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Can sticky prices account for the variations and persistence in real exchange rates?

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Abstract

This paper provides an empirical assessment of the importance of sticky prices in accounting for the variations and the persistence in real exchange rates. Vector autoregressions with five variables from two countries that always include the United States are estimated. Restrictions are imposed to identify a global shock, and two sets of country specific output shocks. One set of shocks is associated with instantaneous price adjustments, while the other has delayed effects on prices. Data from the G7 countries reveal that US sticky price shocks are the dominant source of real exchange rate variations. But these shocks have reasonably short half-lives and cannot account for the observed real exchange rate persistence. Non-sticky price shocks can induce very persistent real exchange rate dynamics, even though they account for little of the historical real exchange rate variations.

JEL classification: F30; F31; F41

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1. Introduction

Casual observation suggests that that prices are sticky, in the sense that they do not change on a frequent basis. Evidence provided by Carlton (1986), Cecchetti (1986), Blinder et al. (1997), among many others, confirm that many firms adjust prices only with delays. The assumption of nominal ridigity is now at the heart of models we use to study business cycles.[1] When coupled with real rigidities such as

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[1] See, for example, Goodfriend and King (1997).

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imperfect competition, closed economy sticky price models have properties that are consistent in many respects with the observed data.

In an open economy setting, it is generally observed that the law of one price, or purchasing power parity (PPP), does not always hold. Even though transportation costs, trade barriers, and border effects can in theory explain why the price of traded goods between countries are not perfectly arbitraged after exchange rate adjustments, Engel and Rogers (1996) and Parsley and Wei (1996) have also found that distance alone cannot account for the observed deviations from the law of one price. Indeed, if frictions to international trading are time invariant, deviations from PPP, or the real exchange rate, should be constant over time. Yet, two observations stand out. Deviations in the law of one price since the collapse of the Bretton Woods have taken longer to dissipate. The consensus view, as surveyed by Froot and Rogoff (1995), is that the half-life of shocks to real exchange rates is between three to five years. Furthermore, as Mussa (1986) noted, real exchange rates track nominal exchange rates closely, and therefore inherit the volatility of the nominal exchange rates. The profession is thus left to explain why real exchange rates can be highly persistent on the one hand, and yet have high short-term volatility on the other. Rogoff (1996) referred to this as the Purchasing Power Parity Puzzle.

Two leading explanations have been used to explain persistence in real exchange rates. One view is that firms set prices for local markets and adjust for changes in the nominal exchange rate only with a lag. Another view is that firms set prices for goods sold in foreign markets to compete with foreign firms selling in that market. An exporting firm would not adjust prices in response to nominal exchange rate changes. Although the micro foundations of the two theories differ, they share the common thread that some prices are presumed to be sticky. Sticky prices have also been used to explain the variability in real exchange rates since nominal exchange rate changes will then translate one-for-one into real exchange rate changes.[2]

Therefore, taken as a whole, there is a presumption that sticky prices will help resolve bits and pieces of the purchasing power parity puzzle. But quantitatively, just how much of the persistence and variations in real exchange rates are attributable to sticky prices? Is real exchange rate persistence a result of price stickiness in one country, or both? The objective of this paper is to provide such an investigation using vector autoregressions (VARs). Many authors have used VARs to study real exchange rate dynamics[3], relying primarily on longrun restrictions to identify demand and supply shocks. The present study does not impose cointegration and is not concerned with which shocks have permanent effects. Instead, I classify shocks according to whether they induce delayed price responses. I take as a starting point the observation that the largest source of variations in wages and prices in identified VARs is shocks to themselves, and these disturbances produce substantial instantaneous response by the nominal variables (see, e.g. Leeper et al. (1996)). This is

[2] Stockman (1988) suggests that the larger variance of real shocks in the floating exchange rate era can explain the increased variability in real exchange rates since 1973. But the importance of real shocks in output variations is itself an unresolved issue.

[3] See, for example, Clarida and Gali (1994); Lee and Chinn (1998); Kim et al. (1999).

in spite of the fact that prices and wages respond sluggishly to other disturbances like monetary shocks in the same VAR. Sims (1997) pointed out that this slow response of prices and wages to some shocks but quick reaction to other shocks is not uncommon. Indeed, Roberts et al. (1994) found from estimation of a structural model that prices at the industry level respond rather rapidly to cost shocks, while using the same data, Clark (1999) found output prices to respond sluggishly to monetary policy shocks.[4]

To the extent that the sluggish response of prices to some shocks does not preclude speedy response of prices to other shocks, if sticky prices are indeed important in explaining real exchange rate dynamics, shocks that induce delayed price responses should also play an important role in real exchange rate variations. The objective of my empirical analysis is to see if this is the case. I use a two-country VAR to identify five shocks—two country-specific shocks to output for which country-specific prices can adjust instantaneously, two shocks to output that prices can only adjust with a one period lag, and one global shock. Thus, prices in both countries can have delayed response to what will be referred to as 'sticky price shocks'. I use the model to study the real exchange rates of the G7 countries.

To motivate the empirical analysis, a framework is developed in Section 2 in which the role of sticky price shocks is made explicit. The econometric framework is laid out in Section 3. The results are reported in Section 4. The main findings are that US sticky price shocks have been the main source of real exchange rate variations, but these shocks have relatively short half-lives. However, shocks which induce contemporaneous price responses can cause lengthy real exchange rate adjustments. The evidence suggests that mechanisms unrelated to market rigidities are also responsible for the persistence in real exchange rates.

2. The model

In this section, I use a two country model to motivate my definition of a sticky price shock. The model is an extension of Clarida and Gali (1994) in various dimensions. There are two countries, labelled *A* and *B*, that are identical ex-ante and differ only in terms of the realization of the shocks. Each country produces and consumes two goods, labelled 1 and 2, with prices p_{1t} and p_{2t} respectively. It is convenient to define variables in terms of differences between two countries. Throughout, if x^A and x^B denote the value of x in countries *A* and *B* respectively, then $x = x^B - x^A$. The supply for goods 1 and 2 for country j = A,B, are given by

$$y^{js}_{1t} = y^{js}_{1t-1} + z^{j}_{1t} + \phi_1 z^{j}_{1t-1},$$

$$y^{js}_{2t} = y^{js}_{2t-1} + z^{j}_{2t} + \phi_2 z^{j}_{2t-1}$$

where z^{j}_{1t} is a shock to Good 1 in country j. Therefore, the difference in supply is:

[4] McLaughlin (1994) also noted that wages could be rigid with respect to some shocks and flexible with respect to others.

$$y^s_{1t} = y^s_{1t-1} + z_{1t} + \phi_1 z_{1t-1},$$

$$y^s_{2t} = y^s_{2t-1} + z_{2t} + \phi_2 z_{2t-1}$$

where z_{1t} and z_{2t} are linear combinations of the i.i.d., country-specific innovations. Note that y_{1t} and y_{2t} are consistent with the presence of a global shock, z_{0t}. For example, if

$$y^{As}_{1t} = y^{As}_{1t-1} + z_{0t} + z^A_{1t} + \phi_1 z^A_{1t-1},$$

$$y^{Bs}_{1t} = y^{Bs}_{1t-1} + z_{0t} + z^B_{1t} + \phi_1 z^B_{1t-1}$$

the same y^s_{1t} as defined above will obtain. We will return to the role of a global shock subsequently.

