German central bank adjusted its policy rate in response to exchange rate movements. The connection between changes in the exchange rate and domestic prices through the monetary policy may be neglected if the nominal interest rate is excluded from the analysis (see Hahn 2003).

Foreign export price level is also essential in modeling exchange rate PT and the data are constructed in the same way as the effective nominal exchange rate that is described in footnote 6. Suppose that import price index in country i, $P^{m,i}$, equals the export price in its trading partners, $P^{x,i}$, times the bilateral exchange rate:

$$P^{m,i} = ER^{i} P^{x,i} \tag{1}$$

where the exchange rate (ER) is quoted as domestic currency per unit of foreign currency.

Further suppose that the export price is a mark-up ($markup^{x}$) over the exporter's marginal costs MC^{x}. Using lower letters to denote logarithms of upper-case letters, Eq. 1 can be rewritten as:

$$p^{m,i} = er + markup^{x} + mc^{x}. \tag{2}$$

Changes in the exchange rate can have direct effects on import prices according to Eq. 2. In addition, they can also affect mark-ups and marginal costs of exporting firms. In the presence of short-run price rigidity, mark-ups will fall with exporting firms' currency appreciation and rise with a currency depreciation (Kim 1990). Marginal costs may also decrease when exporting country's currency appreciates if some of exporter's inputs are imported from other countries. Imported inputs used by exporters become cheaper when exporting country's currency appreciates. For instance, see Devereux and Genberg (2010). Foreign export price index is included to control for the indirect transmission of exchange rate changes to domestic prices through mark-ups and marginal costs of trading partners.

[4] Industrial production is used because GDP is not available at a monthly frequency.

The exchange rate, IMP, PPI, and CPI are the focus of our analysis, so they are naturally included. Effective nominal exchange rates are calculated from bilateral exchange rates and shares of trade.[5] The exchange rate is constructed in such a way that an increase in the index implies a depreciation of the domestic currency. IMP, PPI, and CPI in each country are obtained from IFS.

The model is summarized in the reduced-form VAR:

$$Y_t = \Gamma_0 + \sum_{i=1}^{n} B_i Y_{t-i} + u_t, \tag{3}$$

where Y_t is an 8×1 vector of variables $[Poil,\ S,\ GAP,\ NER,\ FP,\ IMPP,\ PPI,\ CPI]'$, B_i are 8×8 coefficient matrices, u_t is the one-step ahead prediction error with variance-covariance matrix Σ, and 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 the shortest lag length that can produce white noise residuals, which turns out to be 5 for the US and 6 for other countries in our sample.

3.2 The Sign Restriction Approach

Different identification methods are employed by economists to decompose the prediction error u_t in Eq. 3 into economically meaningful fundamental innovations. For instance, works relying on the Choleski decomposition method usually assume different orderings among the variables, based on assumptions about the transmission mechanism of shocks. In this paper, we employ the sign restriction approach developed by Uhlig (2005). This approach does not aim to achieve a complete decomposition of one-step-ahead prediction errors into all components due to underlying structural shocks. Instead, it focuses on only identifying the shock(s) of interest. The intention is to be "minimalistic and to impose not (much) more than the sign restrictions themselves" (Uhlig 2005, p.p. 385), as these restrictions can be reasonably agreed upon by many economists. For example, most previous studies find that the depreciation of domestic currency will lead to an increase in IMP, PPI and CPI. The primary interest of this paper is to obtain evidence on how exchange rate shocks affect different prices over time. Instead of identifying all structural disturbances, the model uses minimal restrictions that are sufficient to identify the exchange rate shock and then quantifies the extent of price changes to exchange rate changes.

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

[5] The nominal effective exchange rate of country j is constructed as the trade-weighted average of bilateral exchange rates between country j and its trading partners:

$$NER_j = \Pi_{i=1}^{q} ER_{i,j}^{\ \omega_i},$$

Where $ER_{i,j}$ is the index of bilateral nominal exchange rate between country i and j, expressed as units of currency j per unit of currency i. The weight, ω_i, is the average share of imports of country j from country i during our sample period. For each country, q largest trading partners are included such that at least 80% of that country's imports are covered in our calculation. The foreign export price index is calculated similarly.

data and identification uncertainty, respectively.[6] As the first step of the simulation, which is "outer-loop draws", n_1 random draws are taken from the posterior distribution of the reduced form VAR coefficients, B_i, and the covariance matrix of disturbance, $\sum$.[7] Each draw from the posterior distribution of the VAR parameters is decomposed with the Choleski decomposition. In the second step, n_2 draws are randomly taken from the unit sphere assuming a flat prior, which is the "inner-loop draws".[8] Thus, $n_1 \times n_2$ draws and $n_1 \times n_2$ corresponding sets of impulse responses to exchange rate shocks are generated.[9] Only the impulse responses, whose ranges are compatible with the sign restrictions, are kept and used to calculate the median impulse response and the probability bands.

The following sign restrictions are imposed on impulse responses:

1. The short-term interest rate does not decrease (≥0) in response to a positive exchange rate shock, i.e., an exchange rate depreciation, because the monetary policy will tighten to support the currency. This restriction is consistent with the finding of Clarida et al. (1998).
2. By definition, the exchange rate will not decrease (≥0) in response to its own positive shocks.
3. The foreign export price index does not increase (≤0) in response to a positive exchange rate shock, as the mark-up and costs of imported inputs decrease when foreign firms' currency appreciates.
4. The IMP, PPI, and CPI do not decrease (≥0) in response to a depreciation of the domestic currency.

These restrictions are reasonable because they simply make use of a priori appealing and consensual views about the effects of exchange rate shocks on monetary policy and various prices. However, there is a potential shortcoming if we impose restrictions on all three prices (IMP, PPI, and CPI). Imposing ex ante restrictions on the responses of IMP, PPI, and CPI to exchange rate shocks could taint our results because the response of these variables to the exchange rate is exactly what we tend to estimate from the data. One obvious strategy could be to release all sign restrictions on prices. However, it leaves only three sign restrictions in our model, which would be insufficient to disentangle the exchange rate shock from other shocks. In order to examine the response of prices to exchange rate shocks as agnostically as possible, and at the same time, make sure that exchange rate shocks can be identified from other shocks, the restriction on a price is relaxed when examining exchange rate PT to that price. For example, the sign restriction on IMP is relaxed when we study PT to IMP, and so on.

