Retail Prices and the Real Exchange Rate
by
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ABSTRACT

This paper uses daily frequency relative prices gathered from online retailers for a basket of countries to investigate the Purchasing Power Parity relationship, exchange rate pass-throughs and the effect of price shocks on nominal exchange rates. We fit a structural VAR model on exchange rate and relative price data to compute impulse responses for each country. We find evidence of exchange rate pass-through for most countries, even at short horizons. Contrary to PPP predictions, we find that most countries witness an exchange rate appreciation post a domestic inflation shock. We study the persistence of each variety of shock and the overall effect on the real exchange rate. We find that real exchange rates are more likely to mean revert if the shock arises from nominal exchange rates as opposed to relative prices.

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# Contents

1 Introduction ........................................................................................................... 6

2 Model .................................................................................................................. 9
   2.1 Model ............................................................................................................. 9
   2.2 Impulse-Responses and Confidence Intervals ............................................. 11

3 Data ..................................................................................................................... 14

4 Results ............................................................................................................... 18
   4.1 Impulse Responses by Country .................................................................. 18
   4.2 Observations ............................................................................................... 27
   4.3 Exchange rate pass-through ...................................................................... 27
   4.4 FX response to Inflation ........................................................................... 29
   4.5 Long-run effects ........................................................................................ 33
   4.6 Persistence of shocks ................................................................................ 36

5 Real Exchange Rates ........................................................................................ 39
   5.1 Response to a nominal exchange rate shock ............................................. 40
   5.2 Response to a price shock .......................................................................... 41

6 Conclusion ......................................................................................................... 42

A Sample Data and Stationarity ........................................................................... 44

B Structural VAR models and Long-run Effects .............................................. 46

C Choice of lag for the SVAR model .................................................................... 48

D Different Endogeneity Restriction ..................................................................... 49
1 Introduction

Global economies are more connected than ever before. As markets for both goods and services get more efficient one would expect the Law of One Price (LOP) to hold more often than before. LOP is equivalent to absence of arbitrage. One way of testing whether prices across the world align with one another is to observe the time variation of real exchange rates. If nominal exchange rates were fixed, for prices to align i.e. LOP to hold, a price shock in one economy had to be matched by a similar movement in prices in the other. Post the fall of Bretton Woods in 1971, major economies have floated their currencies. Floating exchange rates provide a second channel for adjustment. To capture the adjustment process in one variable, one defines the real exchange rate as the ratio of the nominal exchange rate and the relative prices between the economies\(^1\). Real exchange rates are useful in testing the efficacy of LOP.

The idea that similar baskets of goods should be priced similarly across economies is also referred as Purchasing Power Parity or PPP. There are varying degrees of strictness one can impose on the condition\(^2\). Deviations from PPP is failure of LOP. And deviation of PPP is captured by real exchange rates. If real exchange rates are stationary i.e. shocks to real exchange rates are not permanent, this would prove that any deviation is bound to disappear over time. However, if real exchange rates are non-stationary i.e. has a unit root, then shocks to the real exchange rate will remain in the system\(^3\). As such, validity of LOP or PPP boils down to the behavior of the real exchange rate. Research on PPP using unit root tests and other econometric techniques came to the conclusion that real exchange rates were indeed stationary but had large half-lives\(^6\). This led to research trying to explain the source of shocks to real exchange rates in an effort to explain the unusually high half-life. Rogoff (1996)\(^{10}\) proposed the PPP puzzle: that real exchange rates are

\(^1\) If \(n_t\) is the exchange rate and \(p_t\) is the relative price, the real exchange rate \(r_t\) is defined as

\[ r_t = \frac{n_t}{p_t} \]

To clarify the construction further, say \(n_t\) is the exchange rate between the US and a foreign country F in terms of number of foreign currency per unit of USD. In this convention \(n_t\) going up implies USD appreciating (same as the foreign currency depreciating). The relative price \(p_t\) is defined as

\[ p_t = \frac{p_t^F}{p_t^{US}} \]

Therefore, relative price \(p_t\) going up would imply inflation in the foreign country F

\(^2\) Absolute PPP or relative PPP:

In absolute PPP, the nominal exchange rate responds to the level of prices while in relative PPP, changes in the nominal exchange rate are linked to changes in the prices in each economy

\(^3\) Research efforts in explaining the permanence of real exchange rates tries to model a permanent shock to a macro variable that leads to a permanent shock in the real exchange rate. If such a model fits the data, then stationarity of real exchange rates need not hold and could be justified as an outcome of said shocks
volatile. What could cause such short-term volatility? Productivity shocks\textsuperscript{4} or technology shocks couldn’t since they are not as volatile. Monetary or fiscal shocks, portfolio-rebalancing, short-term price bubbles etc. could explain deviations based on nominal price stickiness. However, half-lives from nominal price and wage rigidities couldn’t be 3-5 years, the typical real exchange rate half-life observed in data. Subsequent research has tried to explain the puzzle by showing that the half-lives are indeed lower. Rey et. al (2003)[7] show that accounting for heterogeneity in sectoral price setting indeed produces relative prices which imply lower half-lives, ones which can be explained by nominal rigidity.

In this paper, we use novel data\textsuperscript{5} to study real exchange rates, their response to both relative prices and nominal exchange rate shocks. In addition, we also look at

- exchange rate pass-through - effect of a nominal exchange rate shock on relative prices
- effect of relative price shocks on the nominal exchange rate

Exchange rate pass-throughs, or fraction of exchange rate movements passed on to prices, are well studied in literature. Following a nominal exchange rate shock, firms find their costs and prices out of line and as such, an adjustment ensues. Firms adjust prices based on their expectations of future demand and future costs. Transitory shocks, therefore, are likely to be ignored to protect market share but permanent shocks, like a shift in monetary policy regime could change pricing substantially. The fraction of the shock that translates to prices depends on the type of the shock. As discussed in Forbes (2015)[4], different shocks have different pass-throughs. Pass-throughs are time varying\textsuperscript{6} and different for import prices and consumer prices. Also, pass-throughs depend on the pricing currency of the good concerned (Gopinath et. al (2015)[5]). Response of prices to nominal exchange rate shocks also depend on monetary policy mandates. In an inflation-targeting mandate, the central bank expecting exchange-rate pass-through could tighten domestic conditions thereby affecting the subsequent outcome. We compute exchange rate pass-throughs for a set of countries. We find evidence of pass-through even in short time horizons for select countries\textsuperscript{7}.

\textsuperscript{4} Used by Balassa-Samuelson (1964)[1][1] to argue why rich countries should have higher prices compared to poorer countries.

\textsuperscript{5} Daily frequency relative prices based on retail prices, from PriceStats. PPP related research has mostly relied on quarterly or monthly data. As such, results on the daily granularity throw new light on the PPP hypothesis. Relative prices are gathered from the internet by scouring over 1000 retailers across countries and as such, captures the price rigidity in the current world. See section 3 for more details.

\textsuperscript{6} Since economies suffer from different kinds of shock from time to time. Also, sometimes the shocks are domestic, sometimes global.

\textsuperscript{7} See Table 2
We also look at the effect of shocks to relative prices on the nominal exchange rate. The response here is complex and country specific. Source of relative price shocks could be demand, supply, monetary or even productivity. Shocks could be both domestic or global. These shocks are managed by central banks, under their respective mandates, in turn altering the consequences of the shock. The resultant capital flows\textsuperscript{8} - the net magnitude and direction of which is dependent on the nature of the shock and the nature of the economy, determines how the nominal exchange rate will react. In this paper, we do not attempt to classify the effects by type of shock. Instead, we focus more on what daily frequency retail data have to tell us about the overall response in nominal exchange rates from relative price shocks. Contrary to PPP hypothesis, we find that nominal exchange rates instead of depreciating after a domestic inflation shock, more often than not, appreciates. We study the significance of this move in detail in section 4.4.

In this paper we model nominal exchange rates and relative prices jointly in a structural VAR. This allows us to study the effect of shocks of one variable on the other. We also look at the evolution of the shock itself. A VAR system allows for efficient calculation of long-run behavior of the variables. From our system we also observe real exchange rates, and how shocks to real exchange rates evolve. We observe how the source of the shock determines the evolution. In particular, we find that nominal exchange rate shocks lead to pass-through, known as exchange rate pass-through. This pass-through leads to mean reversion in the real exchange rate as predicted by PPP. Real exchange rate shocks coming from shocks in relative prices, however, are very persistent. Often the relative price shock is self-reinforcing. Also the nominal exchange rate usually appreciates after domestic inflation shocks instead of depreciating as would be predicted by PPP. Together, these moves result in persistence in the real exchange rates shock. We present the results in section 5.

