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Abstract

There has been a considerable recent debate on the causes of low pass-through from exchange rates to consumer prices. This paper develops a simple model of a small open economy in which exchange rate pass-through is determined by the frequency of price changes of importing firms. But this, in turn, is determined by the monetary policy rule of the central bank. 'Looser' monetary policy, which implies a higher mean inflation rate, and a higher volatility of the exchange rate, will lead to more frequent price changes and a higher rate of pass-through. The model implies that there should be a positive, but non-linear, relationship between pass-through and mean inflation, and a positive relationship between pass-through and exchange rate volatility. In a sample of 122 countries, this is strongly supported by the data. Our conclusion is that, at least partly, low exchange rate pass-through is a result of short-term price rigidities.

1. Introduction

In the early years of floating exchange rates, economists expected to find a close association between movements in exchange rates and national price levels. Based on the presumption of approximate purchasing power parity (PPP), it was felt that control of domestic inflation would become more problematic in an environment of exchange rate volatility. However, a substantial literature, covering many different countries, has by now documented that exchange rate changes are at best weakly associated with changes in domestic prices at the consumer level. The low degree of 'exchange rate pass-through' both at the disaggregated level, for individual traded goods prices, and more generally in aggregate price indices, has been extensively documented.

Recently, a debate on the causes of low exchange rate pass-through has begun. Some writers argue that the ultimate explanation is microeconomic, based on various structural features of international trade, such as pricing to market by imperfectly competitive firms (Corsetti and Dedola 2002), domestic content in the distribution of traded goods (Corsetti and Dedola 2002; Burstein, Neves and Rebelo 2000), the importance of non-traded goods in consumption (Betts and Kehoe 2001), or the role of substitution between goods in response to exchange rate changes (Burstein, Eichenbaum and Rebelo 2002). Others argue, however, that the failure of pass-through is a more macroeconomic phenomenon, related to the slow adjustment of goods prices at the consumer level (Engel 2002). Campa and Goldberg (2002) provide evidence for OECD countries that both factors are important in the evolution of exchange rate pass-through estimates over time, but ultimately come down on the side of a microeconomic explanation, based on the changing composition of import goods.

Whether the behavior of exchange rate pass-through is attributed to sticky prices or to more structural features of international trade is important. For example, if pass-through is systematically related to the stance of monetary policy, as suggested by Taylor (2000), this would have significant implications for the appropriate way to conduct monetary policy in an open economy.

In this paper, we develop a simple framework within which to investigate the importance of slow price adjustment in explaining exchange rate pass-through in an open economy. Our approach closely follows the celebrated paper of Ball, Mankiw and Romer (1988), and borrows their methodology for testing the role of sticky prices in explaining the differing slopes of estimated Phillips curves in cross-country data. Based on our theoretical model, and the empirical evidence, we argue that sticky prices play an important role in cross-country variations in exchange rate pass-through. As a result, we argue that exchange rate pass-through is endogenous to the monetary policy regime.

We first develop a simple theoretical model of endogenous exchange rate pass-through. The model abstracts from many factors that might limit pass-through, and focuses exclusively on the role of price rigidities that come about due to the presence of 'menu-costs'. Modeling monetary policy as a 'Taylor-type' interest-rate rule, we show that monetary policy determines both the average rate of inflation and the volatility of the nominal exchange rate. However, if the frequency of price changes is constant, exchange rate pass-through is independent of monetary policy, but is instead determined by the types of shocks in the economy, and their persistence.

But the frequency with which prices change is chosen by firms, and in general will vary with the monetary policy regime. For a given size of the menu cost of price changes, firms will choose a higher frequency of price adjustment the higher is the average rate of inflation, and the more volatile is the nominal exchange rate. And the higher is the frequency of price changes, the greater is exchange rate pass-through. In a calibration of our model, we find that for annual rates of inflation higher than 25 per cent firms will adjust prices every period, so that price rigidity disappears completely.

In our empirical implementation of the model, we estimate simple aggregate pass-through coefficients for 122 countries. A closely related paper by Choudhri and Hakura (2001) shows that estimated exchange rate pass-through tends to vary systematically with the mean inflation rate. For countries with very high inflation rates we find, as in Choudhri and Hakura (2001), that aggregate pass-through is very high, and in many cases statistically indistinguishable from unity. Using the methodology of Ball, Mankiw and Romer (1988), we then show that there is a non-linear relationship between estimated pass-through coefficients and average inflation rates. As inflation rises, pass-through rises, but at a declining rate. These results offer prima facie evidence of the importance of sticky prices in determining the average rate of pass-through. For countries with very high inflation, prices become essentially flexible, the cost to firms of maintaining fixed prices fully offsetting the menu costs of price changes, and exchange rate pass-through is complete.