When imposing sign restrictions, we need to specify the horizon of the restrictions, in other words, for how many periods the responses remain positive

[6] Detailed description of the methodology is available in Uhlig (2005).

[7] The posterior distribution is derived under the assumption of a diffuse Jeffries prior over the parameters of the VAR.

[8] Drawing from flat prior on the unit sphere will make the results independent of the chosen decomposition of $\sum$. Thus, reordering the variables and choosing different Choleski decompositions in order to parameterize the impulse vectors will not yield different results.

[9] We set $n_1 = n_2 = 500$, so there are 250,000 draws in total.

or negative. We follow the convention of setting horizon (K) equals five and leave other possible values of K as robustness checks.

4 Results

This section first reports the estimated exchange rate PT into various price indexes in each country. Differences between our results and previous studies are discussed. We then explore the cross-country difference in exchange rate PT by calculating the Spearman rank correlations between the PT estimates and the macroeconomic factors discussed in Section 2.

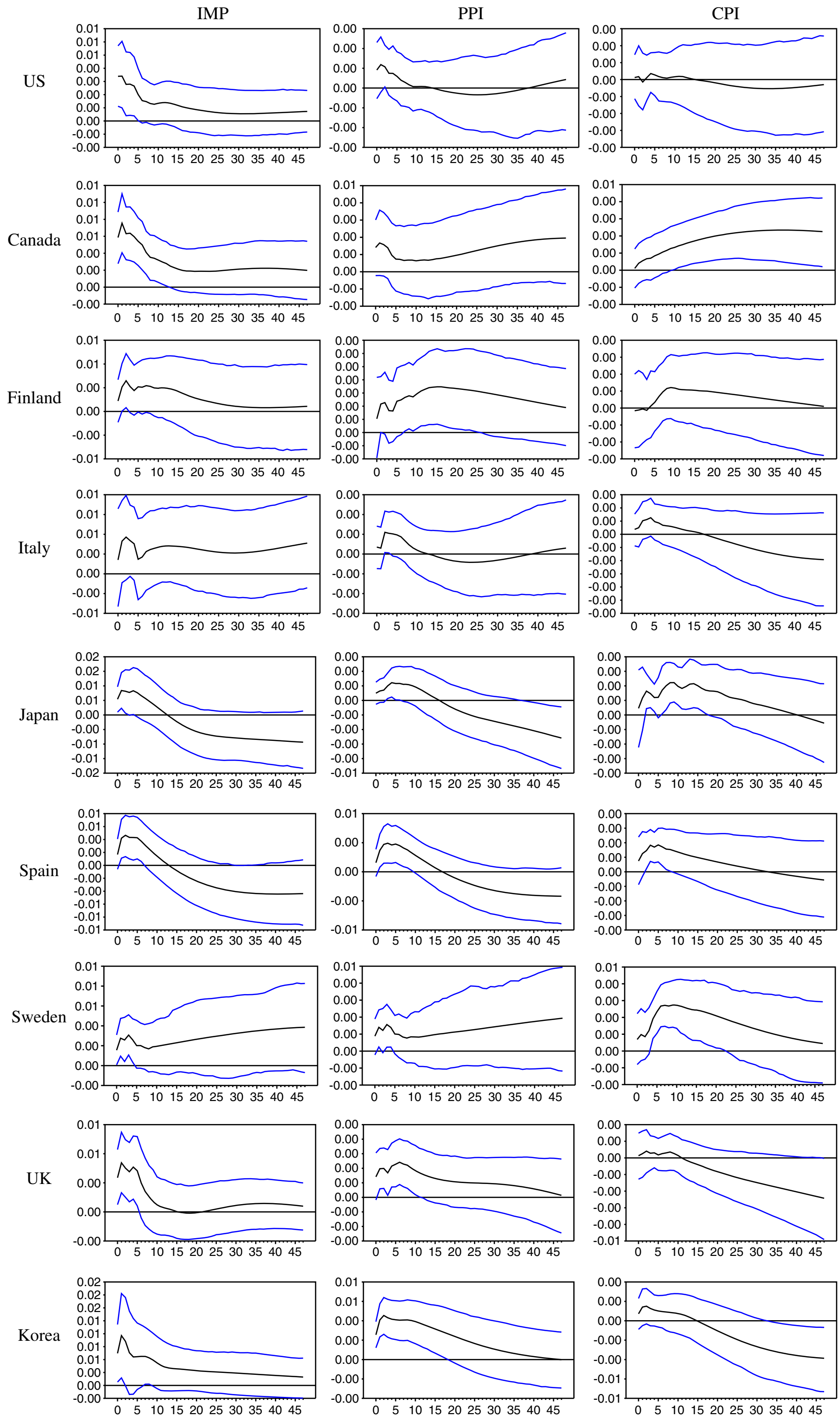
4.1 Exchange Rate PT to Aggregate Prices

Figure 1 displays the impulse responses of IMP, PPI, and CPI to a one-standard-deviation positive exchange rate shock (indicating depreciation) in each country over 48 months. We plot in each chart the median of estimated responses and the 16% and 84% quintiles. It is interesting to note that the error bands are typically symmetric around the median. Our main results of the impulse responses include:

1. IMP, PPI, and CPI in most countries increase immediately following a positive exchange rate shock. This is consistent with the conventional view that a depreciation of a currency generally induces an increase in aggregate prices.
2. The reaction of output to the exchange rate shock is ambiguous across countries. Output gap increases in the US, Canada, and Finland, but decreases in Sweden, the UK, and South Korea following a positive exchange rate shock. Output gap does not significantly react to the exchange rate shock in Italy, Japan, and Spain. This result is consistent with previous empirical findings that the exchange rate depreciation can be either expansionary or contractionary in different countries and during different sample periods.
3. The short-term interest rate increases significantly following a depreciation of the exchange rate in all the countries for 5–12 months. The increase in the interest rate is consistent with the inflation-targeting monetary policy. The central banks increase the short-term rate in response to an increase in the CPI inflation rate following a depreciation of the exchange rate. In addition, some central banks may also increase the interest rate to support the exchange rate when its currency faces depreciation pressures. We acknowledge that part of the result is also driven by the sign restrictions we impose ex ante.[10]