On the demand side, I assume that Good 1 is traded internationally, is interest rate and exchange rate elastic, with (differential) demand:

$$y^d_{1t} = d_{1t} - \sigma(i_t - [E_t p_{1t+1} - p_{1t}]) + \eta(s_t - p_{1t})$$

where d_{1t} is a taste shifter, i_t is the nominal interest rate, s_t is the spot exchange rate, and $\sigma > 0$, $\eta > 0$. Let $q_{1t} = s_t - p_{1t} = s_t + p^A_{1t} - p^B_{1t}$ be the real exchange rate. If purchasing power parity holds, the price of tradables should be arbitraged and $q_{1t} = 0$.

The demand for Good 2 in the two countries are, respectively,

$$y^A_{2t} = d^A_{2t} - \beta p^A_{2t},$$

$$y^B_{2t} = d^B_{2t} - \beta p^B_{2t},$$

where d^A_{2t} and d^B_{2t} are country specific taste shifts, and $\beta > 0$. I think of Good 2 as those whose market is driven by supply at home and hence exchange rate insensitive (such as local fish and vegetables), and whose demand has little room for intertemporal substitution. Differential demand is:

$$y^d_{2t} = d_{2t} - \beta p_{2t}.$$

At the aggregate level, output is

$$y^d_t = y^d_{1t} + y^d_{2t}.$$

I consider a fixed weight aggregate price index,

$$p_t = \theta p_{1t} + (1-\theta) p_{2t},$$

where θ is the weight on Good l. The demand for real balances is:

$$m_t - p_t = y^d_t - \lambda i_t,$$

and interest rate parity is assumed:

$$i_t = E_t S_{t+1} - S_t.$$

To close the model, the following stochastic assumptions are used:

$$d_{1t} = d_{1t-1} + \delta_{1t} - \gamma_1 \delta_{1t-1},$$

$$d_{2t} = d_{2t-1} + \delta_{2t} - \gamma_2 \delta_{2t-1},$$

$$m_t = m_{t-1} + v_t - \psi v_{t-1}.$$

As specified, (d_{1t}, d_{2t}, m_t) are all non-stationary processes. But by setting the relevant moving-average parameter to −l, 1 can also restrict the series to be stationary instead. I allow for this more general specification to show that the results to follow do not depend on which shocks have permanent effects and which ones do not.

To understand the effects of sticky prices, it helps to solve first the flexible price equilibrium where prices move to equate supply and demand. I solve the model by the method of undetermined coefficients. Denoting the equilibrium values in a flexible price setting with a $*$, we have:

The Flexible Price Equilibrium

$$y^*_{1t} = y^s_{1t},$$

$$y^*_{2t} = y^s_{2t},$$

$$p^*_{2t} = \frac{d^*_{2t} - y_{2t}}{\beta},$$

$$q^*_{1t} = \frac{y^*_{1t} - d_{1t}}{\eta} + \frac{\sigma}{\sigma + \eta}\left[\frac{\gamma_1 \delta_{1t} + \phi_1 z_{1t}}{\gamma}\right],$$

$$p^*_t = m_t - y^*_t + v^* e_t$$

where $v^* = \dfrac{\lambda}{\lambda + \theta}$. Note that

$$e_t = \theta\left[\frac{\phi_1 z_{1t} + \gamma_1 \delta_{1t}}{\sigma + \eta}\right] - (1-\theta)\left[\frac{\phi_2 z_{2t} + \gamma_2 \delta_{2t}}{\beta}\right] - [\phi_1 z_{1t} + \phi_2 z_{2t} + \psi v_t]$$

summarizes all the effects due to serial correlation in the shocks. Since output is supply determined, equilibrium output is a function of supply shocks only. To the extent that the real exchange rate affects the demand for Good 1, the equilibrium real exchange rate only depends on supply and demand shocks to Good 1. Monetary policy shocks do not affect the real exchange rate. The real variables are thus neutral to nominal shocks. Because prices adjust freely to clear the market, the aggregate price level is a function of all shocks in the economy, as seen from the composition of e_t.

In empirical analysis, the real exchange rate is often defined in terms of a general price index. According to Balassa (1964) and Samuelson (1964), a country whose traded goods' sector grows faster should see a faster increase in the price of non-traded goods, and therefore in the CPI. Therefore, if the national growth rate of one country is faster than another, sustained appreciation should be expected of a real exchange rate based on a general price index. Let $q_t = s_t + p^A_t - p^B_t \equiv s_t - p_t$. In the flexible price setting, it can be shown that

$$q^*_t = q^*_{1t} + \frac{(1-\theta)}{\theta}\left[m_t - y^*_t - \left(\frac{y^*_{2t} - d_{2t}}{\beta}\right)\right] + (1-\theta)v^* e_t - \frac{v^* \lambda \phi_2 z_{2t}}{\theta}.$$

Since $y_t = y_t^B - y_t^A$, persistent deviations in trend output can generate persistent variations in q_t, as predicted by the Balassa-Samuelson hypothesis. But such persistent deviations can occur even in the absence of sticky prices. It is thus possible for real exchange rates to be persistent even when prices are flexible.

I now assume that the price for Good 1 is set one period in advance, so that $p_{1t} = E_{t-1}p_{1t}^*$. Let $\varepsilon_t = E_{t-1}p_{1t}^* - p_{1t}^*$ be the expectational error. It can be shown that

$$\theta\varepsilon_t = [z_{1t} + z_{2t} - v_t] + \left(\frac{1-\theta}{\beta}\right)[\delta_{2t} - z_{2t}] - v^* e_t.$$

Since e_t is a function of all shocks as defined earlier, the expectational error on p_{lt} also depend on all shocks. This drives most of the results to follow. Denote with a superscript '*f*' values in the sticky price equilibrium. We have:

Sticky Price Equilibrium

$$y_{1t}^f = y_{1t}^s - v(\sigma + \eta)\theta\varepsilon_t,$$

$$y_{2t}^f = y_{2t}^s,$$

$$p_{2t}^f = p_{2t}^*,$$

$$q_{1t}^f = q_{1t}^* - v\theta\varepsilon_t,$$

$$p_t^f = p_{1t}^* + \theta\varepsilon_t$$

where $v = \dfrac{\lambda + \theta}{\lambda + \sigma + \eta}$. While Good 2 still achieves the flexible price equilibrium, y_{1t}^f will be lower than y_{1t}^* for the same increase in z_{lt}. This is because p_{lt} does not fall as in the flexible price case. The market for good 1 is now affected by all shocks in the economy, and serially correlation in shocks further increase the variance of y_{lt}.