Section 2 presents our model, followed by a description of the data in section 3. In section 4 we look at the impulse-responses for the different countries. We tabulate the exchange rate pass-throughs over different time horizons. We also look at model predicted long-run pass-through. We repeat the exercise for relative price shocks and their effect on nominal exchange rates. In section 5 we study the real exchange rate to see the joint effect of the responses to any particular shock. We note the country specific idiosyncrasies and how the source of the shock influences the response. Section 6 concludes.

\textsuperscript{8} From business investment, portfolio reallocation, or even speculative flows
2 Model

This section describes the model we use to investigate the relationship between relative prices and exchange rates. Unless specified otherwise, we refer to relative prices as EPPP and nominal exchange rates as Nominal throughout this paper. Broadly speaking, we fit a structural VAR (SVAR) model to capture endogeneity in the variables. Based on the estimated SVAR coefficients we produce impulse-responses on the system for both kinds of shock - shocks to Nominal and to EPPP. The SVAR also helps us compute long-run effects. Below we describe the model followed by structural parameter estimation, impulse-responses and confidence bands.

2.1 Model

Our system of variables are nominal exchange rates, denoted by \( n_t \) and relative prices in tradables of two countries, denoted by \( p_t \). We refer to the former as Nominal and later as EPPP from time to time. Our level data is in logarithms to make better sense of changes and to be able to make cross country comparisons. Let \( X_t \) be our system variable, defined as below:

\[
X_t = (\log(n_t), \log(p_t))', \quad n_t = \text{nominal exchange rate}, \quad p_t = \text{relative prices}
\]  

(1)

We work with first differences to ensure stationarity in our system. As such, the variables we fit are

\[
\Delta X_t = X_t - X_{t-1}
\]

Assume the system \( \Delta X_t \) follows a VAR(p) process. Since \( n_t \) and \( p_t \) are simultaneously determined, we have to impose structural restrictions in an otherwise reduced form VAR model of our system. To better comprehend the requirement for an SVAR let us start with a reduced form VAR(p) on the first-differences, \( \Delta X_t \):

\[
\Delta X_t = \alpha + \hat{\beta}_1 \Delta X_{t-1} + \hat{\beta}_2 \Delta X_{t-2} + \cdots + \hat{\beta}_p \Delta X_{t-p} + \epsilon_t
\]

(2)

Define the VAR residuals \( \epsilon_t \) as \( (\epsilon^p_t, \epsilon^n_t)' \). We know that \( \epsilon^p_t \) and \( \epsilon^n_t \) are not orthogonal to each other since there are possibilities of real time interaction between the state variables i.e. \( n_t \) can be affected by \( p_t \) and vice-versa. This means that the model suffers from endogeneity. As such, we fit an SVAR(p) model as shown below.

\[
A \Delta X_t = c + \psi_1 \Delta X_{t-1} + \psi_2 \Delta X_{t-2} + \cdots + \psi_p \Delta X_{t-p} + B u_t
\]

(3)

9 Nominal exchange rates or market FX rates
10 See Appendix A
Here \( u_t = (u^n_t, u^p_t)' \) are structural shocks such that \( u^n_t \perp u^p_t \). We do not impose long-run restrictions\(^{11}\) and set \( B = I_2 \). The estimation of coefficients \( \mathbf{c}, \psi_1, \psi_2, \ldots, \psi_p \) is possible given appropriate structural restriction on the matrix \( A \)^{12} to take into account the endogeneity in the system. In an SVAR with \( K \) variables, an unrestricted \( A \) i.e. with \( K^2 \) i.e. 4 degrees of freedom cannot be estimated from data\(^{13}\). There needs to be at least \( K(K - 1)/2 \) restrictions and therefore at most \( K(K + 1)/2 \) elements of the structural matrix can be identified. This translates to at least one restriction in our model instance. In fact, we impose not one but three restrictions. We fix the diagonal elements of \( A \) to 1, thereby equating the volatility of the structural shock and the reduced form residuals. The third restriction we impose is forcing one of the two off-diagonal elements to be zero. The choice corresponds to the two simple endogeneity specifications:

- \( n_t \) is endogenous\(^{14}\) i.e. \( p_t \) appears in the equation of \( n_t \) but not vice-versa
- \( p_t \) is endogenous\(^{15}\) i.e. \( n_t \) appears in the equation of \( p_t \) but not vice-versa

When \( p_t \) is endogenous the matrix \( A \) looks like
\[
\begin{bmatrix}
1 & 0 \\
\mathbf{b} & 1
\end{bmatrix}
\]
where \( \mathbf{b} \) is the coefficient on \( n_t \) in the equation for \( p_t \). In similar spirit, when \( n_t \) is endogenous the matrix \( A \) looks like
\[
\begin{bmatrix}
1 & \mathbf{a} \\
0 & 1
\end{bmatrix}
\]

\(^{11}\) The matrix \( B \) is used for imposing long run restrictions in spirit of Blanchard-Quah (1989)[2]
\(^{12}\) Please refer to Appendix for details regarding the estimation of structural matrix \( A \) and SVAR coefficients
\(^{13}\) To develop some intuition on this, consider the residuals from eq.(2) above. We can estimate the covariance matrix of the residual \( \Sigma_e = \mathbb{E}[e_i e_j'] \). \( \Sigma_e > 0 \) i.e. the covariance matrix is positive definite, \( \therefore \) a unique Cholesky decomposition

\[
\Sigma_e = DD'
\]
where \( D \) is a diagonal matrix. Now from eq.(3), we can see that \( \Sigma_u = A^{-1} \Sigma_u (A^{-1})' \) where \( \Sigma_u \) is a diagonal matrix.

\[
\Sigma_u = \begin{bmatrix}
\sigma^2_e & 0 \\
0 & \sigma^2_{ep}
\end{bmatrix}
\]

If the inverse of the structural matrix i.e. \( A^{-1} \) can be represented as
\[
A^{-1} = \begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{bmatrix}
\]

then we can write the following:

\[
A^{-1} \Sigma_u (A^{-1})' = \begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{bmatrix} \begin{bmatrix}
\sigma^2_e & 0 \\
0 & \sigma^2_{ep}
\end{bmatrix} \begin{bmatrix}
a_{11} & a_{21} \\
a_{12} & a_{22}
\end{bmatrix}
\]

\[
= \begin{bmatrix}
a_{11} \sigma_{en} & a_{12} \\
a_{21} & a_{22} \sigma_{ep}
\end{bmatrix} \begin{bmatrix}
a_{11} \sigma_{en} & a_{21} \\
a_{12} & a_{22} \sigma_{ep}
\end{bmatrix}
\]

\[
= CC'
\]

Since, only three independent equations can be formed using the information in \( D \), we have to put restrictions on \( A \) i.e. \( a_{ij} \forall i, j \) cannot be identified independently.

\(^{14}\) denoted by "Endo=Nominal" in the figures
\(^{15}\) denoted by "Endo=EPPP" in the figures
is the coefficient on \( p_t \) in the equation for \( n_t \). An SVAR (eq. 3) instead of a reduced-form VAR (eq. 2) helps capture how shocks are generated simultaneously in the system variables from uncorrelated structural shocks\(^{16}\). We can see the implications of the structural specifications in the impulse-responses we discuss in Section 4.1. Estimation is straightforward. Estimation of the SVAR coefficients of eq (3) proceeds as follows:

1. Estimate the coefficients of the reduced form VAR as in eq (2) by running line by line OLS

2. For a particular endogeneity specification, estimate the structural matrix \( A \) by minimizing the negative of the log-likelihood function i.e.

\[
\min_A \mathcal{L}(A) = \min_A -\frac{KT}{2} \ln(2\pi) + \frac{T}{2} \ln|A|^2 - \frac{T}{2} \text{tr}(A'A\Sigma_e)
\]

Now, we look at how impulse-responses and confidence bands for the impulse-response functions are estimated.