To compare exchange rate PT to IMP, PPI, and CPI across countries, we calculate the PT ratios according to: $PT_t = \frac{P_{0,t}}{E_0}$, where $P_{0,t}$ is the change of a price index from period 0 to period t, and E_0 is the change in the exchange rate on impact of the exchange rate shock. Figure 2 displays the PT ratios of the price indexes for each country with 16% and 84% bands over 48 months. Table 1 reports the PT ratios to IMP, PPI, and CPI in each country at horizons 0, 3, 6, 9, 12, and 15 months. For

[10] The impulse responses of output gaps and interest rates are not presented in the paper, but available upon request.


IMP
PPI
CPI
US
Canada
Finland
Italy
Japan
Spain
Sweden
UK
Korea

◀ **Fig. 1** Impulse responses of price indexes to a positive exchange rate shock. Note: Plots are impulse response functions to a one-standard-deviation positive exchange rate shock

example, the PT ratio to IMP in the US is 0.62 at the contemporaneous horizon (horizon 0), 0.5 at the 3-month horizon, and 0.28 at the 6-month horizon. The last column of Table 1 reports the (un-weighted) average of PT ratios across countries. For instance, at horizon zero, the average exchange rate PT ratio is 0.56 across 9 OECD countries in our sample. Our main findings can be summarized as follows:

1. In Table 1, the average exchange rate PT estimates in the first 16 periods are between 0.31 and 0.88 for IMP, 0.16 and 0.27 for PPI, and 0.02 and 0.10 for CPI. The PT estimates are generally incomplete (less than one) and broadly in line with previous literature. For instance, the average exchange rate PT ratios of IMP in Campa and Goldberg (2005) for 23 OECD countries range from 0.46 to 0.64. The average PT ratios to IMP, PPI, and CPI in Choudhri et al. (2005) for non-US G-7 countries is 0.22–0.73, 0.01–0.15, and 0.02–0.19, respectively. It is also interesting to note that the PT ratio usually rises above its long-run level following an exchange rate shock and then reverts back gradually. The "overshooting" pattern of PT ratios is also present in the IMP PT estimates in Choudhri et al. (2005).
2. Incomplete PT seems to be common across countries in our sample and at most horizons. However, there are some cases where the PT ratios are greater than one, such as IMP PT ratios in Spain at horizons 3, 6, and 9, indicating that import prices increase more than the depreciation of the exchange rate. In theory, there are at least two potential reasons for PT ratios being greater than one. First, the decline of import demand caused by the depreciation of importer's currency can increase the producer's cost in the case of increasing returns to scale. As a result, import prices can increase more than the depreciation of the exchange rate. Second, exchange rate pass-through also depends on the demand elasticity. If the elasticity declines with output, the optimal markup charged by monopolistic suppliers increases following a depreciation of the importer's currency. As a result, the exchange rate PT ratio can be greater than one (Yang 1998). Although similar empirical findings are also documented in several previous studies, such as Campa and Goldberg (2005), caution should be exerted when interpreting such findings. The error bands are usually very wide in these cases, indicating low accuracy in such estimates.
3. In most countries, the PT ratios are largest for IMP, followed by PPI, and smallest for CPI. This result confirms the previous findings that the exchange rate PT ratios decline along the distribution chain. The PT ratio of CPI is larger than PPI for Japan and Sweden at horizons 12 and 15 months. However, the difference is statistically insignificant.
4. Exchange rate PT to CPI is modest (usually less than 0.1) in most countries except Sweden. This finding may reflect that final consumption bundles purchased by households contain a large fraction of nontradable components such as distribution and retail services. The prices of these nontradable components are not affected by exchange rate movements, shielding CPI from exchange rate fluctuations. For instance, Burstein et al. (2005, 2007) find that