Of special interest is the consequence of nominal rigidity for the price level. After some simplification, it can be shown that:

$$p_t^f = \frac{1-\theta}{\theta\beta}(z_{2t} - \delta_{2t}) + m_{t-1} - \psi_1 v_{t-1} - y_{t-1}^* - \phi_1 z_{1t-1} - \phi_2 z_{2t-1}.$$

The aggregate price level will still respond contemporaneously to shocks to Good 2. However, neither shocks to Good 1 nor monetary policy shocks will have a contemporaneous effect on prices. These latter are the sticky price shocks of this economy. This non-response of the aggregate price to some shocks does not depend on ψ_1 and ϕ_1, and thus does not depend on whether the shocks are permanent or transitory.

In the model considered, flexible price shocks are those that affect markets which are essentially supply determined. Sticky price shocks are those that hit sectors in which nominal rigidities are present, and whose market equilibrium is determined by both supply and demand. In economies with ridigities, shocks other than those to Good 1 will also affect the real exchange rate. Although it seems natural to conjecture that $q_t = s_t - p_t$ will also be more persistent because p_t is sticky with respect to some shocks, this need not be the case since the sum of two time series processes can have stochastic properties that can be quite different from the two underlying series. In the next section, we will assess the importance of price stickiness for the dynamic properties of real exchange rates.

3. The SVAR and identification

The above equations characterize the behavior of output and prices of country A relative to B, but I am interested in country-specific responses to the shocks. I make use of two observations to back out these responses. First, as mentioned earlier, y^s_{1t} is invariant to the presence of a global shock that have symmetric effects on both countries. This suggests that global shocks should also have no contemporaneous effect on relative prices, including the real exchange rate. Second, I assume that a shock initiating in a small country has no effect on a larger country.

More specifically, my econometric analysis is based on the assumption that there are $n = 5$ types of shocks. Denote these by $e_t = [e^A_{0t}\ e^B_{0t}\ e^A_{1t}\ e^B_{1t}\ e^G_t]'$. I assume these innovations are mutually orthogonal, each have a unit variance, and thus $e \sim (0,I_n)$. Let $x_t = [p^A_t\ p^B_t\ y^A_t\ y^B_t\ q_t]'$ with a structural moving-average representation $x_t = C(L)e_t = C_0e_t + C_1e_{t-1} + \ldots$. I leave the coefficients on C_j, $j \geq 1$ unrestricted, but impose restrictions on C_0. Let C_{0ij} be the contemporaneous response of the i^{th} variable in x_t to the j^{th} shock in e_t. More precisely, I have:

$$\begin{bmatrix} p^A_t \\ p^B_t \\ y^A_t \\ y^B_t \\ q_t \end{bmatrix} = \begin{bmatrix} C_{011} & 0 & 0 & 0 & C_{015} \\ 0 & C_{022} & 0 & 0 & C_{025} \\ C_{031} & 0 & C_{033} & 0 & C_{035} \\ C_{041} & C_{042} & 0 & C_{044} & C_{045} \\ C_{051} & C_{052} & C_{053} & C_{054} & 0 \end{bmatrix} \begin{bmatrix} e^A_{0t} \\ e^B_{0t} \\ e^A_{1t} \\ e^B_{1t} \\ e^G_t \end{bmatrix} + C_1 \begin{bmatrix} e^A_{0t-1} \\ e^B_{0t-1} \\ e^A_{1t-1} \\ e^B_{1t-1} \\ e^G_{t-1} \end{bmatrix} + \ldots \quad (1)$$

The C_0 matrix reflects the following four ideas. First, e^A_{0t} is a shock to y^A_t that has a contemporaneous effect on p^A_t of C_{011}. Analogously, e^B_{0t} is a shock to y^B_t that has a contemporaneous effect on p^B_t of C_{022}. These are country specific shocks, hence $C_{012} = C_{021} = 0$. Second, as in Keating (1998), I define sticky price shocks as those innovations to output that do not have a contemporaneous effect on prices. Specifically, let e^A_{1t} be a shock which affects y^A_t by C_{033}. It has no effect on p^A_t or p^B_t and thus $C_{013} = C_{023} = 0$. Likewise, e^B_{1t} is a shock that has an output effect on y^B_t of C_{044}. It has no effect on p^B_t or p^A_t and thus $C_{024} = C_{014} = 0$. Then e^A_{1t} and e^B_{1t} are the two sticky price shocks in this framework. Third, I assume that country A is large relative to country B, and thus e^A_{0t} affects y^B_t but e^B_{0t} does not affect y^A_t. Hence $C_{041} \neq 0$ but $C_{032} = 0$. I also assume that sticky price shocks in A do not have contemporaneous effects on output of B and vice versa. Thus, $C_{034} = C_{043} = 0$. Fourth, the global shocks have absolute but do not have relative effects contemporaneously. Thus, global shocks do not affect the real exchange rate contemporaneously and $C_{055} = 0$. I assume that global shocks have output effects instantaneously, and hence C_{035} and C_{045} are non-zero. I also allow global shocks to have contemporaneous effects on prices. This is because global shocks will affect not just firms who preset prices, but also those who are free to adjust prices. For this reason, C_{015} and C_{025} are also non-zero. The model has five variables. I need ten restrictions for the model to be identified. The above specification of C_0 achieves exact identification.

Let $x_t = D(L)u_t$ be the moving average representation associated with the reduced form VAR with $D_0 = I_n$. Let Ω be the variance-covariance matrix based upon u_t, the residuals from the VAR. Equating the structural model with the reduced form model, we have $C_0e_t = u_t$, and therefore

$$C_0C'_0 = \Omega. \tag{2}$$

I solve for C_0 by equating the unique elements of $C_0C'_0$ with the sample estimate of Ω. In practice, a non-linear solver is used to obtain the solution. I then recover $C(L)$ as $D(L)C_0$. Given the focus of the analysis, a sign convention is adopted so that the response of the real exchange rate to a US sticky price shock is positive. This merely affects the presentation of the impulse response functions but not the forecast error decompositions to follow.