### 2.2 Impulse-Responses and Confidence Intervals

Having estimated \( \hat{A}, \hat{c} \) and \( \hat{\Psi}_t \) \( \forall i \in [1, 2, \ldots, p] \) i.e. the entire SVAR model of eq(3), we proceed with computing impulse-responses in our system. A shock is essentially a perturbation to the steady-state of eq (3). In steady-state, \( \Delta X_t = 0, \forall t \in (-\infty, t) \). A structural shock to one of the variables, say \( n_t \), denoted by \( u_{t+1} = \begin{bmatrix} \delta \\ 0 \end{bmatrix} \) then passes through the system as follows:

\[
\Delta X_t = A^{-1} u_{t+1}
\]

\[
\therefore A \neq I_2 \text{ the structural shock } \delta \text{ to } n_t \text{ doesn't affect } p_t \text{ only if } p_t \text{ is exogenous. In the two endogeneity conditions we consider in our system}\(^{17}\), if we assume } p_t \text{ to be the endogenous variable instead, a structural shock to } n_t \text{ would transmit as follows: Say } A = \begin{bmatrix} 1 & 0 \\ b & 1 \end{bmatrix} \neq I_2 \text{ i.e. } b \neq 0. \text{ Endogeneity would imply that a shock of magnitude } \delta \text{ to } n_t

---

\(^{16}\)For example, consider the endogeneity specification where \( p_t \) is exogenous and \( n_t \) is endogenous. \( A \) looks like \( \begin{bmatrix} 1 & a \\ 0 & 1 \end{bmatrix} \). Say, \( u_t^p = \gamma \) and \( u_t^n = 0 \) i.e. \( u_t = (0, \gamma)' \). A structural shock to EPPP transmits to \( n_t \) because of our endogeneity specification. The reduced form residuals \( \varepsilon_t = (\varepsilon_t^p, \varepsilon_t^n)' \) are given by

\[
\varepsilon_t = A^{-1} u_t = \begin{bmatrix} 1 & -a \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ \gamma \end{bmatrix} = \begin{bmatrix} -a \gamma \\ \gamma \end{bmatrix}
\]

As we can see above, a shock to \( p_t \) transmits to a non-trivial shock to \( n_t \) as \( \varepsilon_t^n = -a \gamma \neq 0 \).

\(^{17}\)either \( p_t \) is endogenous or \( n_t \),
translates to a shock of \(-b\delta\) to \(p_t\). However, if \(p_t\) were exogenous, there would be no instantaneous effect. To compute the response of the system to various shocks i.e.

\[
\frac{\partial X_t}{\partial u^p_{t-j}} \quad \text{(Nominal shocks),} \quad \frac{\partial X_t}{\partial u^p_{t-j}} \quad \text{(EPPP shocks),} \quad \forall j > 0
\]

we perturb the steady state with a \(\delta = 1\) shock\(^{18}\) and use the model to produce the evolution of the shock through the system. Since we work with the first differences, the above coefficients of interest are retrieved by accumulating the changes on each variable.

**Confidence Intervals on IRF**

We generate confidence bands for our impulse-responses by generating 100 bootstrap draws of the data. The bootstrap procedure is described next. For each bootstrapped data sample, we fit the SVAR and generate the IRF.

**Bootstrap**

Suppose the original data sample is \(\{X_t\}_{t=1}^T\). Given a VAR\((p)\) model,

\[
X_t = \alpha + \beta_1 X_{t-1} + \beta_2 X_{t-2} + ... + \beta_p X_{t-p} + \epsilon_t
\]

a bootstrapped sample \(\{X^*_t\}_{t=1}^T\) is created as follows:

- The pre-sample \(\{X_i\}_{t=1}^p\) is same for all the draws i.e. \(X^*_t = X_t\) \(\forall i \in [1, p]\)
- \(\{X_i\}_{t=p+1}^T\) is constructed iteratively, starting from \(i = p + 1\), using the following equation:

\[
X_t = \hat{\alpha} + \hat{\beta}_1 X^*_{t-1} + \hat{\beta}_2 X^*_{t-2} + ... + \hat{\beta}_p X^*_{t-p} + \nu_{t+1}
\]

where \(\nu_{t+1}\) is drawn uniformly at random with replacement from the sample \(\{\epsilon_t\}_{t=p+1}^T\), the fitted residuals from the VAR\((p)\) model

In our exercise, we proceed along the above lines using the reduced-form VAR model in eq (2). For all the countries in our analysis, we find almost zero serial correlation in our VAR residuals i.e. \(\mathbb{E}[\epsilon_t \epsilon'_{t-j}] \approx 0\). Since VAR residuals are close to independent, a uniform at random draw from the empirical distribution was sufficient for the residuals and no block bootstrap is required. We use the above procedure to create 100 bootstrap draws of the data \(\{X^{(1)}_t\}_{t=1}^T, \{X^{(2)}_t\}_{t=1}^T, \ldots, \{X^{(100)}_t\}_{t=1}^T\). For each bootstrapped universe \(\{X^{(j)}_t\}_{t=1}^T\), we reproduce the entire model:

\(^{18}\) to either \(\Delta \log n_t\) or \(\Delta \log p_t\)
• Fit VAR(p) along the lines of eq (2)

• Estimate SVAR coefficients as per eq (3)

• Compute impulse-response on the system using the estimated coefficients

The 100 bootstrap samples provide 100 estimates of the impulse-responses which are then used for estimation of the confidence bands for a desired level of significance. We also compute the response of the real exchange rate $r_t = \frac{n_t}{p_t}$ from either shock along with confidence bands. For choice of lag, $p$, we choose 240 lags to cover one year's worth of history. Our motivation stems from the fact that past research points to 1-2 year time horizon for nominal rigidities as well as upwards of 2 years half-life for real exchange rates. As part of our analysis, we also compute several estimates for other lag values as well. The broad conclusions are unchanged by the choice of lag.

Summary

In a nutshell, for every country we stack Nominal and EPPP together to get our system of variables $X_t$. We fit an SVAR on $\Delta X_t$ using which we compute impulse-response coefficients in our system. To generate confidence bands for the impulse-responses, we bootstrap 100 draws of the data $\{X^*_{t(j)}\}_{j=1}^{100}$. We apply the same procedure as for the point estimate on the bootstrapped data to generate impulse-response bands. Responses are computed for Nominal, EPPP and real exchange rates. The impulse-responses along with 95% confidence bands are presented in section 4. Next we discuss our data.

For any given set of impulse-responses, say the response of $p_t$ to a structural shock to $n_t$, the effect of the shock $k$ periods into the future is given by

$$f_k(n \to p) = \frac{\partial p_t}{\partial u_{t-k}} \quad k \in \{1, 2, \ldots, H\}$$

where $H$ is the future look out horizon. For the bootstrapped universe $\{X^*_{t(j)}\}_{j=1}^{100}$, we will have a particular sequence $\{f^*_{k}(n \to p)\}_{k=1}^{H}$. The $1 - \alpha$ significance confidence bands around our point estimate of each coefficient $f_k(n \to p)$ is computed using the $\alpha$ and $1 - \alpha$ quantile points over the 100 instances of $f^*_{k}(n \to p)$ where $i \in \{1, 2, \ldots, 100\}$. Computing quantiles for each $k \in \{1, 2, \ldots, H\}$ gives us the confidence band for the entire impulse-response. We use the same procedure to compute the bands for the other impulse responses - $f(p \to n)$, $f(p \to p)$ and $f(n \to n)$ as well.

To compute the confidence bands for $f_k(p \to r)$ or $f_k(n \to r)$, $k \in \{1, 2, \ldots, H\}$, we use the same approach as above - we compute bootstrapped universe specific impulse-response coefficients $f^*_{k}(p \to r)$ and $f^*_{k}(n \to r), \forall i \in \{1, 2, \ldots, 100\}$ and take the $\alpha$ and $1 - \alpha$ quantiles of the series $\{f^*_{k}(i)\}_{i=1}^{100}$ as the confidence interval for $f_k$.

See Appendix C.

Nominal divided by EPPP or in our model, we deal with log, we define real exchange rate as the difference of the two.
3 Data

We use relative prices between tradable goods from PriceStats\textsuperscript{24} for the following countries - Australia, Argentina, Brazil, China, Germany, Japan, South Africa and United Kingdom as our \textit{EPPP} series. As noted in Cavallo and Rigobon (2016)[3], \textit{PriceStats} uses about 15 million products from over 900 retailers to build daily inflation indexes in about 20 countries. Relative price series are computed by \textit{PriceStats} at the product level and aggregated using a Fisher index with official expenditure weights for food, fuel, and electronics. The work is an outcome of the \textit{Billion Prices Project}\textsuperscript{25} at MIT. For \textit{Nominal}, we use market foreign exchange rates. All our nominal series are \textit{USDXYZ}\textsuperscript{26} i.e. number of foreign currency per unit USD. As such, in the charts, a positive shock to \textit{Nominal} corresponds to a devaluation of the local (non-USD) currency. As to the \textit{EPPP} series, positive shocks correspond to local (non-USD) inflation. Table 1 provides the time period covered by our data for each country.