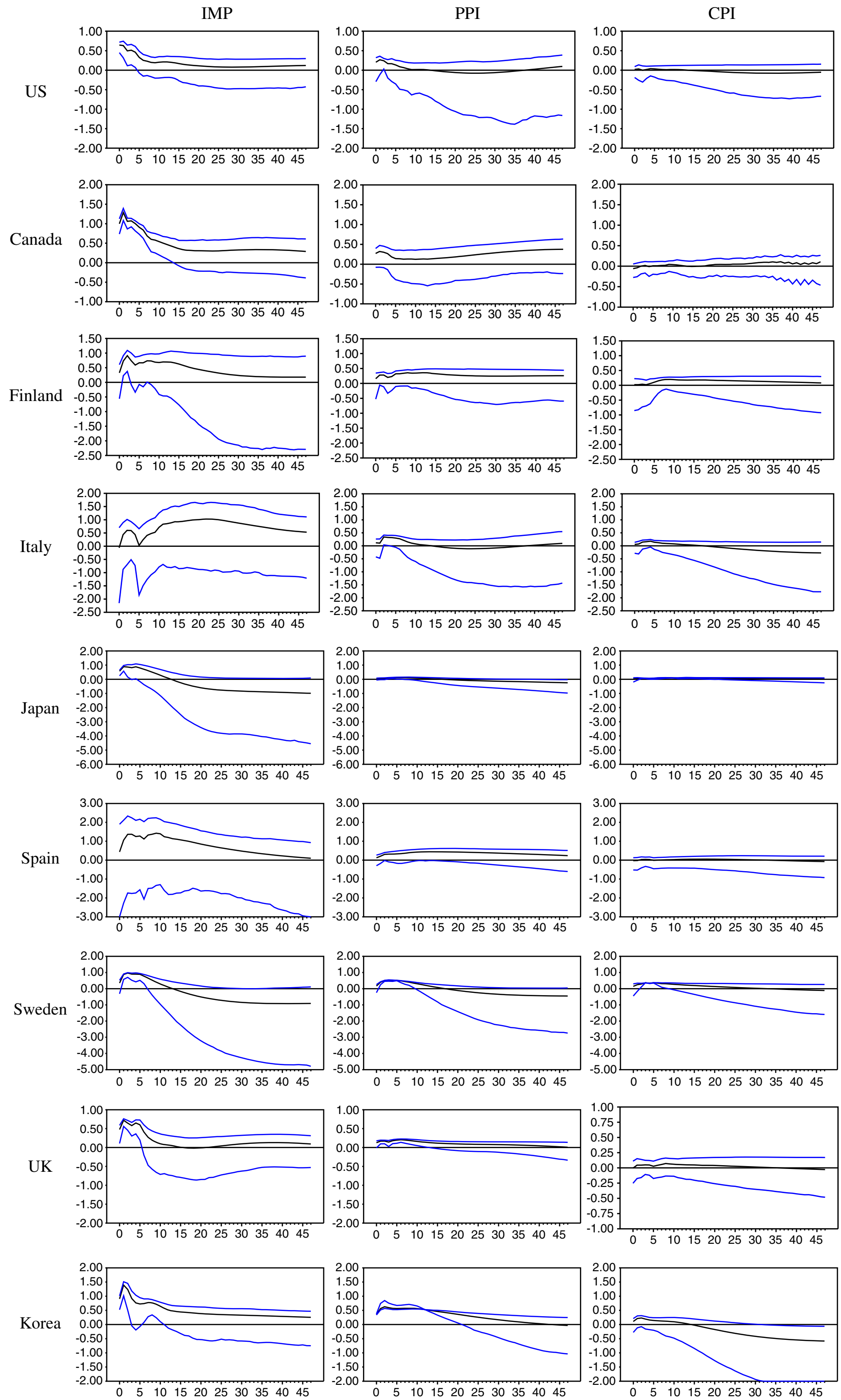


Fig. 2 Exchange rate pass-through ratios into aggregate prices (Benchmark)

Table 1 Exchange rate pass-through ratios in the benchmark model

Response horizons	US	Canada	Finland	Italy	Japan	Spain	Sweden	UK	Korea	Average
Import Price (IMP)										
0	0.62	0.95	0.32	0.45	0.57	0.47	0.35	0.52	0.81	0.56
3	0.50	1.08	0.74	1.11	0.82	1.41	0.90	0.60	0.81	0.88
6	0.28	0.84	0.69	0.56	0.70	1.15	0.78	0.44	0.67	0.67
9	0.22	0.57	0.68	0.86	0.41	1.36	0.40	0.19	0.61	0.59
12	0.23	0.45	0.66	0.94	0.07	1.00	0.10	0.11	0.44	0.44
15	0.19	0.33	0.56	0.93	−0.25	0.76	−0.17	0.04	0.39	0.31
Producer Price (PPI)										
0	0.21	0.20	0.11	0.12	0.05	0.12	0.17	0.12	0.34	0.16
3	0.13	0.13	0.18	0.29	0.10	0.32	0.53	0.14	0.58	0.27
6	0.10	0.11	0.28	0.27	0.11	0.34	0.48	0.20	0.55	0.27
9	0.02	0.07	0.30	0.16	0.10	0.41	0.35	0.16	0.54	0.23
12	0.02	0.01	0.38	0.15	0.06	0.44	0.21	0.13	0.43	0.20
15	0.01	0.05	0.40	0.15	0.02	0.44	0.07	0.11	0.38	0.18
Consumer Price (CPI)										
0	0.01	−0.07	−0.02	0.05	0.02	−0.04	0.15	0.02	0.09	0.02
3	0.02	0.02	−0.02	0.14	0.07	0.02	0.36	0.05	0.17	0.09
6	0.04	0.02	0.10	0.11	0.08	0.02	0.34	0.04	0.11	0.09
9	0.06	0.05	0.18	0.07	0.11	0.01	0.29	0.04	0.09	0.10
12	0.08	0.03	0.16	0.05	0.10	0.02	0.23	0.02	0.04	0.08
15	0.01	0.02	0.15	0.02	0.10	0.03	0.20	−0.07	−0.03	0.05

distribution and retail services account for about half of the retail prices of consumption goods.

5. There is significant heterogeneity in exchange rate PT ratios across countries for all aggregate prices at various horizons. For instance, the average PT ratio for IMP is 0.56 at horizon 0. However, the PT ratio across countries in our sample ranges from 0.32 (Finland) to 0.95 (Canada).

4.2 Cross-Country Differences in Exchange Rate PT

In this section, we study the potential factors that explain the cross-country difference in exchange rate PT. Understanding the determinants of exchange rate PT to aggregate prices is important for the conducting monetary policy. To explain the cross-country difference, we calculate the Spearman rank correlation at various horizons between the PT ratios and the macroeconomic variables that are expected to influence PT.[11] From the discussion in Section 2, the factors we consider include: (1)

[11] Our results do not change qualitatively in the simple correlation coefficients. Results of the simple correlation coefficients are available upon request.

the size of a country measured by the average real GDP converted into US dollars at the average nominal exchange rate of year 2000; (2) The openness of a country measured by the average import share of GDP over the sample period; (3) Exchange rate 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[12]; (5) Aggregate demand volatility measured by the variance of real GDP growth during the sample period; (6) Inflation environment measured by the average annualized CPI inflation rate in the sample period; (7) Monetary policy stability measured by the average monthly growth rate of money supply over the sample period. A higher money supply growth rate indicates a less stable monetary policy environment.

Tables 2 and 3 present the descriptive summary statistics of the above macroeconomic variables for the nine OECD countries in our sample. To illustrate the evolution of these variables, we also calculate the summary statistics for sub-samples of 1980s, 1990s, and 2000s.