The multivariate framework adopted here offers a different perspective to half-lives typically computed from univariate autoregressions. In those analyses, the characteristics of the shocks are completely unidentifiable. Here, the characteristics of the shocks are not a total black-box because we know which ones have delayed responses and which do not. I refer to $x_t = C(L)e_t$ as a semi-structural VAR (SVAR) to distinguish it from a standard structural VAR in which the sources of the shocks are made specific (as in Eichenbaum and Evans, 1995). It is semi-structural because the identified shocks are still combinations of the primitive shocks to the economy. As the model in Section 2 suggests, this could be monetary policy, taste or supply shocks, or combinations of all shocks. But if prices adjust instantaneously, these so-called sticky price shocks cannot be statistically important. Although the SVAR does not identify the source of the shocks, they help understand the quantitative implications of price stickiness. The approach adopted here is also very different from Mcgrattan et al. (1998). In their dynamic equilibrium framework, the role of nominal rigidities is assumed. In the present analysis, the implications of price stickiness are studied without being specific about their source.

4. Results

My main objective is to understand the dynamic properties and the sources of variations in real exchange rates since the collapse of Bretton Woods agreement. Since I have autoregressions in five variables, use of quarterly data would restrict the degrees of freedom. I therefore take monthly data for industrial production, the CPI, and the exchange rate from the International Financial Statistics for the sample 1974:1–1997:12 (or longer where available). The choice of data at the monthly frequency also implies that sticky price shocks are defined as those shocks to output with a one month delayed response in prices.

The analysis is conduced for the G7 countries: the US, Canada, Japan, Germany, the UK, France, and Italy. I consider six SVARs, always with the US as country A (the large country). The spot rate s_t is the units of foreign currency one US dollar can buy. Hence an increase in the nominal exchange rate indicates an appreciation of the US dollar. The real exchange rate is $q_t + p_t^A - p_t^B$. An increase in q_t is an appreciation of the US dollar real exchange rate with *B*. I take logs of all variables and include a constant and a time trend in each SVAR. The multivariate BIC is used to select the lag length. Impulse response functions and decomposition of variances are obtained for up to 60 periods.

Before turning to the analysis on real exchange rates, it is useful to examine the importance of the various shocks for output. Table 1 presents the decomposition of variances for output of all countries, excluding the US, for forecast horizons of 1, 6, 12, 24, 36, 48, and 60 periods. As a matter of terminology, I refer to short horizons as 12 periods or less, and periods greater than 36 months as long term. There is a remarkable conformity in the results: variations in output in *B* are largely attributable to country-specific sticky price shocks (see column labelled e_t^B), especially over the short horizons. The four small open economies, namely, Canada, the UK, Italy and France, are quite heavily influenced by US shocks. The importance of US shocks in output variations of Japan and Germany are noticeably smaller.

Recall that a sticky price shock is not a shock to the price level, but a shock propagated via channels that generate delayed price response. As such, the sticky price shocks being identified depend on the pair of countries under consideration. Since I have six SVARs, there are six decomposition of variances for US output. In all cases (see Table 2), global shocks explain only small amounts of the variations in US output. In every case except Germany, US flexible price shocks account for most output variations in the US.

4.1. Decomposition of real exchange rate variations

According to the results of Tables 1 and 2, most of output fluctuations in Canada, the UK, Japan, Italy, and France are explained by their own sticky price shocks, while US flexible price shocks explain most of output variations in the US. What then accounts for variations in these bilateral real exchange rates? Table 3 reports the decomposition of forecast error variances in the real exchange rates. Except for the case of Germany, sticky price shocks are indeed important in explaining short term real exchange rate variations. But more precisely, it is US sticky price shocks (and not those of country *B*) that are important.

Table 3 also reveals four features of the data:- *i*) shocks important for US output variations are not important for bilateral real exchange rate variations, and vice versa; *ii*) shocks that affect foreign but do not affect US output play trivial roles in real exchange rate variations at all horizons; *iii*) the country *B* shocks, whether associated with flexible or sticky prices, tend to be unimportant at all horizons; and *iv*) global shocks are generally unimportant for real exchange rate variations.[5]

[5] Standard errors for the variance decompositions are computed by Monte-Carlo simulations with C_0 held fixed. However, because in all five cases considered, US sticky price shocks are given such over-

To highlight the four points just described, I compute what the log level of the real exchange rates would have been, if each of the five shocks were set to zero, one at a time. These are computed as follows. After estimation of C_0, we have $e_t = C_0^{-1}u_t$. I then set the i^{th} column of e to zero. Denote this by $e(i)$. I then obtain a new set of reduced form residuals $\tilde{u}_t = C_0\tilde{e}_t(i)$. The reduced form VAR is used to generate a new set of data with innovations $\tilde{u}$. Fig. 1 graphs the actual q_t, along with the two counterfactual real exchange rates obtained by setting the two US shocks to zero. The results reveal that the real exchange rates would have been much smoother than the data if shocks to US output had not occurred. US sticky price shocks (the dark dotted line) have resulted in large movements in many of the real exchange rates especially in the mid to late eighties. US flexible price shocks (dotted line) are responsible for the appreciation of the dollar-mark real exchange rate in the eighties.

Fig. 2 depicts what q_t would have been, if shocks in country B were set to zero. There were historical episodes when these shocks were important. For example, absent sticky price shocks (dark line) in Japan in the early nineties, the dollar-yen real exchange rate would have been higher. Although these shocks generally have smaller effects on the real exchange rates than the US shocks, to be able dismiss their role in real exchange rate dynamics, one also needs to establish that the country B shocks have no implications for real exchange rate persistence. I now turn to such an analysis.

4.2. Persistence

In this subsection, I first present impulse responses of real exchange rates to US sticky price shocks. I then assess the duration of real exchange rate adjustments to all shocks.

Fig. 3 presents the impulse response functions for the six real exchange rates to 100 basis points increase in the US sticky price shock in each of the SVARs. Estimated standard errors for the impulse responses at selected horizons are given in Table 4. A US sticky price shock always increases q_t (real appreciation of the US dollar). The dynamic responses of the UK, France, Italy, and Japan real exchange rates are remarkably similar. After an initial increase of 3%, the real exchange rates gradually return to control. The initial effect on the Canada-U.S. real exchange rate is smaller. Although the impact effect is smallest with the German real exchange rate, it does not seem to be mean reverting. The standard errors for the impulse responses in Table 4 confirm that this is statistically the case.[6] Overall, Fig. 3 reveals

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whelming weights in explaining real exchange rate variations, the standard errors for the decomposition of variances are very tight. These are not reported without loss of generality, but are available on request. Suffice it to say that, the maximum standard error on e_1^A does not exceed 10%.