<table>
<thead>
<tr>
<th>Sample coverage by country</th>
<th>Start Date</th>
<th>End Date</th>
<th>No. of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>31-Aug-2008</td>
<td>30-Aug-2016</td>
<td>2861</td>
</tr>
<tr>
<td>Australia</td>
<td>12-Aug-2008</td>
<td>30-Aug-2016</td>
<td>2880</td>
</tr>
<tr>
<td>Brazil</td>
<td>29-Feb-2012</td>
<td>30-Aug-2016</td>
<td>1645</td>
</tr>
<tr>
<td>China</td>
<td>15-Aug-2010</td>
<td>30-Aug-2016</td>
<td>2208</td>
</tr>
<tr>
<td>Germany</td>
<td>27-Nov-2011</td>
<td>30-Aug-2016</td>
<td>1739</td>
</tr>
<tr>
<td>Japan</td>
<td>27-Apr-2011</td>
<td>30-Aug-2016</td>
<td>1953</td>
</tr>
<tr>
<td>South Africa</td>
<td>16-Jul-2012</td>
<td>30-Aug-2016</td>
<td>1507</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>12-Aug-2010</td>
<td>30-Aug-2016</td>
<td>2211</td>
</tr>
</tbody>
</table>

\textsuperscript{24}http://www.pricestats.com/
\textsuperscript{25}http://bpp.mit.edu/
\textsuperscript{26}market convention like USDJPY
The *Nominal* and *EPPP* series are plotted for each country in Figure 1. We also plot the real exchange rate for each country in Figure 2. We can see that the countries vary a lot in terms of their exchange rate management. On one end of the spectrum are countries with free floating exchange rates like Germany and United Kingdom. On the other hand are countries like Argentina and China where the exchange rate is actively managed by the authorities. One can see in the chart for Argentina the depreciation of ARS throughout our sample followed by the devaluation from floating the currency on December of 2015. Similarly one can observe the low volatility of the *Nominal* series for China owing to the explicit management of the Renminbi by the PBOC. Between the two extremes are emerging market economies like Brazil and South Africa where exchange rates are implicitly monitored by their central banks and the trend as well as the volatility of the exchange rate factor into their respective monetary policy functions. These economies are also subject to their own idiosyncratic behavior as both rely extensively on commodity exports and both being high interest rate economies are subject to yield chasing capital inflows from time to time. The other countries in our sample - Japan and Australia, though G10 countries, have exchange rates which are also far from purely market determined. In Japan, *Abenomics*'s first arrow - massive monetary stimulus has actively worked towards depreciating the Yen to boost local inflation as well demand through the export sector. The same is true for Australia, where the central bank has tried to talk the exchange rate down to provide demand support through exports or inflation support from exchange rate pass-throughs.

In our analysis of how the nominal exchange rate interacts with the price setting in the economy, and consequently the joint effect on real exchange rates, we therefore expect to see a lot of country specific variations. Countries where the exchange rate is mostly market determined are the ones where the exchange rate can act as stabilizers to exogenous shocks whereas in more sticky exchange rate regimes, the stabilization happens through other channels in the economy. We will see later below, how inflation shocks have supposedly opposite effects on the former group of countries as compared to the latter.
Figure 1: De-meaned series of log Nominal and log EPPP

(a) Argentina

(c) Brazil

(e) Germany

(g) South Africa

(b) Australia

(d) China

(f) Japan

(h) United Kingdom
Figure 2: De-meaned series of log of real exchange rate

(a) Argentina

(b) Australia

(c) Brazil

(d) China

(e) Germany

(f) Japan

(g) South Africa

(h) United Kingdom
4 Results

In this section we present the impulse-response functions of our VAR system for the different countries in our data set. Specifically, we show the responses of the nominal exchange rate, relative prices and the real exchange rate for both types of impulses. We also produce bootstrap based 95% confidence bands for each point estimate. Since we are dealing with first difference data, the impulse-response plots are in cumulative to better represent the evolution of the different variables in our system over time. For sake of brevity, we present charts for the structural specification where relative prices are endogenous. The impulse-responses do not change by much when the endogeneity specification is changed.

The figures for each country presented below is a 3 x 2 grid. The left three plots correspond to the evolution of Nominal, EPPP and real exchange rates from a Nominal shock while the right three plots correspond to responses of the same three variables from an EPPP shock. The color coding is variable specific i.e. Nominal is blue, EPPP is red and real exchange rates are in green. We produce responses up to 480 time points into the future, roughly 2 years out.

4.1 Impulse Responses by Country

In this section, we present the impulse-responses on all the eight countries in our data-set for the structural restriction where is the endogenous variable. The SVAR is fitted with 240 lags and the confidence intervals are calculated using 100 bootstrap draws.

---

27 Based on an SVAR(240) model. The number of lags do not change the broad conclusions of the analysis. Our analysis using SVAR(120) models provides similar responses to each impulse.

28 We are plotting and therefore the impulse is like a percentage shock. Also note, positive change denotes local currency devaluation.

29 Again we are plotting and the impulse corresponds to a percentage change. Also note that positive change corresponds to local country inflation.

30 Defined as and therefore a positive change means a real depreciation i.e. increased competitiveness.

31 The confidence bands are estimated from 100 bootstrap draws. An SVAR(240) model is estimated for each bootstrapped sample and the Impulse-Response confidence bands are the 5% and 95% quantiles of the 100 such impulse-response functions we estimate. For the real exchange rate (Real), the bands are computed using the draw (or sample) specific difference of the responses of nominal exchange rate and relative prices

\[ \log r_t = \log n_t - \log p_t \]

32 Please see Appendix D to compare the two endogeneity scenarios. More charts available on request.
Figure 3: Impulse-Response Function for Argentina
Figure 4: Impulse-Response Function for **Australia**
Figure 5: Impulse-Response Function for Brazil

Response of Nominal, impulse = nominal, endo = EPPP

Response of Nominal, impulse = EPPP, endo = EPPP

Response of Real, impulse = nominal, endo = EPPP

Response of Real, impulse = EPPP, endo = EPPP
Figure 6: Impulse-Response Function for China
Figure 7: Impulse-Response Function for Germany
Figure 8: Impulse-Response Function for Japan

Response of Nominal, impulse = nominal, endo = EPPP

Response of EPPP, impulse = nominal, endo = EPPP

Response of Real, impulse = nominal, endo = EPPP
Figure 9: Impulse-Response Function for **South Africa**

Response of Nominal, impulse = nominal, endo = EPPP

Response of EPPP, impulse = nominal, endo = EPPP

Response of Real, impulse = nominal, endo = EPPP

Response of Nominal, impulse = EPPP, endo = EPPP
Figure 10: Impulse-Response Function for **United Kingdom**

Response of Nominal, impulse = nominal, endo = EPPP

Response of EPPP, impulse = nominal, endo = EPPP

Response of Real, impulse = nominal, endo = EPPP

Response of Real, impulse = EPPP, endo = EPPP
4.2 Observations

Despite considerable country-specific variation in the figures above, we do observe common features in the impulse-responses. We consider the two impulses separately. The first impulse is a depreciation of the local currency. Such shocks are all too evident in the market place - arising from monetary policy changes\textsuperscript{33}, political events\textsuperscript{34}, removal of a peg\textsuperscript{35}, sudden stops\textsuperscript{36} etc. Sharp depreciations are way more common than sharp appreciations\textsuperscript{37}. The other impulse is to relative prices. One can think of it as a domestic inflation shock. Inflation shocks can arise from both the supply and demand side. Supply-side inflation shocks can be like the oil shocks of '73 or '79, from failure of trade talks or natural disasters. Demand-side inflation shocks arise from both domestic and foreign growth shocks. We discuss the responses of exchange rates, relative prices and real exchange rates from these two kinds of shocks in the subsequent sections.

4.3 Exchange rate pass-through

The left side of each panel, which corresponds to a local currency devaluation, usually leads to inflation as can be seen by an increase in the level of relative prices. More importantly, the shock doesn't die out over time and the effect seems to be quite permanent. The fraction of pass-through, as can be expected, is different for different countries, ranging from 0.13 - 0.64 after six months and from 0.12 - 0.94\textsuperscript{38} after a year has passed.

In Table 2, we list the pass-through fraction for each country in our analysis. Even though the pass-through is not statistically significant for all of them, they are very pronounced for some like Australia, Brazil and Germany. A depreciation induced inflation is expected to be strong for exporters, as is the case for the selection of countries mentioned, because absent negative global demand shocks, a depreciation directly translates to higher demand from abroad for the tradables of that country. In our impulse-response charts one can clearly discern the pattern where the central estimates of the relative prices (in red) move in a similar fashion towards the top right of the chart for almost all countries. Interestingly, countries for which the pass-through is statistically significant, the effect accumulates instead of reverting\textsuperscript{39}. This can be seen in the

\textsuperscript{33} recall ECB PSPP (Public Sector Purchase Program) a.k.a. QE
\textsuperscript{34} recall Brexit referendum
\textsuperscript{35} like ARS
\textsuperscript{36} hot money leaving emerging markets from a confidence crisis. Recall Latin American currency crisis and the Asian crisis of '97
\textsuperscript{37} notable ones are like CHF when SNB let go of the EUR/CHF 1.2 peg
\textsuperscript{38} excluding China here
\textsuperscript{39} As far as point estimates go, except for South Africa and the UK, all countries have a larger pass-through after 1 year than the corresponding 6 month fraction
pass-through coefficients after one year, which are strictly larger than the ones after six months. This goes on to show two things - first that retailers permanently incorporate the information of the depreciation in price setting and second, as can expected from sticky prices, it takes time for full adjustment. We discuss long-run effects in a subsequent section.