According to Table 2, the inflation rate has declined steadily over the last three decades in all countries of our sample. There is also some evidence that the average monthly money supply growth rate has decreased during this period. Among these countries, Italy, Spain, and South Korea have the relatively high money supply growth rate and the inflation rate. Note that these countries also have relatively high exchange rate PT rates in our estimation. South Korea and Finland have the highest variance of real GDP growth, indicating high aggregate demand volatility. Table 3 shows that the rank of the country size is stable in our sample with the US and Japan being the two largest economies and Finland being the smallest. Openness approximated by the import share has increased steadily over the last three decades in almost all countries. South Korea, Sweden and Canada have higher import shares. As discussed in Section 2, if a high import share indicates high domestic market penetration, we expect high PT in these countries holding other things constant. Japan and South Korea have the highest exchange rate volatility in our sample while Spain, Italy, and Finland have experienced the most persistent exchange rate shocks. These factors may increase the exchange rate PT ratio in these countries according to our discussion in Section 2.

Tables 4, 5 and 6 displays the Spearman rank correlations between PT ratios and the above macroeconomic variables at horizons 0, 3, 6, and 12 months. The rank correlations are generally consistent with theoretical predictions discussed in Section 2. Country size is negatively correlated with PT in general. The negative relationship is particularly strong for IMP at horizon 6, PPI at horizons 3, 6, and 12, CPI at horizon 12. This is in contrast with Campa and Goldberg (2005), who do not find systematic relationship between the country size and exchange rate PT. Openness (measured by the import share) is positively correlated with PT in most cases except for IMP at horizon 0 and CPI at horizons 0, 3, and 12, indicating more open economies have higher PT.

The previous empirical findings are mixed on the relation between PT and exchange rate volatility. For example, Campa and Goldberg (2005) and Choudhri and Hakura (2006) report a positive correlation, while McCarthy (2007) and Wei and Parsley (1995) find a negative one. Our empirical results suggest a negative

[12] We follow McCarthy (2007) in measuring the exchange rate volatility and persistence.

Table 2 Descriptive summary statistic of the inflation rate, GDP growth rate, and money supply growth rate

	Inflation rate (in percent)								GDP growth rate (in percent)								Money supply growth rate (in percent)							
	1980s		1990s		2000s		Full sample		1980s		1990s		2000s		Full sample		1980s		1990s		2000s		Full sample	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
US	5.6	3.6	3.0	1.1	2.8	0.6	3.8	2.6	3.0	2.5	3.1	1.5	2.6	1.0	2.9	1.8	0.6	0.3	0.3	0.3	0.5	0.4	0.5	0.4
Canada	6.5	3.3	2.2	1.7	2.3	0.3	3.7	3.0	3.0	2.4	2.4	2.3	2.8	1.0	2.7	2.0	0.8	0.5	0.2	0.3	0.5	0.3	0.5	0.5
Finland	7.3	3.1	2.1	1.3	1.7	1.1	3.9	3.4	3.5	1.0	1.5	4.2	3.4	1.4	2.8	2.8	1.1	1.2	0.2	1.2	0.4	1.4	0.6	1.3
Italy	11.2	5.7	4.1	1.8	2.3	0.3	6.1	5.2	2.3	1.1	1.7	1.7	1.5	1.2	1.8	1.4	1.0	4.8	0.6	3.7	0.5	3.7	0.8	4.1
Japan	2.5	2.3	1.2	1.3	−0.3	0.4	1.2	1.9	4.4	1.4	1.4	2.1	1.7	1.0	2.6	2.0	0.7	0.3	0.2	0.3	0.1	0.2	0.4	0.3
Spain	10.2	3.9	4.2	1.7	3.2	0.3	5.8	4.1	2.6	1.9	2.9	2.4	3.5	0.7	3.0	1.8	1.1	4.1	0.8	2.5	0.2	3.7	0.8	3.5
Sweden	7.9	3.1	3.3	3.8	1.5	0.8	4.4	3.9	2.3	1.3	1.9	2.2	3.1	1.1	2.4	1.7	0.7	1.2	0.3	1.8	0.7	1.2	0.6	1.4
UK	7.4	4.5	3.7	2.4	2.8	0.8	4.8	3.6	2.4	2.4	2.5	2.2	2.7	0.6	2.5	1.9	0.5	2.9	0.5	2.8	0.5	2.6	0.5	2.8
Korea	8.4	9.1	5.7	2.4	3.0	0.7	5.9	5.9	8.2	4.1	6.4	4.6	5.1	1.8	6.7	3.9	2.1	1.0	1.4	0.8	0.7	0.6	1.5	1.0

Tables 2 and 3 show the summary statistics of macroeconomic variables in the 9 OECD countries in our sample. Std is the abbreviation of standard deviation. The inflation rate is measured by the CPI inflation rate in each country

Table 3 Descriptive summary statistics of country size, openness, exchange rate shock volatility and persistence

	Country size (in billion dollar)				Openness (in percent)				Exchange rate shock volatility				Exchange rate shock persistence			
	1980s	1990s	2000s	Full	1980s	1990s	2000s	Full	1980s	1990s	2000s	Full	1980s	1990s	2000s	Full
US	6716.4	9118.4	12134.1	9122.1	7.3	10.6	15.6	10.8	0.0116	0.0089	0.0073	0.0116	1.03	0.87	0.16	0.39
Canada	522.4	661.6	886.5	676.2	22.8	33.1	39.5	31.3	0.0075	0.0076	0.0092	0.0110	0.30	0.31	0.52	0.47
Finland	88.7	103.8	140.2	108.8	22.2	27.0	36.9	28.1	0.0057	0.0102	0.0023	0.0096	0.80	0.96	1.32	1.12
Italy	910.1	1119.9	1307.5	1098.6	15.7	21.1	27.1	21.0	0.005	0.0105	0.0022	0.0092	1.01	1.21	1.11	1.32
Japan	2985.3	4132.0	455.0	3841.9	6.2	8.0	10.2	8.0	0.0151	0.0183	0.0114	0.0211	0.22	0.56	0.50	0.49
Spain	433.1	583.7	801.8	592.2	11.3	22.4	35.6	22.2	0.0078	0.0064	0.0025	0.0082	1.77	0.89	1.54	1.45
Sweden	186.0	222.3	290.4	228.8	25.3	31.6	40.1	31.8	0.0098	0.011	0.0072	0.0124	0.55	0.49	0.73	0.69
UK	1082.7	1378.6	1836.3	1403.7	17.6	23.3	32.1	23.8	0.0106	0.0099	0.0075	0.0135	0.70	0.52	0.40	0.56
Korea	202.1	450.7	724	440	34.3	30.0	35.7	33.2	0.0068	0.0219	0.0113	0.0194	1.01	0.81	0.52	0.96