[6] US sticky price shocks identified from the SVARs with Canada, Japan, and Germany are found to reduce US output and prices in the short run but increase output and reduce prices in the long run. Those identified from the SVARs with the UK, Italy, and France immediately increase US output and reduce US prices. With the exception of Italy, US flexible price shocks increase both US output and prices in the short run.

Table 1
Decomposition of variances in output of country B: 1974:1–1998:12

Country *B*	t	e_0^A	e_0^B	e_1^A	e_1^B	e^G
Canada	1	17.83	0.34	0.00	81.34	0.48
	6	29.79	1.68	0.49	61.32	6.70
	12	33.98	1.08	1.49	50.39	13.04
	24	32.21	1.77	9.76	34.62	21.61
	36	27.00	2.80	17.88	28.76	23.52
	48	23.64	3.15	21.78	28.87	22.53
	60	22.28	3.10	22.74	30.43	21.42
UK	1	3.55	0.30	0.00	95.79	0.34
	6	5.65	0.23	1.28	92.05	0.77
	12	7.29	0.22	5.56	85.41	1.50
	24	7.06	0.26	15.03	74.89	2.73
	36	8.24	0.26	17.99	70.60	2.88
	48	11.48	0.44	17.60	67.71	2.74
	60	13.37	1.28	17.04	65.41	2.87
Japan	1	2.66	0.10	0.00	97.16	0.06
	6	10.59	0.80	0.24	87.41	0.93
	12	10.88	3.20	1.45	83.47	0.97
	24	8.69	10.20	3.96	76.35	0.77
	36	6.83	16.47	4.97	71.11	0.61
	48	5.71	20.76	5.05	67.96	0.50
	60	5.07	23.46	4.88	66.13	0.43
Italy	1	3.22	1.52	0.00	93.04	2.20
	6	9.36	5.46	0.12	81.07	3.97
	12	17.69	5.24	0.29	69.45	7.30
	24	27.60	5.99	0.33	58.00	8.05
	36	29.87	7.92	0.49	53.81	7.88
	48	28.94	9.03	1.21	51.50	9.29
	60	28.36	9.06	2.14	49.91	10.55
France	1	5.63	0.02	0.00	92.25	2.08
	6	14.27	0.09	0.99	83.78	0.86
	12	22.49	0.10	2.06	74.67	0.67
	24	31.94	0.45	3.99	62.99	0.60
	36	33.53	0.81	5.61	58.61	1.41
	48	32.52	0.94	6.95	56.69	2.86
	60	32.49	0.93	7.89	54.85	3.82
Germany	1	0.23	0.16	0.00	99.32	0.27
	6	0.17	3.01	0.05	90.41	6.33
	12	0.14	4.35	0.25	87.51	7.72
	24	0.42	4.96	0.71	85.04	8.85
	36	0.76	4.87	0.85	83.83	9.67
	48	1.11	4.75	0.84	83.00	10.28
	60	1.47	4.68	0.93	82.24	10.64

e_0^A and e_1^A are flexible and sticky price shocks to country A respectively. e_0^B and e_1^B are flexible and sticky price shocks to country B respectively. e^G is a global shock.

Table 2
Decomposition of variances in US output: 1974:1–1998:12

Country *B*	t	e_0^A	e_0^B	e_1^A	e_1^B	e^G
Canada	1	88.27	0.00	10.17	0.00	1.55
	6	85.96	0.09	10.17	0.02	3.73
	12	85.22	0.48	7.10	0.15	7.02
	24	76.88	1.71	6.44	2.00	12.95
	36	66.92	2.53	9.47	5.58	15.47
	48	60.96	2.71	11.68	9.00	15.62
	60	58.68	2.64	12.35	11.15	15.16
UK	1	93.43	0.00	0.42	0.00	6.13
	6	84.30	1.05	3.03	2.20	9.40
	12	67.53	4.14	7.55	7.98	12.77
	24	41.13	10.53	14.37	18.22	15.72
	36	36.24	12.36	15.83	20.73	14.81
	48	42.22	11.16	14.56	19.08	12.97
	60	46.60	10.72	13.28	17.40	11.98
Japan	1	93.25	0.00	5.73	0.00	1.00
	6	92.23	0.57	3.56	0.02	3.60
	12	86.48	3.360	4.04	0.01	6.09
	24	74.71	10.56	3.57	0.03	11.12
	36	66.94	13.22	4.83	0.09	14.90
	48	61.81	12.44	8.90	0.34	16.48
	60	57.52	12.07	12.97	0.97	16.45
Italy	1	59.31	0.00	14.89	0.00	25.79
	6	59.07	0.15	20.51	0.14	20.10
	12	60.08	0.52	23.06	0.70	15.62
	24	55.75	1.58	28.82	1.93	11.89
	36	48.55	1.82	32.76	3.26	13.58
	48	45.04	1.72	33.70	4.37	15.15
	60	44.71	2.37	32.94	5.00	14.95
France	1	56.75	0.00	29.68	0.00	13.55
	6	58.37	1.30	31.92	0.17	8.21
	12	59.73	1.79	31.58	0.85	6.01
	24	57.77	2.35	32.43	2.73	4.70
	36	53.50	2.46	33.45	4.33	6.24
	48	51.35	2.30	33.17	5.17	7.99
	60	51.92	2.19	32.04	5.39	8.44
Germany	1	11.22	0.00	88.09	0.00	0.68
	6	11.21	0.31	86.63	1.47	0.36
	12	7.68	2.91	80.64	6.64	2.12
	24	5.21	10.78	65.84	11.77	6.37
	36	4.69	16.78	58.52	11.15	8.82
	48	4.88	18.73	55.64	11.50	9.23
	60	5.47	17.83	54.13	13.98	8.57

Table 3
Decomposition of variances in real exchange rates with US: 1974:1–1998:12