2. The Importing Firm

Consider a set of domestic firms that import a consumer good from abroad, and sell the good to local consumers. Each firm has marginal costs of P_t^* in terms of foreign currency. Suppose that each individual firm selling to the domestic market faces demand given by

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\lambda} C_t,$$

where $P_t(\mathrm{i})$ is the firm's price, and P_t is the composite price index for foreign goods sold on the domestic market (this demand function can be derived from the domestic country's utility maximization - see below). The firm's profit is then given by

$$\Pi_t(i) = P_t(i)C_{ft}(i) - S_t P_t^* \Theta_t C_t(i).$$

Here S_t is the exchange rate, and Θ_t captures a per-unit transportation or distribution cost associated with selling the good in the domestic country. Note that, by assumption, the firm sets prices in terms of the domestic currency. If the firm could freely adjust its price at any time, it would set the price

$$\hat{P}_t(i) = \frac{\lambda}{\lambda - 1}\Theta_t S_t P_t^*.$$

However, suppose that there is some 'menu cost' F that must be paid by the firm whenever it changes its price, where F is measured as a fraction of steady state profits. As in Calvo (1983), we assume that there is a probability of $1-\kappa$ that the firm changes its price at any period, and thus a probability κ that the firm's price will remain unchanged, *irrespective of the length of time* it has been fixed in the past. In a later section, we will allow the probability of price changes to be endogenous.

How do we determine what price the firm will set? As has been shown in many previous papers (e.g. Walsh 1998), the inter-temporal profit maximization condition of the firm may be approximated as a negative function of the expected squared deviation of the log price from the desired log price in each period. Thus the firm's objective function can be written as

$$L_t = F + E_t\left[\sum_{j=0}^{\infty}(\beta\kappa)^j(\tilde{p}_t(i) - \hat{p}_{t+j}(i))^2 + \frac{(1-\kappa)}{\kappa}\sum_{j=1}^{\infty}(\beta\kappa)^j L_{t+j}\right],$$

where small case letters represent logs. Here L_t represents the proportional difference between unconstrained profits, when the firm adjusts its price in every period, and actual profits, when the firm sets its price at time t under the assumptions of the Calvo model, inclusive of the cost of price change F. The total loss L_t is comprised of the immediate loss of F, interpreted as the share of average profits going to price adjustment (or the size of 'menu-costs'), and the expected discounted value of losses from having the newly set price $\tilde{p}_{ft}(i)$ differ from the desired price $\hat{p}_{ft+j}(i)$, plus the expected value of the loss function that applies when the firm will be able to change its price again in the future, which happens each period with probability $1-\kappa$.

It is straightforward to show that the optimal price for the newly price setting firm obeys the recursive equation

$$\tilde{p}_t(i) = (1-\beta\kappa)\hat{p}_t + \beta\kappa E_t\tilde{p}_{t+1}(i).$$

From the definition of $\hat{p}_{ft}$, this implies that

$$\tilde{p}_t(i) = (1-\beta\kappa)(\hat{\lambda} + s_t + p_t^* + \theta_t) + \beta\kappa E_t\tilde{p}_{t+1}(i), \tag{1}$$

where $\hat{\lambda} = \ln(\lambda/(\lambda-1))$.

Now if we impose symmetry so that all importing firms who adjust their price at time t choose the same price, then we may write the price index for imported goods facing the home country as the log approximation

$$p_t = (1-\kappa)\tilde{p}_t + \kappa p_{t-1}. \tag{2}$$

Equations (1) and (2) together determine the degree of 'pass-through' from exchange rates to prices. But since (1) gives the newly set price as a function not just of the current exchange rate but the whole path of expected future exchange rates, it is clear that the relationship between s_t and p_t will depend on the time series properties of s_t. Note that as $\kappa \to 0$, the law of one-price holds, so that pass-through is complete.[1]

1 As we will later show, as $\kappa \to 0$, monetary policy continues to influence both prices and the nominal exchange rate, but proportionately, so that there is no net effect on pass-through.