Table 2: Exchange rate pass-through as a fraction of the percentage devaluation

<table>
<thead>
<tr>
<th>Country</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>0.14*</td>
<td>0.38*</td>
<td>0.37*</td>
<td>0.32</td>
<td>0.55</td>
</tr>
<tr>
<td>p value</td>
<td>0.05</td>
<td>0.02</td>
<td>0.04</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>Australia</td>
<td>0.38**</td>
<td>0.56**</td>
<td>0.64**</td>
<td>0.64**</td>
<td>0.94**</td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.1</td>
<td>0.31**</td>
<td>0.43**</td>
<td>0.51**</td>
<td>0.68*</td>
</tr>
<tr>
<td>p value</td>
<td>0.13</td>
<td>0.01</td>
<td>0</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>China</td>
<td>0.15</td>
<td>0.71</td>
<td>0.46</td>
<td>0.38</td>
<td>1.77*</td>
</tr>
<tr>
<td>p value</td>
<td>0.41</td>
<td>0.15</td>
<td>0.25</td>
<td>0.34</td>
<td>0.03</td>
</tr>
<tr>
<td>Germany</td>
<td>0.45**</td>
<td>0.59**</td>
<td>0.67**</td>
<td>0.55**</td>
<td>0.77**</td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Japan</td>
<td>0.12</td>
<td>0.27*</td>
<td>0.37*</td>
<td>0.24</td>
<td>0.32</td>
</tr>
<tr>
<td>p value</td>
<td>0.13</td>
<td>0.02</td>
<td>0.03</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>SA</td>
<td>0.24*</td>
<td>0.32**</td>
<td>0.15</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>p value</td>
<td>0.01</td>
<td>0</td>
<td>0.07</td>
<td>0.11</td>
<td>0.24</td>
</tr>
<tr>
<td>UK</td>
<td>0.35**</td>
<td>0.29*</td>
<td>0.34*</td>
<td>0.33</td>
<td>0.28</td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0.04</td>
<td>0.03</td>
<td>0.06</td>
<td>0.15</td>
</tr>
</tbody>
</table>

p value refers to the 1 - fraction of paths in bootstrap that are greater than 0
* 95% confidence
** 99% confidence
4.4 FX response to Inflation

The charts on the right of each panel captures the effect of a price level increase in the tradables of a country. Our analysis doesn’t control for the cause of such a price level increase. Inflation could arise from a demand shock or a supply-side effect like a factor shock as in oil price jumps or trade deals gone wrong. Local inflation is usually a symptom of a stronger economy. In a booming economy, imports should go up leading to a currency devaluation. However, a stronger economy could also lead to increased capital inflows and therefore currency appreciation. Capital mobility and the openness of the economy determine which of the two dominates.

Table 3 is similar to that of the previous section, but pertaining to domestic inflation shocks and its effect on nominal exchange rates. As we can see, we have less statistically significant coefficients than before. This is understandable as foreign exchange markets are very close to random walks and are affected by a lot of other information apart from inflation\(^\text{40}\). The only country for which the response is statistically significant is Argentina, that too for only over a six month horizon. Even the central estimates do not have a consistent sign. Argentina, China and Germany see a depreciation while the exchange rate appreciates for the others. Indeed, Argentina and China are special cases where the exchange rate is managed and hence, their behavior can be expected to be very different from others. The case for Germany is also not that shocking. The Euro represents a broader economy but we are only considering prices of German traded products. In fact, in the Euro area, the business cycles of Germany and the periphery are out of sync. As such, the transmission from inflation in Germany to the euro is not straight forward.

We look at the impulse-responses for each country closely, noting down the statistical significance over time. As we see in Figures 11 and 12, for a few countries, price shocks do have predictive power over otherwise hard to predict nominal exchange rate moves. For example, observe the time variation of the \(p\) values for South Africa and the United Kingdom. For both of these, around 100 days after the shock, the \(p\) value dips to quite a low level implying statistically significant movement of the nominal exchange rate. In both cases, the direction is of a nominal exchange rate depreciation which is in sharp contrast to the long-run appreciation implied by the impulse-response. Recall that a depreciation of the exchange rate from an inflation shock is consistent with PPP.

\(^{40}\) capital flows - both long-term and short-term, risk sentiment etc. add noise to nominal exchange rate prices despite presence of underlying factors\(^{8}\)
Table 3: Exchange rate response to Inflation shocks

<table>
<thead>
<tr>
<th>Country</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>0.5</td>
<td>0.83</td>
<td>0.97</td>
<td>1.51*</td>
<td>1.68</td>
</tr>
<tr>
<td>p value</td>
<td>0.11</td>
<td>0.06</td>
<td>0.12</td>
<td>0.04</td>
<td>0.1</td>
</tr>
<tr>
<td>Australia</td>
<td>-0.17</td>
<td>-0.05</td>
<td>-0.08</td>
<td>-0.06</td>
<td>-0.29</td>
</tr>
<tr>
<td>p value</td>
<td>0.61</td>
<td>0.55</td>
<td>0.58</td>
<td>0.52</td>
<td>0.71</td>
</tr>
<tr>
<td>Brazil</td>
<td>-1.27</td>
<td>-0.27</td>
<td>0.31</td>
<td>-0.67</td>
<td>-1.64</td>
</tr>
<tr>
<td>p value</td>
<td>0.87</td>
<td>0.47</td>
<td>0.32</td>
<td>0.49</td>
<td>0.6</td>
</tr>
<tr>
<td>China</td>
<td>-0.04</td>
<td>-0.06</td>
<td>0.02</td>
<td>0.02</td>
<td>0.07</td>
</tr>
<tr>
<td>p value</td>
<td>0.66</td>
<td>0.71</td>
<td>0.42</td>
<td>0.41</td>
<td>0.35</td>
</tr>
<tr>
<td>Germany</td>
<td>0.73</td>
<td>0.24</td>
<td>1.27</td>
<td>0.59</td>
<td>0.6</td>
</tr>
<tr>
<td>p value</td>
<td>0.26</td>
<td>0.5</td>
<td>0.23</td>
<td>0.43</td>
<td>0.46</td>
</tr>
<tr>
<td>Japan</td>
<td>-0.28</td>
<td>-0.5</td>
<td>-0.73</td>
<td>-1.31</td>
<td>-1.75</td>
</tr>
<tr>
<td>p value</td>
<td>0.6</td>
<td>0.68</td>
<td>0.69</td>
<td>0.78</td>
<td>0.76</td>
</tr>
<tr>
<td>SA</td>
<td>-0.38</td>
<td>-0.14</td>
<td>0.64</td>
<td>-0.54</td>
<td>-1.15</td>
</tr>
<tr>
<td>p value</td>
<td>0.7</td>
<td>0.53</td>
<td>0.21</td>
<td>0.77</td>
<td>0.93</td>
</tr>
<tr>
<td>UK</td>
<td>0.03</td>
<td>0.18</td>
<td>0.68</td>
<td>0.29</td>
<td>-0.32</td>
</tr>
<tr>
<td>p value</td>
<td>0.46</td>
<td>0.29</td>
<td>0.14</td>
<td>0.29</td>
<td>0.52</td>
</tr>
</tbody>
</table>

*p value refers to the 1 - fraction of paths in bootstrap that are greater than 0
* 95% confidence
** 99% confidence
Figure 11: Effect of inflation shocks on the nominal exchange rate

(a) Argentina

(b) Australia

(c) Brazil

(d) China

p-value, defined as 1 - fraction of paths above 0

Days, shock to prices at t=0
Figure 12: Effect of inflation shocks on the nominal exchange rate