Country *B*	t	e_0^A	e_0^B	e_1^A	e_1^B	e^G
Canada	1	28.03	3.14	67.94	0.87	0.00
	6	26.66	5.25	64.83	3.02	0.21
	12	33.08	4.79	53.36	8.20	0.53
	24	41.25	4.05	36.05	17.42	1.21
	36	44.08	3.85	27.54	22.78	1.73
	48	44.72	3.95	23.74	25.54	2.02
	60	44.53	4.18	22.16	26.99	2.12
UK	1	1.40	7.18	91.33	0.07	0.00
	6	0.54	7.66	86.26	5.46	0.05
	12	0.82	8.11	76.75	14.00	0.30
	24	2.68	9.73	64.31	21.62	1.63
	36	2.99	11.57	60.59	21.38	3.45
	48	3.80	12.19	59.01	20.58	4.41
	60	6.87	11.77	56.95	19.96	4.42
Japan	1	9.96	3.25	85.97	0.80	0.00
	6	13.21	5.85	77.95	2.69	0.27
	12	17.29	8.77	68.99	4.16	0.76
	24	24.07	12.26	54.69	7.23	1.73
	36	27.95	13.01	46.79	9.93	2.30
	48	29.46	12.76	43.33	11.93	2.48
	60	29.75	12.48	41.96	13.30	2.49
Italy	1	6.73	0.55	92.29	0.41	0.00
	6	2.96	0.87	93.46	2.64	0.04
	12	3.42	3.56	85.40	6.97	0.63
	24	4.55	9.31	72.44	9.75	3.93
	36	4.24	13.19	63.66	9.50	9.39
	48	4.19	14.46	58.13	8.78	14.41
	60	5.42	14.20	55.12	8.33	16.91
France	1	16.33	0.00	82.42	1.23	0.00
	6	13.72	0.03	85.49	0.69	0.04
	12	14.99	0.02	83.78	0.62	0.57
	24	16.00	0.08	77.75	1.30	4.85
	36	14.54	0.16	71.58	1.50	12.20
	48	14.40	0.17	65.18	1.38	18.84
	60	17.60	0.17	59.19	1.29	21.72
Germany	1	98.18	0.03	1.68	0.10	0.00
	6	97.60	1.04	1.22	0.12	0.00
	12	96.50	1.67	1.41	0.22	0.18
	24	92.82	2.60	1.52	1.29	1.74
	36	88.58	3.06	1.47	2.31	4.55
	48	84.48	3.27	2.30	2.50	7.42
	60	80.30	3.35	4.54	2.42	9.37

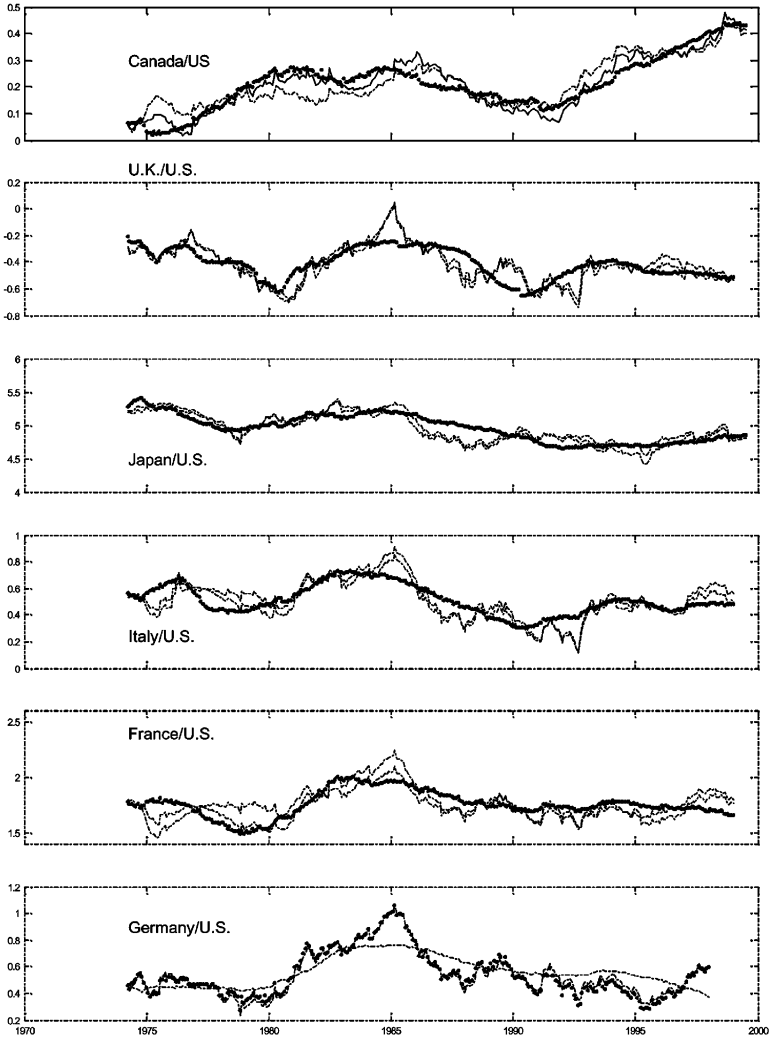

Fig. 1. Counterfactual real exchange rates: actual $-e_0^A$ (dotted line), e_1^A (dark dotted line).

that except for the German case, the impulse response functions all die off completely after five years, with the bulk of the adjustments completed within two years.

Fig. 4 shows the impulse responses to a sticky price shock in country *B* (using the same scale as Fig. 3). Although these shocks account for little of the real exchange rate variations as previously indicated in Table 3, and the absolute magnitudes of the responses are much smaller than those to a US sticky price shock, the dynamic responses to e_1^B are extremely persistent. The real exchange rate with Italy and with the UK both display large swings, while the effects on the Canadian dollar and the Yen do not seem to die off.