3. Determination of the Exchange Rate

We must go on to determine how s_t behaves by developing a model of a small open economy. Agents in the economy consume only imported goods,[2] and produce an export good using only labor. The representative agent has preferences given by

$$U = E_t \sum_{j=0}^{\infty} \beta^j \left(\frac{C_{t+j}^{1-\sigma}}{1-\sigma} - \frac{\eta}{1+\psi} H_{t+j}^{1+\psi} \right),$$

where $C_t = \left(\int_{i=0}^{1} C_t(i)^{1-\frac{1}{\lambda}} di \right)^{\frac{1}{1-\frac{1}{\lambda}}}$ is consumption of the imported good, and H_t is the labor supply. Defining the CPI as $P_t = \left(\int_{i=0}^{1} P_t(i)^{1-\lambda} di \right)^{\frac{1}{1-\lambda}}$ (the price index for imported goods), the demand for imported goods varieties given above may be derived. Domestic consumers face a budget constraint given by

$$S_t B_{t+1}^* + B_{t+1} + S_t B_{t+1}^* + P_t C_t = Q_t Y_t + S_t B_t^* (1+i_t^*) + (1+i_t) B_t + \Pi_t .$$

That is, the home consumer receives income from the sales of export goods Y_t at price Q_t, interest payments on bonds, and profits from the importing goods firms, which is used to consume imported goods, and to invest in domestic and foreign-currency denominated bonds, repaying nominal interest rates i_t and i_t^* respectively. For the moment, we can abstract from the details of the domestic production sector, since it is irrelevant to exchange rate pass-through in this simple version of the model.

The optimality conditions for the home consumer include the Euler equations

$$\frac{1}{1+i_{t+1}^*} = E_t \beta \frac{C_t^{\sigma} P_t S_{t+1}}{C_{t+1}^{\sigma} P_{t+1} S_t}, \tag{3}$$

$$\frac{1}{1+i_{t+1}} = E_t \beta \frac{C_t^{\sigma} P_t}{C_{t+1}^{\sigma} P_{t+1}}. \tag{4}$$

Suppose that monetary policy is described by an interest-rate rule,

$$(1+i_{t+1}) = \Phi \exp(v_t) \left(\frac{P_t}{P_{t-1}} \right)^{\delta}, \tag{5}$$

where Φ is a constant, and v_t is an i.i.d. interest-rate shock to the policy rule. The monetary authority sets interest rates to respond to CPI inflation, with the elasticity of response given by δ. In what follows, we assume that $\delta > 1$, so that the monetary authority follows a policy of increasing the real interest rate in response to a rise in current inflation.

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2 We abstract from non-traded goods. The effect of non-traded goods on exchange rate pass-through is well understood (e.g. Hau 2000). Our aim is to focus specifically on the implications of menu costs for exchange rate pass-through.

The combination of the interest rate rule (5), the two Euler equations (3) and (4), and the foreign firm pricing equations (1) and (2) represent a self-contained model of inflation and real exchange rate determination. To see this, note the following. First, we may combine (1) and (2) to derive the inflation equation for imported goods prices,

$$\pi_t = \eta(\hat{\lambda} + \theta_t + q_t) + \beta E_t \pi_{t+1}, \tag{6}$$

where $\pi_t = p_t - p_{t-1}$ is the inflation rate, $q_t = s_t + p^*_t - p_t$ is defined as the real exchange rate, and $\eta = (1-\beta\kappa)(1-\kappa)/\kappa > 0$. This 'forward-looking' inflation equation has been used in much previous work.[3] Imported goods inflation will be higher when the real exchange rate is higher than its flexible price equilibrium level, given by $-(\hat{\lambda} + \theta_t)$. The degree to which the real exchange rate can differ from the flexible price fundamentals depends on the degree of price rigidity. As $\kappa \to 0$, the parameter η rises, and the deviation of the real exchange rate from the flexible price fundamentals falls.

Now, taking a logarithmic approximation of the Euler equations (3) and (4), we obtain the uncovered interest rate parity (UIRP) relationship,

$$i_t = i^*_t + E_t s_{t+1} - s_t .$$

Note also that the interest rate rule (5) implies that

$$i_t = -\phi + \delta\pi_t + v_t ,$$

where $\phi = -\ln\Phi$ is a measure of the average monetary policy bias. If $\phi > 0$, the monetary authority systematically attempts to hold the nominal interest rate below its zero-inflation steady state.