(a) Germany

(b) Japan

(c) South Africa

(d) United Kingdom
4.5 Long-run effects

Given an SVAR model

\[ a(L)z_t = v_t \]

where,

\[ a(L) = A - A_1L - A_2L^2 - \ldots - A_pL^p, \quad z_t = \Delta Y_t, \quad Y_t = (\log n_t, \log p_t)', \quad A \neq I_2 \]

and the choice of \( A \) determines the endogeneity restriction as discussed in Section 2. The long-run effect\(^{41}\) of shocks to variables \( n_t \) and \( p_t \) are given by the long-run matrix \( \mathcal{L} \), where

\[ \mathcal{L} = (I_2 - A_1 - A_2 - \ldots - A_p)^{-1}A^{-1}; \quad A_i = A^{-1}A_i \]

Given, our estimate of the long-run matrix \( \hat{\mathcal{L}} \), the theoretical long-run effect of a shock to the variables are computed by multiplying \( \hat{\mathcal{L}} \) and the shock \( v_t \). Say, for example we are interested in the long-run impact of a depreciation on domestic inflation\(^{42}\). This can be estimated as \( \lambda_2 \) in the equation below

\[ \hat{\mathcal{L}} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = (I_2 - \sum_{i=1}^{p} A_i^*)^{-1}A^{-1} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \end{bmatrix} \text{ (say)} \]

The long-run effect of inflation shocks to the exchange rate can be calculated similarly. As can be seen in the equation above, the long-run impact depends on the structural i.e. endogeneity specification \( A \). However, \( A_i^*, \forall i \), comes from the reduced form VAR model and is independent of structural assumptions. Table 4 tabulates the long-run exchange rate pass-through using the SVAR(240) model for either endogeneity specification.

Our estimation of the long-run pass-through also depends on the number of lags in our SVAR model. To get a better understanding of which pass-throughs are stable i.e. consistent over different model selections, we estimate Table 4 for a number of model specifications. Figure 13 presents the long-run exchange rate pass-through fraction for different choice of lag for each country. As we can see, for some countries like South Africa and Japan the pass-through fraction is quite stable. For other like Argentina and Brazil, it increases and then decreases as we increase the model lag. Nonetheless, the point estimates for these pass-throughs are all positive. In short, we can conclude that in almost all the countries considered in our sample, a depreciation is very likely to cause some domestic inflation, though the fraction can vary a lot.

\(^{41}\) See Appendix B for more details
\(^{42}\) exchange rate pass-through
Table 4: Long-run exchange rate pass-through

<table>
<thead>
<tr>
<th>Country</th>
<th>Endogenous = EPPP</th>
<th>Endogenous = Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>0.52</td>
<td>0.53</td>
</tr>
<tr>
<td>Australia</td>
<td>1.01</td>
<td>0.64</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.47</td>
<td>0.64</td>
</tr>
<tr>
<td>China</td>
<td>1.40</td>
<td>1.39</td>
</tr>
<tr>
<td>Germany</td>
<td>0.87</td>
<td>0.55</td>
</tr>
<tr>
<td>Japan</td>
<td>0.24</td>
<td>0.35</td>
</tr>
<tr>
<td>SA</td>
<td>0.13</td>
<td>0.17</td>
</tr>
<tr>
<td>UK</td>
<td>0.29</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Note: Numbers above denote the fraction of depreciation shock that translates into inflation in the long-run. For example, in the case of Argentina, 52-53% of the depreciation results in inflation in the long-run.

Figure 13: Long-run exchange rate pass-through from different models
Similarly, Table 5 captures the long-run effect of inflation shocks on the exchange rate. As noted in the previous section, the exchange rate response to an inflation shock is economy dependent with most countries seeing an appreciation in the nominal exchange rates. Managed or pegged countries differ in their behavior as can be seen for Argentina and China. Germany is a basket case since the exchange rate is Euro area determined but our data captures only German prices. This highlights the dichotomy in the Eurozone where German growth is probably coming at the expense of the larger EZ and hence a demand shock in Germany leads to an exchange rate depreciation to stabilize the falling demand in the periphery.

The estimate of the long-run effect of inflation shocks on the exchange rate, however, is very volatile and highly subject to model specification. Unlike the exchange rate pass-through case, here, even the direction of the long-run effect is not consistent, as can be seen in Figure 14. For countries which have some consistency in the estimates - like Australia or South Africa, the estimate itself is very close to zero. Only exception seems Japan, where the estimate shows a consistent appreciation from an inflation shock. The other consistent estimate is Argentina. However, its hard to draw conclusions about the inflation to exchange rate channel for managed economies. Germany and Brazil have the most volatile estimate swinging from large positive values to large negative ones.

<table>
<thead>
<tr>
<th>Country</th>
<th>Endogenous = EPPP</th>
<th>Endogenous = Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>1.89</td>
<td>1.89</td>
</tr>
<tr>
<td>Australia</td>
<td>-0.30</td>
<td>-0.26</td>
</tr>
<tr>
<td>Brazil</td>
<td>-0.75</td>
<td>-0.76</td>
</tr>
<tr>
<td>China</td>
<td>0.07</td>
<td>0.14</td>
</tr>
<tr>
<td>Germany</td>
<td>0.53</td>
<td>0.54</td>
</tr>
<tr>
<td>Japan</td>
<td>-1.69</td>
<td>-1.69</td>
</tr>
<tr>
<td>SA</td>
<td>-0.55</td>
<td>-0.55</td>
</tr>
<tr>
<td>UK</td>
<td>-0.20</td>
<td>-0.18</td>
</tr>
</tbody>
</table>

Note: Numbers above denote the fraction of inflation shock that percolates into the exchange rate in the long-run.
4.6 Persistence of shocks

So far we have looked at the response of prices from a shock to the nominal exchange rate and vice-versa. Now we look at the persistence or lack thereof of the shock itself. The nominal exchange rate $n_t$ and the relative prices $p_t$ are non-stationary\(^{43}\) and therefore the long-run distribution is non-standard. However, we can look into the country specific behavior from our impulse-responses.

From impulse-responses

As we can see in Figure 15, the SVAR based IRFs show that Nominal shocks are very persistent. Except for South Africa, in all other countries the shock stays in the system even after one year. For most of the countries, there is further depreciation after the initial shock. The confidence bands confirm that the persistence is statistically significant for all countries except South Africa. The same, however, is not true for retail price shocks in the one year horizon. Only for Argentina and Australia, the price shock is different from zero with 95% statistical significance. Focusing on the point estimates, countries like Argentina, Australia, Germany and Japan see momentum in prices after the initial shock resulting in further inflation while in China and South Africa we see the shock dissipate somewhat after a year. The differing behavior of inflation owes to country

\(^{43}\) Refer to Appendix A
specific macroeconomic adjustments\textsuperscript{44} and as such, it is not unusual that we have a mixed bag of responses.

Long-run persistence

As in section 4.5, we can compute the long-run effect from the estimated model coefficients. However, as we have noted before, these long-run estimates are highly subject to model specifications. Below, we plot the long-run persistence of the shocks - both nominal and relative

\textsuperscript{44} depends on a lot of factors like the real economy’s adjustment to an inflation shock but most importantly monetary policy and its effectiveness. Inflation can spiral up if higher domestic inflation is a symptom of higher growth and leads to an import binge, which in turn leads to depreciation of the currency (can happen in a few countries as we saw in an earlier section) which in turn leads to inflation of domestic tradables. This spiral can be broken by higher rates a la Volker or through other measures like capital controls or exchange rate management
prices for different lag choice. We only consider the structural specification where $p_t$ is the endogenous variable. Figure 16 shows that for most countries the nominal shock is indeed persistent with the exception of South Africa. Figure 17 reports the persistence of inflation shocks. The picture here is more volatile and differ a lot by lag choice, especially for countries like Brazil and Germany. However, a common pattern across countries is that inflation shocks stay in the system.

Figure 16: Long-run persistence of nominal shocks for different models

Figure 17: Long-run persistence of inflation shocks for different models
5 Real Exchange Rates

Real Exchange Rates determine the long-term competitiveness of an economy\(^{45}\). Real exchange rates are also a powerful tool for testing the *Purchasing Power Parity* hypotheses. As such, it makes sense to look at our system and study the effect of the two shocks on the real exchange rate. So far, we have seen that a shock to the nominal exchange rate is quite persistent. It also results in pass-through to inflation, though with varying magnitudes for different countries. A higher pass-through would stabilize the real exchange rate after the initial shock. Similarly, we have seen relative price shocks, which are also very persistent in the long-run. Their effect on exchange rates, however, is very country specific. As per *PPP*, we would expect a depreciation in the nominal exchange rate following a domestic inflation shock, thereby causing a mean-reversion in the real exchange rate. However, this is not what we observe in the data. For majority of the countries in our data set, we have seen an appreciation instead of a depreciation following a relative price shock. Moreover, we have also seen that relative price shocks themselves could feed off itself generating momentum in prices. This is because of the strong positive auto-correlation in our retail price data. The two effects together push real exchange rates further away from the stationary long-run mean of zero. Below, we tabulate our results for the impact of the two kinds of shocks on the real exchange rate along with our bootstrap based confidence intervals. Note, however, that if the real exchange rate is significantly different from zero at the one year horizon, it doesn’t disprove *PPP* since reversion could happen very slowly. Indeed as noted before, *PPP* half-lives could be very large. Indeed this is part of the *PPP puzzle* put forward by Rogoff (1996)[10]. In other words, real exchange rates could be very persistent as well as stationary at the same time.