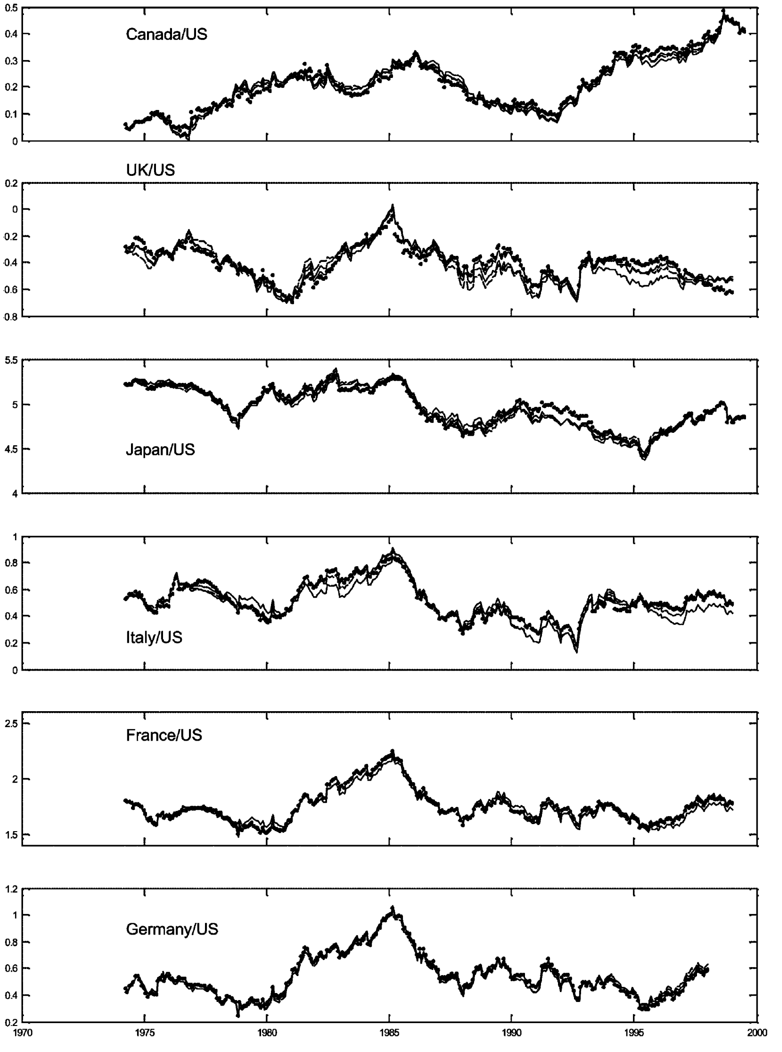

Fig. 2. Counterfactual real exchange rates: actual $-e_0^B$ (dotted line) e_0^B (dark dotted line) e^G (dot).

One objective of the present paper is to assess the duration of real exchange rate response to the different shocks. To make more formal statements about the speed of adjustments and to anticipate the results to follow, I need measures of persistence that are meaningful whether or not an impulse response function is monotonically declining. Therefore, for each impulse response, I first find the period at which the absolute response to the shock is largest. Denote this by τ_0. Let τ_1 be the period in which the impulse response function never rises above half the absolute response at τ_0. If the impulse response function moves towards zero monotonically, τ_1 is simply the half-life. For non-monotonic impulse responses, counting the adjustments from

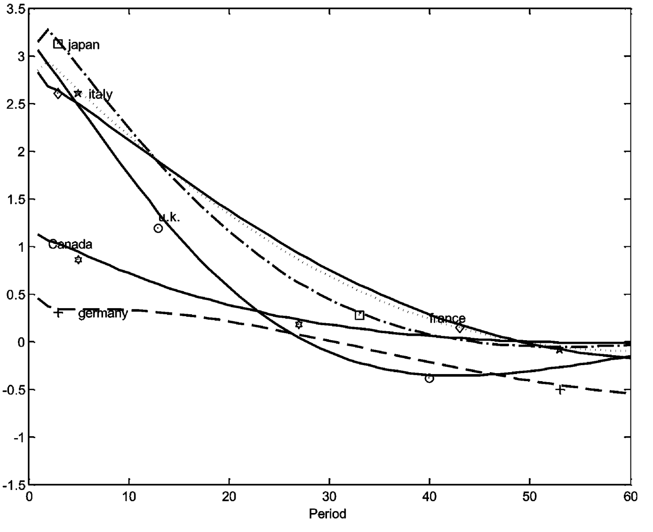

Fig. 3. Response of real exchange rate to $e^{A}{}_{1}$.

the peak at τ_0 rather than the origin seems more appropriate because it takes into account the time required to reach the peak response. For the sake of comparison, the mean lag, defined as

$$\tau_2 = \frac{\sum_{j=1}^{J} j|C_{jxy}|}{\sum_{j=1}^{J} |C_{jxy}|}$$

is also reported as a measure of persistence.

Table 5 summarizes the dynamic responses to all the shocks. The results reinforce the observation that i) sticky price shocks to country *B* dissipate much more slowly than sticky price shocks to the US (compare panel 4 with 3); ii) the responses to the two flexible price shocks are extremely persistent and sometimes explosive (panels 1 and 2), and iii) global shocks (panel 5) have effects that take a long time to peak, thereby generating disequilibrium effects that last a long time.

The results in the e_1^A column are of special interest, as real exchange rate variations were seen earlier to be dominated by these US sticky price shocks. But according to Table 5, the bulk of real exchange rate adjustments to US sticky price shocks take place immediately after the shock. With the exception of Germany, the half-lives are shorter than 20 months. While these speeds of adjustment are not short, they also are not as long as our prior, given the widely documented evidence of unit roots in real exchange rates based on univariate analysis. Sticky prices have been emphasized as a possible explanation for the real exchange rate puzzle. Surprisingly, adjustments to US sticky price shocks are arguably speedy when compared to other shocks. Shocks that explain real exchange rate variations need not be those that have the most persistent effects on prices.

Table 4
Standard errors for the impulse response functions

Country *B*	t	e_0^A	e_0^B	e_1^A	e_1^B	e^G
Canada	1	0.00	0.00	0.00	0.00	0.00
	6	0.13	0.08	0.12	0.11	0.11
	12	0.20	0.12	0.17	0.17	0.14
	24	0.24	0.15	0.20	0.22	0.18
	36	0.22	0.13	0.18	0.20	0.17
	48	0.19	0.11	0.16	0.16	0.13
	60	0.15	0.09	0.12	0.12	0.10
UK	1	0.00	0.00	0.00	0.00	0.00
	6	0.20	0.16	0.25	0.31	0.09
	12	0.31	0.25	0.35	0.40	0.15
	24	0.35	0.27	0.27	0.30	0.17
	36	0.29	0.22	0.20	0.21	0.15
	48	0.25	0.20	0.20	0.19	0.12
	60	0.26	0.18	0.17	0.17	0.10
Japan	1	0.00	0.00	0.00	0.00	0.00
	6	0.36	0.27	0.34	0.28	0.30
	12	0.51	0.38	0.45	0.41	0.31
	24	0.49	0.41	0.43	0.45	0.30
	36	0.37	0.32	0.37	0.39	0.26
	48	0.28	0.26	0.32	0.31	0.21
	60	0.22	0.24	0.26	0.26	0.17
Italy	1	0.00	0.00	0.00	0.00	0.00
	6	0.24	0.23	0.30	0.32	0.26
	12	0.34	0.27	0.42	0.35	0.37
	24	0.41	0.30	0.41	0.27	0.43
	36	0.36	0.28	0.33	0.21	0.39
	48	0.30	0.22	0.29	0.18	0.33
	60	0.27	0.19	0.26	0.16	0.28
France	1	0.00	0.00	0.00	0.00	0.00
	6	0.26	0.17	0.30	0.31	0.23
	12	0.38	0.16	0.42	0.41	0.29
	24	0.44	0.15	0.40	0.35	0.34
	36	0.39	0.13	0.30	0.26	0.33
	48	0.34	0.12	0.27	0.25	0.31
	60	0.36	0.11	0.29	0.25	0.28
Germany	1	0.00	0.00	0.00	0.00	0.00
	6	0.32	0.29	0.31	0.31	0.24
	12	0.40	0.38	0.40	0.37	0.23
	24	0.32	0.36	0.36	0.34	0.19
	36	0.24	0.27	0.29	0.28	0.18
	48	0.21	0.22	0.25	0.23	0.18
	60	0.22	0.22	0.25	0.22	0.17