Country size is measured by the average real GDP converted into dollars at the year 2000 average nominal exchange rate. Openness is measured by the import share of GDP. Exchange rate volatility is measured by the variance of the residuals from the exchange rate equation in the VAR system. Exchange rate shock persistence is measured by the impulse response at the 12-month horizon of the exchange rate to its own initial shock following McCarthy (2007)

Table 4 Spearman rank correlation between IMP PT rates and factors influencing PT

Horizons factors	0	3	6	12
Country size	0.71**	−0.43	−0.57*	−0.38
Country openness	−0.33	0.16	0.40	0.05
ER volatility	0.31	−0.62**	−0.31	−0.98**
ER persistence	−0.76**	0.64**	0.36	0.62**
AD volatility	0.18	−0.35	−0.11	−0.17
Inflation rate	−0.55*	0.43	−0.05	0.60**
MP volatility	−0.7**	0.65**	0.27	0.81**

ER exchange rate, *AD* aggregate demand, *MP* monetary policy. * Significant at the 10% conference level (critical value=0.467). ** Significant at the 5% conference level (critical value=0.583)

correlation for IMP and PPI, but a positive (although statistically insignificant) one for CPI. The correlation between exchange rate persistence and the PT ratios is positive and significant, consistent with the theory discussed in Section 2.

Aggregate demand volatility, which is approximated by the real GDP growth volatility, is negatively correlated with the PT ratios in most cases, suggesting that more volatile aggregate demand is associated with lower PT.

We find a positive relationship between the inflation rate and exchange rate PT in most cases except for IMP at horizons 0 and 6, CPI at horizon 12. Similar results are also reported in Choudhri and Hakura (2006). Lastly, a more stable monetary policy environment leads to lower PT in most cases, which gives support to the theoretical prediction in Devereux et al. (2003).

Note that the correlation coefficients are statistically significant in more cases for PT to IMP and PPI than for CPI. This result may reflect the fact that the cross-country variation in the CPI PT rate is smaller than the variation in IMP and PPI PT rates.[13]

In summary, the import share, the persistence of exchange rate shocks, the inflation rate, and the stability of the monetary policy are positively correlated with exchange rate PT, while the size of an economy, exchange rate volatility and aggregate demand (GDP) volatility are negatively correlated with PT.

5 Robustness Checks

In this section, we show that our results are robust under different values for horizon K of the sign restrictions. In the benchmark results, K is set to 5. In our robustness checks, we consider two alternative horizons for sign restrictions: $K=2$ and $K=11$.

Figures 3 and 4 present the PT ratios with the 16th and 84th error bands for $K=2$ and $K=11$, respectively. The magnitudes and dynamics of estimated PT ratios are similar to those in our benchmark specification. The only noticeable difference is that the distance between upper and lower bands of the PT estimates is wider when $K=2$ and narrower when $K=11$ than in our benchmark specification. This finding is

[13] We thank the referee for suggesting we add more countries into our sample to alleviate this problem.

Table 5 Spearman rank correlation between PPI PT rates and factors influencing PT

Horizons factors	0	3	6	12
Country size	0.17	−0.69**	−0.82**	−0.69**
Country openness	0.29	0.51*	0.55*	0.21
ER volatility	−0.10	−0.5*	−0.38	−0.5*
ER persistence	−0.45	0.77**	0.82**	0.90**
AD volatility	−0.39	−0.59**	−0.31	−0.2
Inflation rate	0.10	0.77**	0.61**	0.64**
MP volatility	0.00	0.89**	0.80**	0.79**

ER exchange rate, *AD* aggregate demand, *MP* monetary policy. * Significant at the 10% conference level (critical value=0.467). ** Significant at the 5% conference level (critical value=0.583)

not surprising: the more horizons that the restrictions are imposed, the less uncertainty is allowed in estimation, therefore, the narrower distance between upper and lower bands.

6 Conclusion

This paper estimates exchange rate PT to aggregate prices for nine OECD countries, using a VAR model with sign restrictions. We have the following main findings. First, the empirical evidence is supportive of partial exchange rate PT for most countries. The magnitudes of the PT ratios are broadly in line with previous literature. Second, the extent of PT declines along the distribution chain. The (un-weighted) average PT ratios of IMP, PPI, and CPI are 0.31–0.88, 0.16–0.27, and 0.02–0.10 for the first 16 months, respectively. Furthermore, it is found that, a greater PT coefficient is associated with an economy with a smaller size, higher import share, more persistent and less volatile exchange rate, less stable monetary policy environment, higher inflation rate, and less volatile aggregate demand.

An interesting extension to our analysis would be to identify other shocks such as demand, monetary, and productivity shocks, that drive exchange rate fluctuations.