Combining these last two equations gives

$$\delta\pi_t + v_t = r^*_t + \phi + E_t q_{t+1} - q_t + E_t \pi_{t+1}, \tag{7}$$

where $r^*_t = i^*_t + E_t\,(p^*_{t+1} - p_t)$ is the foreign real interest rate.

Equations (6) and (7) give a simple dynamic system in domestic inflation and the real exchange rate. Equation (6) shows how domestic inflation is determined by the deviation of the real exchange rate from its flexible price equilibrium, and (7) implies equality between the nominal interest rate rule followed by the monetary authority, and the UIRP-determined nominal interest rate facing domestic agents.

To solve these equations, we must be more specific about the shock processes. Let us make the following set of assumptions:

$$r^*_t = \rho r^*_{t-1} + \varepsilon_t , \qquad v_t = \gamma v_{t-1} + \varsigma_t , \qquad \theta_t = \mu\theta_{t-1} + \upsilon_t ,$$

3 As applied to exchange rate pass-through, see Devereux (2001), and Monacelli (2001).

where $0 \le \rho \le 1$, $0 \le \gamma \le 1$, $0 \le \mu \le 1$, and ε_t , ς_t , υ_t are i.i.d., mean-zero disturbances. Using these assumptions, it is easy to establish that the solutions for inflation and the real exchange rate are

$$\pi_t = \frac{\phi}{(\delta - 1)} + a_1 r_t^* + a_2 v_t + a_3 \theta_t , \tag{8}$$

$$q_t = \frac{\phi(1-\beta)}{\eta(\delta - 1)} - \hat{\lambda} + b_1 r_t^* + b_2 v_t + b_3 \theta_t , \tag{9}$$

where the coefficients are defined in Table 1.

The intuitive interpretation of these conditions is as follows. If the monetary authority has a target for the nominal interest rate that is less than the steady state foreign real interest rate (normalized to be zero here), i.e. if $\phi < 0$, then steady state inflation is positive. This leads to a higher steady state real exchange rate. It is well known that in the presence of gradual price adjustment, the average real price set by price setters is eroded by inflation. In our context, this translates into a higher average level of the real exchange rate (real depreciation), as the price level continually fails to 'catch-up' with nominal exchange rate depreciation. Note that the higher is the coefficient on inflation in the monetary rule, the smaller are both mean inflation and steady state depreciation in the real exchange rate. Hence, for a given bias parameter ϕ, a 'tighter' monetary policy (a higher δ) implies a lower mean inflation rate. On the other hand, a higher level of the monopoly markup $\hat{\lambda}$ leads to a steady state real appreciation, as it leads to a domestic price level on average higher than the foreign price. Note, however, that the markup parameter has no implications for the average inflation rate.

A shock to the foreign real interest rate leads to a rise in inflation, and a real exchange rate depreciation. The responses of both inflation and the real exchange rate are higher the more persistent is the shock, but lower the higher is the interest rate elasticity of the monetary rule.

The responses of both inflation and the real exchange rate to a shock to the monetary rule are qualitatively equivalent to the response to a foreign real interest rate shock. An expansionary shock (defined as a rise in v_t) leads to a rise in inflation, and real exchange rate depreciation. The impact of a shock to the transport technology θ_t is different, however. This leads to a real exchange rate appreciation, as domestic prices rise above foreign prices. At the same time, because the shock is not permanent, this implies that the real exchange rate is expected to depreciate more rapidly which, from the interest parity condition, leads to a rise in domestic inflation.

Figure 1 illustrates some of the dynamic properties of the model's response to a foreign interest rate shock (or equivalently, a shock to the monetary rule).[4] Three parameters are important in the analysis. First, the monetary policy stance δ affects the scale of the response, with a higher δ reducing the response of both inflation and the real exchange rate. But it does not affect the relative size of the real exchange rate movement to the domestic inflation movement. From equation (6), for a given dynamic response of inflation, the response of the real exchange rate is determined. Thus, for shocks that do not directly affect the forward looking inflation equation, the relationship between inflation and the real exchange rate will be unaffected by parameters that influence only the size of inflation itself.