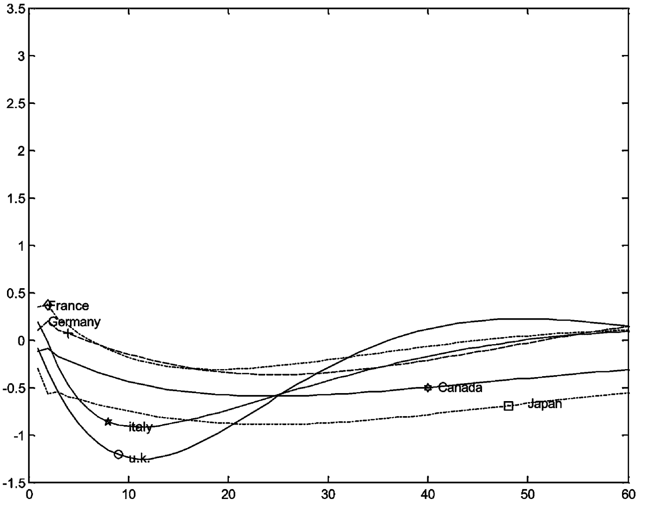

Fig. 4. Response of real exchange rate to $e^{B}{}_{1}$.

To get a sense of how different shocks contribute to persistence, Fig. 5 uses the yen–dollar real exchange rate to illustrate the implications of multiple shocks. The graph depicts what happens when a US sticky price shock e_1^A is combined with a unit increase to e_0^A, e_0^B, e_1^B, and e^G (one at a time). Two combinations are particularly noteworthy. First, a simultaneous increase to e_0^A and e_1^A lengthens the half life from 15 months to 24 months, and the mean lag from 12 to 18 months. This increase in persistence is of some empirical importance because the e_0^A shocks accounted for a non-trivial fraction of output variations in the US in all except the SVAR with Germany (see Table 2). The result is also of conceptual importance because it shows that shocks can be associated with flexible price adjustments and yet have very persistent effects on real exchange rates.

The second interesting shock combination is e_1^A and e_1^B. A positive sticky price shock in Japan partially offsets the effect of e_1^A initially, but prolongs the adjustment period substantially. The mean lag is increased from 12 months to 24 months. This result is important in two ways. First, it indicates that shocks from both countries can interact to magnify real exchange rate persistence. Second, sticky price shocks in Japan were identified to have affected the dollar-yen real exchange rate in the early nineties. Such shocks can have long lasting effects.

Finally, I assess whether it is possible for real exchange rate adjustments to be slow and yet prices are not sticky. Table 6 considers the case of US flexible price shocks, coupled with a country *B* flexible price shock. By definition, these shocks have instantaneous effects on prices in both countries. Yet, their effects on real exchange rates are long lasting. The half-life and the mean lag are usually well over 20 months, longer than the US sticky price shock alone. For example, the dollar-yen real exchange rate has a half life of 42 months. These results suggest that sticky prices are not necessary for real exchange rate persistence.

Table 5
Real exchange rate persistence 1974–1998

	e_0^A			e_0^B			e_1^A			e_1^B			e^G		
	τ_0	τ_1	τ_2	τ_0	τ_1	τ_2	τ_0	τ_1	τ_2	τ_0	τ_1	τ_2	τ_0	τ_1	τ_2
Canada	17	52	26	2	45	27	1	14	13	24	60	30	28	58	31
UK	60	60	35	1	38	22	1	12	16	11	25	19	29	51	30
Japan	15	47	25	13	36	22	2	15	12	24	60	30	21	46	27
Italy	1	23	27	27	42	30	1	20	15	2	4	23	38	60	36
France	1	4	28	22	48	27	2	19	14	11	29	19	37	60	35
Germany	1	15	15	12	43	26	60	60	35	25	42	27	39	60	36

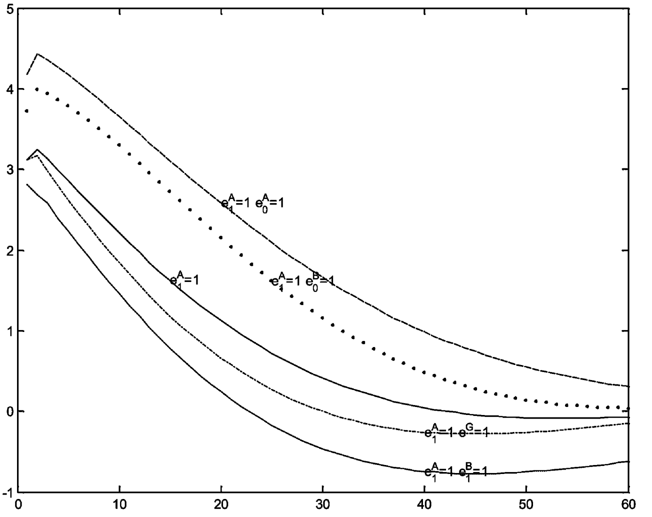

Fig. 5. Impulse responses of q(Japan) to $e^A{}_1$ and $e^B{}_1$.

Table 6
Speed of adjustments: multiple flexible price shocks

	e_1^A			$e_0^A + e_0^B$			$e_0^A - e_0^B$		
	τ_0	τ_1	τ_2	τ_0	τ_1	τ_2	τ_0	τ_1	τ_2
Canada	1	14	13	14	55	26	19	48	26
UK	1	12	16	1	8	32	16	34	24
Japan	2	15	12	14	42	24	34	60	30
Italy	1	20	15	45	60	37	18	38	23
France	2	19	14	1	25	27	1	21	27
Germany	60	60	35	2	18	15	1	12	16

5. Conclusion

A widely held view is that price stickiness arising from nominal rigidities hold the key to the real exchange rate puzzle. This viewpoint is difficult to test because market rigidities are difficult to quantify. This paper suggests a way to study the relation between price stickiness and the dynamics of real exchange rates without being specific about the nature of the rigidities. I use semi structural vector autoregressions to identify sticky price shocks in two countries. I find that US sticky price shocks have been the main source of real exchange rate variations since the collapse of the Bretton Woods agreement. However, real exchange rates adjust to US sticky price shocks reasonably quickly, and by themselves cannot be responsible for real exchange rate persistence. Persistence increases once US sticky price shocks are combined with other shocks. Although shocks to foreign output account for small amounts of real exchange rate variations, they could have contributed substantially to real exchange persistence. Finally, I present evidence to suggest that real exchange rates can be persistent even when prices are allowed to adjust instantaneously to output shocks.

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