Table 6 Spearman rank correlation between CPI PT rates and factors influencing PT

Horizons factors	0	3	6	12
Country size	0.17	0.17	−0.26	−0.53*
Country openness	−0.09	−0.02	0.19	0.31
ER volatility	0.35	0.38	0.24	0.07
ER persistence	0.31	0.17	0.52*	0.43
AD volatility	−0.64**	−0.65**	−0.28	0.06
Inflation rate	0.29	0.24	0.17	−0.21
MP volatility	0.1	0.04	0.18	0.13

ER exchange rate, *AD* aggregate demand, *MP* monetary policy. * Significant at the 10% conference level (critical value=0.467). ** Significant at the 5% conference level (critical value=0.583)

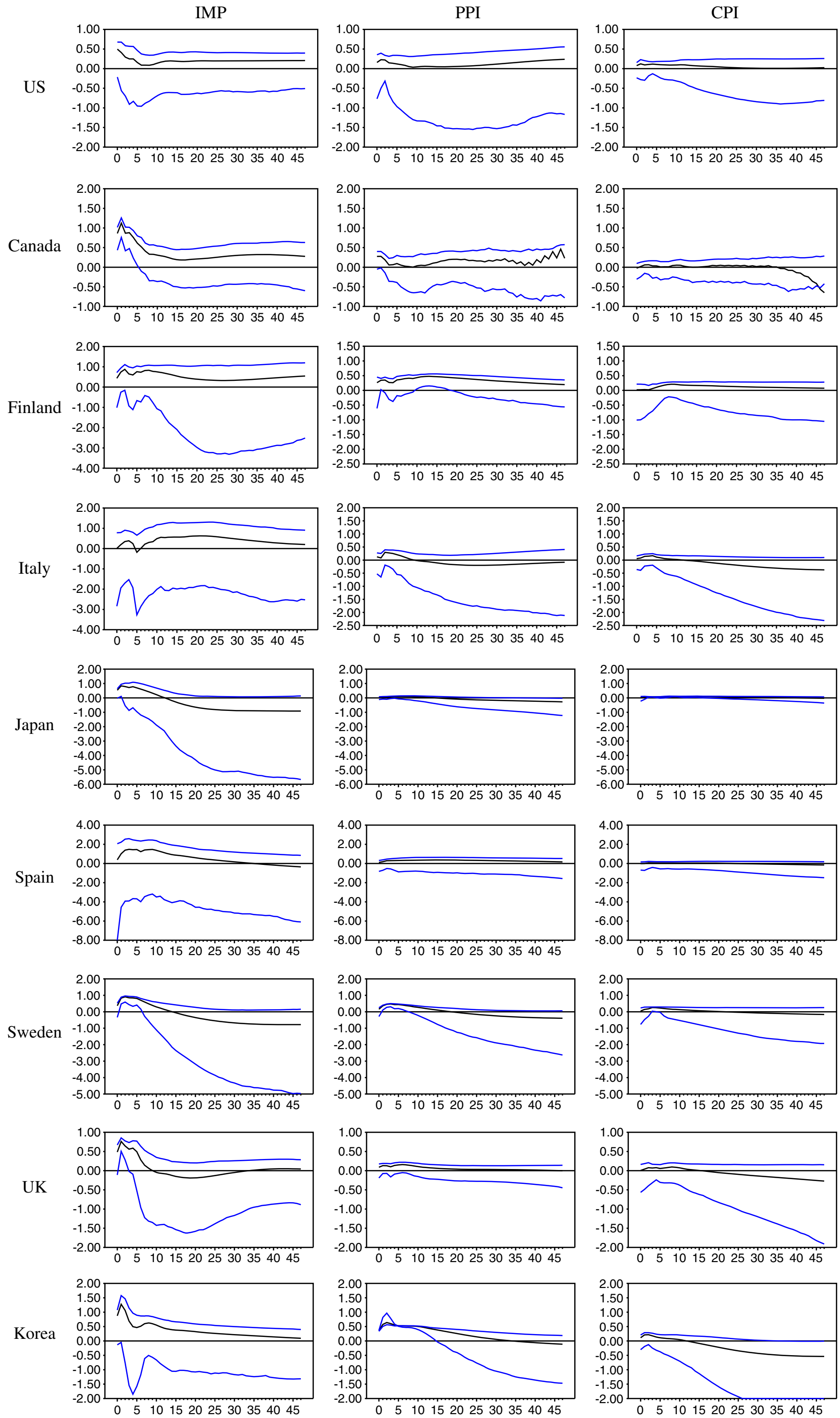


Fig. 3 Exchange rate pass-through ratios into aggregate prices (K=2)