\(^{45}\) Investors and business consider the real exchange rate while committing capital for the long haul - either FDI or setting up factories and plants abroad
5.1 Response to a nominal exchange rate shock

A nominal shock translates one for one to the real exchange rate. As such, in our analysis, a shock of 1 to Nominal is equivalent to a shock of 1 to the real exchange rate ∆ a depreciation to the nominal rate is a depreciation of the real exchange rate. We tabulate what fraction of this initial shock remains in the system at different horizons, ranging from 30 days to 1 year. We would expect the real exchange rate to revert towards zero after the shock dissipates. Automatic stabilizers in international markets should kick-in to ensure Law of One Price. For example, recall that a depreciation leads to inflation in most cases as foreign demand for domestic tradables increases. The inflation causes EPPP to catch up with the new Nominal level, which in-turn leads to log(Nominal) – log(EPPP) to revert to zero. Given this intuition, we would expect the real exchange rate to be lower than 1 in the medium-term from a nominal shock. A value greater than 1 would indicate self-reinforcement or presence of positive feedback loops in the economy. Table 6 shows that the real exchange rate is indeed reverting towards mean zero over the one year horizon. Except for Japan and United Kingdom, we fail to reject the null of real exchange rate at zero after one year at the 5% significance.

Table 6: Real Exchange Rate response to depreciation

<table>
<thead>
<tr>
<th>Country</th>
<th>Future Period (in days)</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td><strong>0.88</strong></td>
<td>0.91**</td>
<td>0.87**</td>
<td>0.8**</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td><strong>0.51</strong></td>
<td>0.53**</td>
<td>0.35</td>
<td>0.41</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0</td>
<td>0.06</td>
<td>0.06</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td><strong>0.91</strong></td>
<td>0.79**</td>
<td>0.71*</td>
<td>0.8*</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0</td>
<td>0.02</td>
<td>0.02</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td><strong>0.99</strong></td>
<td>0.6</td>
<td>0.68</td>
<td>0.71</td>
<td>-0.39</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0.05</td>
<td>0.22</td>
<td>0.26</td>
<td>0.19</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td><strong>0.45</strong></td>
<td>0.54*</td>
<td>0.5*</td>
<td>0.59*</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td><strong>0.99</strong></td>
<td>1.0**</td>
<td>0.97**</td>
<td>1.38**</td>
<td>1.1**</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td><strong>0.67</strong></td>
<td>0.35</td>
<td>0.38*</td>
<td>0.33</td>
<td>-0.23</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0.06</td>
<td>0.03</td>
<td>0.07</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td><strong>0.55</strong></td>
<td>0.54*</td>
<td>0.51*</td>
<td>0.51*</td>
<td>0.79**</td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

*p value refers to the 1 - fraction of paths in bootstrap that are greater than 0
* 95% confidence
** 99% confidence

\[46\] remember we are dealing with logs and as such the steady state value of log(\(r_t\)) is 0
5.2 Response to a price shock

An *EPPP* shock translates one for one to the real exchange rate. As such, in our impulse response analysis, we start off with a value of -1 for the real exchange rate. If real exchange rates were stationary, we would expect it to drift up towards zero. Interestingly, this is not what we observe. As can be seen in Table 7, for most countries, the shock to the real exchange rate persists even after a considerable period of time. The effect is statistically significant for 7 out of the 8 countries at the 6 month horizon and for 4 out of the 8 countries at the 1 year horizon. Also worth noting is the fact that for most countries the real exchange rate instead of mean reverting i.e. depreciating after the initial appreciation (shock) keeps on appreciating for another 6-12 months. Both strong positive auto-correlation in inflation as well as the nominal exchange rate appreciation we observe for many countries following an inflation shock are the likely reasons behind such developments. Quite often inflation in an economy, when coming from a demand shock, would attract foreign capital thereby leading to further appreciation of the real exchange rate. This goes on to show that price increases are usually persistent\(^{47}\).

Table 7: Real Exchange Rate response to Inflation shocks

<table>
<thead>
<tr>
<th>Country</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>-1.76**</td>
<td>-1.76**</td>
<td>-1.77**</td>
<td>-1.29*</td>
<td>-1.92*</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Australia</td>
<td>-1.64**</td>
<td>-1.56**</td>
<td>-1.91**</td>
<td>-2.05**</td>
<td>-1.64**</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Brazil</td>
<td>-4.11**</td>
<td>-3.67*</td>
<td>-3.34**</td>
<td>-3.96**</td>
<td>-2.68</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0.02</td>
<td>0.01</td>
<td>0</td>
<td>0.13</td>
</tr>
<tr>
<td>China</td>
<td>-1.36**</td>
<td>-1.2**</td>
<td>-0.95**</td>
<td>-0.76**</td>
<td>-0.12</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.22</td>
</tr>
<tr>
<td>Germany</td>
<td>-3.7**</td>
<td>-3.34**</td>
<td>-2.19</td>
<td>-2.31</td>
<td>-1.47</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0</td>
<td>0.08</td>
<td>0.06</td>
<td>0.19</td>
</tr>
<tr>
<td>Japan</td>
<td>-3.26**</td>
<td>-3.28**</td>
<td>-3.16**</td>
<td>-3.87**</td>
<td>-3.3</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>SA</td>
<td>-2.14**</td>
<td>-0.74</td>
<td>-0.26</td>
<td>-1.76**</td>
<td>-1.48**</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0.19</td>
<td>0.3</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>UK</td>
<td>-2.26**</td>
<td>-2.5**</td>
<td>-1.92**</td>
<td>-2.04**</td>
<td>-1.46*</td>
</tr>
<tr>
<td><em>p value</em></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*p value* refers to the 1 - fraction of paths in bootstrap that are lesser than 0

* 95% confidence

** 99% confidence

\(^{47}\) Retailers increase prices when they are at supply capacity or when anticipating further demand down the road. Since price increases reduce competitiveness, prices are increased when there is usually a strong reason (not a temporary one) to do so
6 Conclusion

In this paper we model nominal exchange rates and relative prices from online retailers for eight countries. We use a structural VAR model to capture endogeneity in our system. Using impulse-responses from our SVAR framework, we document the exchange rate pass-through for different horizons. We find that for most countries, nominal exchange rate shocks are passed on to prices within a couple months. This pass-through helps stabilize the real exchange rate validating the Purchasing Power Parity hypotheses. We also look at the effect of relative price shocks on nominal exchange rates. We observe that contrary to PPP predictions of an exchange rate depreciation following a domestic inflation shock, most countries in our sample witness an appreciation in their currency. It is worth noting that despite the efficiency of the foreign exchange markets, for a few countries, we find considerable predictive power in the direction of nominal exchange rates after a price shock. Price shocks are persistent in the long-run. Since we do not see sufficient exchange rate response to price shocks, we find considerable persistence in real exchange rates when deviations arise from price shocks, thereby questioning PPP. Worth noting, however, is that nominal exchange rate response to price shocks do not follow a standard pattern and are highly subject to the structure of the economy. Further research is required to compute exchange rate responses for different types of relative price shocks - those coming from the supply-side, or demand, or productivity-related etc. In today’s interconnected global markets, we would expect firms to respond to exchange rates faster than ever before. This is indeed what we find in our impulse-responses constructed using daily frequency retail price data.
References


A Sample Data and Stationarity

The relative price data $p_t$ and the nominal exchange rates $n_t$ are not stationary in their levels. Below, we present the $p$ values of Adjusted Dickey-Fuller tests with AIC based lags. We clearly see the presence of unit roots for the level data for all countries. Therefore, we use first differences in our state variables before proceeding with the SVAR modeling.