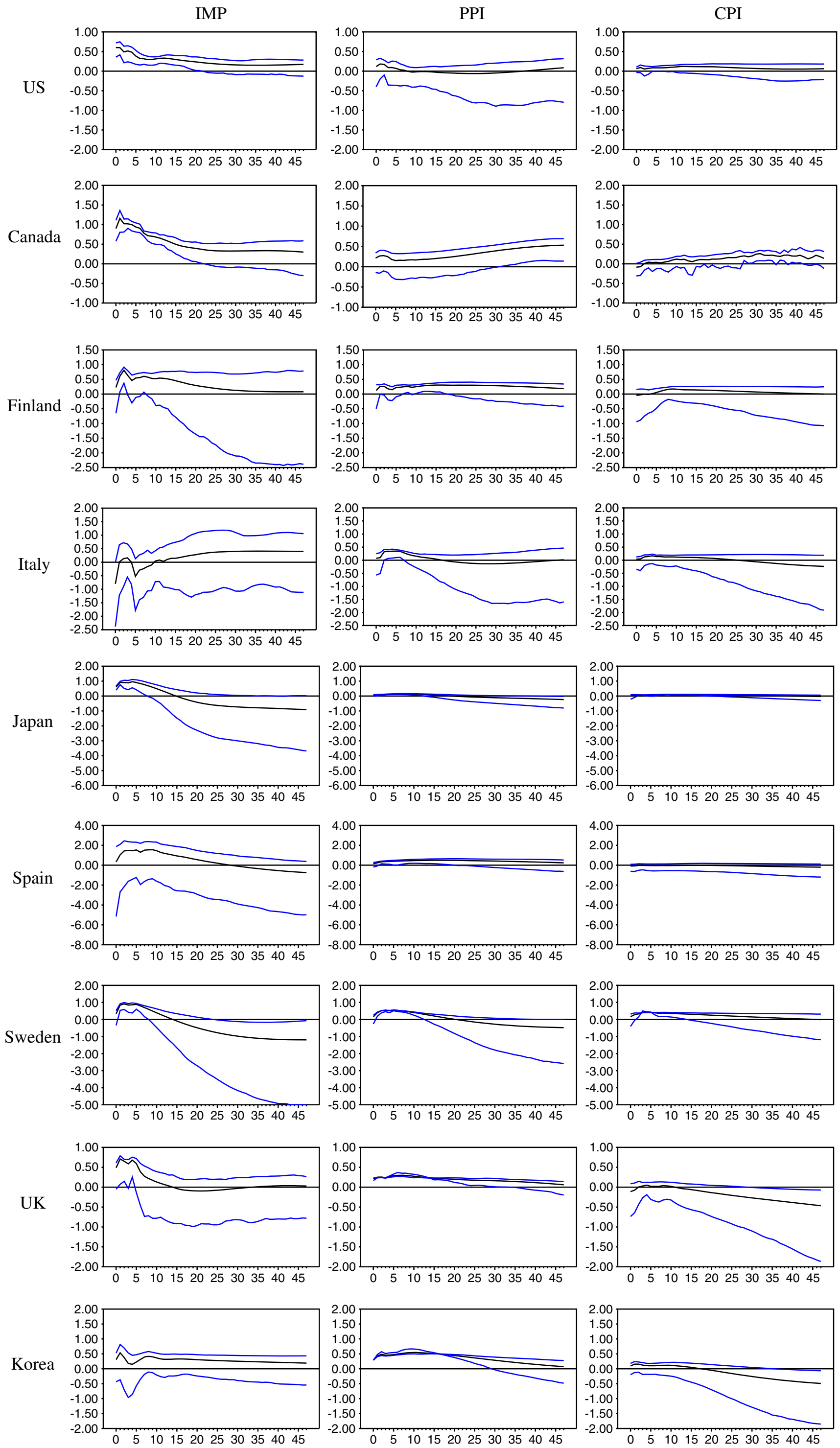


Fig. 4 Exchange rate pass-through ratios into aggregate prices (K=11)

The PT ratio of the exchange rate into aggregate prices may vary with underlying shocks. For instance, see Shambaugh (2008). We could also compare the relative importance of these shocks in driving exchange rate movements under such a framework. We leave these extensions for future research.

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References

Bache IW (2005) Assessing the structural VAR approach to exchange rate pass-through, Norges Bank Working Paper, No. 31

Burstein A, Eichenbaum M, Rebelo S (2005) Large devaluations and the real exchange rate. J Polit Econ 113:742–784

Burstein A, Eichenbaum M, Rebelo S (2007) Modeling exchange rate passthrough after large devaluations. J Monetary Econ 54:346–368

Campa JM, Goldberg L (2005) Exchange rate pass-through into import prices. Rev Econ Stat 87:660–679

Canova F, Pina J (1999) Monetary policy misspecification in VAR models, CEPR Discussion Paper, No.2333

Choudhri EU, Hakura D (2006) Exchange rate pass-through to domestic prices: does the inflationary environment matter? J Int Money Finance 25:614–639

Choudhri EU, Faruqee H, Hakura D (2005) Explaining the exchange rate pass-through in different prices. J Int Econ 65:349–374

Clarida R, Gali J, Gertler M (1998) Monetary policy rules in practice: some international evidence. Eur Econ Rev 42:1033–1067

Clark T (1999) The responses of prices at different stages of production to monetary policy shocks. Rev Econ Stat 81:420–433

Devereux M, Genberg H (2010) Currency appreciation and current account adjustment. J Int Money Finance 26(4):570–586

Devereux MB, Engel C, Storgarrd P (2003) Endogenous exchange rate pass-through when nominal prices are set in advance. J Int Econ 63:263–291

Engel C, West KD (2010) Global interest rates, currency returns, and the real value of the dollar. Am Econ Rev Pap Proc 100(2):562–67

Feinberg R (1986) The interaction of foreign exchange and market power effects on German domestic prices. J Ind Econ 35:61–70

Feinberg R (1989) The effects of foreign exchange movements on U.S. domestic prices. Rev Econ Stat 71:505–11

Hahn E (2003) Pass-through of external shocks to Euro area inflation, European Central Bank Working Papers, No. 243

Ito T, Sasaki Y, Sato K (2005) Pass-through of exchange rate changes and macroeconomic shocks to domestic inflation in East Asian Countries, RIETI Discussion Paper Series, No. 05-E-020

Kim Y (1990) Exchange rates and import prices in the United States: a varying-parameter estimation of exchange-rate pass-through. J Bus Econ Stat 8:305–315

Levchenko A, Lewis L, Tesar L (2009) The collapse of International Trade during the 2008–2009 crisis: In Search of the Smoking Gun, Research Seminar in International Economics Discussion Paper, No. 592

Mann CL (1986) Prices, profit margins and exchange rates. Fed Reserve Bull 72:366–79

McCarthy J (2007) Pass through of exchange rates and import prices to domestic inflation in some industrialized economies. East Econ J 33:511–537

Obstfeld M (2002) Exchange rates and adjustments: perspectives from the new open economy macroeconomics, monetary and economic studies (Special Edition)

Rudebusch GD (1998) Do measures of monetary policy in a VAR make sense? Int Econ Rev 39:907–931

Shambaugh J (2008) A new look at pass-through. J Int Money Finance 27:560–591

Sims C (1988) Bayesian skepticism on unit root econometrics. J Econ Dyn Control 12:463–474

Taylor JB (2000) Low inflation, pass-through, and the pricing power of firms. Eur Econ Rev 44:1389–1408

Uhlig H (2005) What are the effects of monetary policy on output? Results from an agnostic identification procedure. J Monetary Econ 52:381–419

Wang J (2010) Durable goods and the collapse of global trade. Economic Letter 5(2) Federal Reserve Bank of Dallas

Wei S, Parsley D (1995) Purchasing power disparity during the floating rate period: exchange rate volatility, trade barriers, and other culprits, NBER working paper, No.5032

Yang JW (1997) Exchange rate pass-through in U.S. manufacturing industries. Rev Econ Stat 79:95–104

Yang JW (1998) Pricing-to-market in U.S. imports and exports: a time series and cross-sectional study. Q Rev Econ Finance 38:843–861