Table 8: Unit Root Tests

<table>
<thead>
<tr>
<th></th>
<th>$\Delta \log(p_t)$</th>
<th>$\log(p_t)$</th>
<th>$\Delta \log(n_t)$</th>
<th>$\log(n_t)$</th>
<th>$\Delta \log(r_t)$</th>
<th>$\log(r_t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>0.0</td>
<td>1.00</td>
<td>0.0</td>
<td>1.00</td>
<td>0.0</td>
<td>0.52</td>
</tr>
<tr>
<td>Australia</td>
<td>0.0</td>
<td>0.74</td>
<td>0.0</td>
<td>0.50</td>
<td>0.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.0</td>
<td>0.92</td>
<td>0.0</td>
<td>0.67</td>
<td>0.0</td>
<td>0.17</td>
</tr>
<tr>
<td>China</td>
<td>0.0</td>
<td>0.66</td>
<td>0.0</td>
<td>0.44</td>
<td>0.0</td>
<td>0.47</td>
</tr>
<tr>
<td>Germany</td>
<td>0.0</td>
<td>0.91</td>
<td>0.0</td>
<td>0.76</td>
<td>0.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Japan</td>
<td>0.0</td>
<td>0.48</td>
<td>0.0</td>
<td>0.71</td>
<td>0.0</td>
<td>0.59</td>
</tr>
<tr>
<td>SA</td>
<td>0.0</td>
<td>0.69</td>
<td>0.0</td>
<td>0.76</td>
<td>0.0</td>
<td>0.03</td>
</tr>
<tr>
<td>UK</td>
<td>0.0</td>
<td>0.41</td>
<td>0.0</td>
<td>0.90</td>
<td>0.0</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Note: $p$ value less than $\alpha$ (say 5%) signifies rejection of the null hypothesis: presence of unit root. The number of lags for the ADF test is chosen by minimizing AIC. The ADF regressions used above include a constant term $\Delta y_t = y_t - y_{t-1}$ $\log(r_t) = \log(n_t) - \log(p_t)$

$p$ value as defined in MacKinnon (1994)[9]

The table above also reports the $p$ values for the level of the real exchange rate. As per PPP, one would expect very small $p$ values in accordance with stationary real exchange rates. This is indeed the case for the most of the developed countries - Australia, Germany, United Kingdom, except for Japan. Countries with pegged or managed exchange rates have large $p$ values - like Argentina and China. The large $p$ value for countries like Japan and Brazil could be because of auto-correlation in the error terms of the Adjusted Dickey-Fuller regression. As such, we run several ADF regressions with varying number of lags of the first-difference term and note down the $p$ values of the ADF statistic. We conduct ADF tests with a constant term as well as the trend stationary case.

48 large $p$ values signifying failure to reject null hypothesis of unit root i.e. non-stationarity
Figure 18 shows the variation of the $p$ value by number of lags for each country. We see that the $p$ value indeed comes down for a number of countries as we add lags but for countries like Argentina, China, Brazil and Japan, the $p$ value is very stable and we fail to reject a unit root. This is not surprising since our data, though granular, covers at best 8 years in time. If real exchange rates are stationary but persistent, a unit root test on limited data might fail to reject the null of non-stationarity.

Figure 18: ADF test $p$ value versus number of lagged terms in the regression

(a) ADF with drift

(b) ADF with drift and trend
B Structural VAR models and Long-run Effects

Given K-endogenous variables \( y_t = (y_{1,t}, y_{2,t}, y_{3,t}, \ldots, y_{K,t}) \), the SVAR\( (p) \) model is defined as:

\[
A y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + B u_t \tag{6}
\]

where \( A_i, \forall i K \times K \) are matrices and \( u_t \) is the K-dimensional structural shock with \( \mathbb{E}[u_t] = 0 \) and \( \mathbb{E}[u_t u_t'] = I_k \). Estimation proceeds with the reduced-form VAR\( (p) \) which is written as

\[
y_t = A^{-1} A_1 y_{t-1} + A^{-1} A_2 y_{t-2} + \ldots + A^{-1} A_p y_{t-p} + A^{-1} B u_t \\
= A^*_1 y_{t-1} + A^*_2 y_{t-2} + \ldots + A^*_p y_{t-p} + \varepsilon_t \tag{7}
\]

(provided \( A \) is invertible)

Here, \( \varepsilon_t \) is white noise with the variance-covariance matrix given by

\[
\Sigma_{\varepsilon} = \mathbb{E}[\varepsilon_t \varepsilon_t'] \\
= \mathbb{E}[(A^{-1} B u_t) (A^{-1} B u_t)'] \\
= A^{-1} B \mathbb{E}[u_t u_t'] (A^{-1} B)' \\
= A^{-1} B I_k (A^{-1} B)' \\
= A^{-1} B B' (A^{-1})'
\]

We run OLS line by line and obtain estimates \( \hat{A}^*_i, \forall i \) as well as \( \hat{\Sigma}_{\varepsilon} \). For estimation of \( A_i, \forall i \) we need to estimate \( A \). This is done using the eq (8) above by imposing restrictions on \( A \) and/or \( B \). Depending on the restriction we get different kind of models: A-model, B-model, AB-model. Restricting \( B \) is to impose long-run restrictions on the effects of structural shocks on different state variables\(^{49}\). We do not impose any particular long-run restriction and therefore set the off diagonal elements of \( B \) as zero. As such, the number of restrictions on \( A \) is given by \( K(K-1)/2 = K^2 - \sum_{i=1}^{K} \) since the number of independent equations that can be formed from \( \Sigma_{\varepsilon} \) is \( \sum_{i=1}^{K} \) and there are \( K^2 \) elements in \( A \).

In our analysis, \( K = 2 \) and as such, we need to impose at least 1 restriction on \( A \). We set \( A \) as either

\[
\begin{bmatrix}
1 & 0 \\
* & 1
\end{bmatrix}
\] or

\[
\begin{bmatrix}
1 & * \\
0 & 1
\end{bmatrix}
\]

and \( B \) as

\[
\begin{bmatrix}
\sigma_n & 0 \\
0 & \sigma_p
\end{bmatrix}
\]

\(^{49}\) See next section
Long-run effect

Given the SVAR-model we used in this paper

\[ a(L)z_t = v_t \]

where,

\[ a(L) = A - A_1L - A_2L^2 - \ldots - A_pL^p, \quad z_t = \Delta Y_t, \quad Y_t = (\log n_t, \log p_t)' \]

with \( L \) being the lag operator and \( v_t = Bu_t \) as white noise. The state variable \( z_t \) can be represented in the MA(\( \infty \)) form as:

\[ z_t = A^{-1}(L)v_t = \Phi(L)v_t \]

Since, \( Y_t \) is modeled in first differences, to get the cumulative effect of a structural shock i.e. a non-trivial \( v_t \) we have to get the cumulative sum of \( z_t \)'s. Say, \( v_1 = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \) and \( v_{-j} = 0, \forall j > 0 \), then it can be shown that

\[ \lim_{T \to \infty} Y_T = \lim_{T \to \infty} \sum_{t=1}^{T} z_t = \Phi(1)v_1 = a^{-1}(1)v_1 = (A - A_1 - A_2 - \ldots - A_p)^{-1}v_1 \]

The long-run matrix can also be written as

\[ LR = (A - A_1 - A_2 - \ldots - A_p)^{-1} = (I_2 - A_1^* - A_2^* - \ldots - A_p^*)^{-1}A^{-1} \]

where, \( A_i^* \) are the coefficients we observe in the reduced-form VAR(p) model.
C Choice of lag for the SVAR model

The choice of lag in our SVAR model do not materially change the final conclusion. The impulse-responses are broadly similar for the two specifications of the lag. The point estimates of the IRF along with the confidence bands\(^{50}\) for the case of Argentina are shown below:

Figure 19: Impulse-Response Function for Argentina

\(^{50}\) constructed using 100 bootstrap draws
D Different Endogeneity Restriction

Throughout the paper we have presented analysis with the structural restriction that relative prices i.e. $p_t$ is the endogenous variable. Here we present the impulse-responses for the other extreme case where $n_t$, the nominal exchange rate is the endogenous variable. As noted earlier, the endogeneity restriction doesn’t change the broad conclusions of the impulse-responses. As we can see in Figure 21 below, for Argentina, the patterns in the responses of the variables *Nominal*, *EPPP* and *Real* are same as in Figure 3.

This is because we have a large number of lags in our VAR model, the structural parameters$^{51}$ are small and the impulse-responses we report are on levels and as such are a function of the sum of the coefficients. Therefore, even though the structural specification determines the initial shock, the evolution of the system is driven by the coefficients of the reduced-form VAR i.e. eq(2). The endogeneity specification may alter impulse-response behavior if we reduce the number of lags or we found that the structural parameters were significantly away from zero. In Figure 20 below, we report the structural parameters for the two endogeneity specifications along with 90% confidence bands. We can see that the structural parameters are indeed not that large.

Figure 20: Estimates of structural parameters for different endogeneity specification

---

$^{51}$ The non-zero Off diagonal element in the structural matrix $A$
Figure 21: Impulse-Response Function for Argentina when $n_t$ is endogenous instead of $p_t$.