4 The parameter values used in the figure are outlined in Section 5.

As is to be expected, an increase in price stickiness (a fall in η) leads to a rise in the response of the real exchange rate, and a fall in the response of inflation. Finally, a rise in the persistence of the shock (ρ) has two distinct effects. First, there is an increase in the size and persistence of the response of both inflation and the real exchange rate. But greater persistence also affects the *relative* size of the movement in q_t and π_t. A less persistent shock has a lower impact on domestic inflation, relative to the real exchange rate. As the shock gets more and more transitory, most of the response is confined to the real exchange rate. We will see below that this translates into a lower nominal exchange rate pass-through for more transitory shocks.

A shock to the transactions technology θ_t is illustrated in Figure 2. Here, the tighter is the stance of monetary policy, the less the impact of the shock is felt on inflation, and the more on the real exchange rate.

4. Exchange Rate Pass-Through

We now focus on the main issue of interest. How much and how fast do nominal exchange rate changes 'pass-through' into changes in the domestic price level? Our framework is suitable for asking this question. We can isolate the shocks that, in the absence of price rigidity, would affect the real exchange rate, and hence the degree to which there would be a failure of complete exchange rate pass-through in an efficient economy. But when the exchange rate is driven principally by foreign interest rate shocks, or by domestic monetary policy shocks, any deviation from the law of one price is due solely to the failure of prices to adjust quickly enough. The main object of the investigation here is to isolate the structural determinants of low pass-through, due to slow price adjustment.

Pass-through is defined as a relationship between the nominal exchange rate and the domestic price level. From the inflation equation (6), we can write the domestic price level as

$$p_t = \frac{\phi}{(\delta - 1)} + a_1 r_t^* + a_2 v_t + a_3 \theta_t + p_{t-1}.$$

Using this and the real exchange rate equation, we can determine the nominal exchange rate as

$$s_t + p_t^* = \frac{\phi}{(\delta - 1)} + (b_1 + a_1) r_t^* + (b_2 + a_2) v_t + (b_3 + a_3)\theta_t - b_1 r_{t-1}^* - b_2 v_{t-1} - b_3 \theta_{t-1} + s_{t-1} + p_{t-1}^*.$$

Shocks to both the nominal exchange rate and the price level are permanent, since both equations display a unit root. However, their short-run dynamics may be quite different in the face of slow price adjustment, or shocks to the transactions technology. Focusing on the effect of foreign real interest rate shocks, or equivalently domestic monetary shocks, we see that the exchange rate will always respond by more than the domestic price level in the short run, since such shocks cause both an immediate real depreciation as well as domestic inflation. Thus generically, short-run pass-through is incomplete in this economy for these types of shocks. But since the real exchange rate converges back to zero, the subsequent rise in the nominal exchange rate is slower than the rise in the price level.

Figure 3 describes the response of the nominal exchange rate and the price level following a positive shock to r_t^* or v_t. Two parameters are critical in determining the response. For a more persistent shock, both the exchange rate and the price level tend to rise gradually over time, following the initial shock. But for a transitory shock, the exchange rate tends to 'overshoot', rising by more on impact than in the new steady state. The degree of price rigidity determines the extent to which movements in the exchange rate exceed the initial movements in the price level. Hence, we see that the implied 'pass-through' of changes in the exchange rate to the domestic price level is highly sensitive to the persistence of the underlying shock, with transitory shocks having much less pass-through effect.

How does monetary policy affect pass-through? The answer is that, for given values of κ, and given persistence, monetary policy has no effect. A tighter monetary policy (higher δ) reduces both the price and the exchange rate response to the shock, but the relative price to exchange rate response is unchanged. We may describe the immediate pass-through coefficient by the function

$$\frac{\mathrm{cov}_{t-1}(s_t, p_t)}{\mathrm{var}_t(s_t)}.$$

For interest rate shocks, this is equal to $a_1/(a_1 + b_1) = \eta/(\eta+(1-\beta\rho))$. Therefore, for given η, this is independent of the monetary rule. However, as we will see below, when we allow the frequency of price adjustment to be determined endogenously, the monetary rule may have a substantial impact on pass-through.

Table 2 describes the pass-through of a shock as a function of time, depending also on the persistence of the shock, and the size of κ. For more persistent shocks, the immediate pass-through tends to be higher, as inflation rises by more. But the subsequent degree of pass-through is quite small. On the other hand, for highly transitory shocks, the immediate pass-through is very low, but it quickly rises to unity, since the exchange rate falls as the price level rises.

Figure 4 illustrates the response of the exchange rate and the price level to a real-exchange rate shock. In this case, the implied pass-through coefficient is negative since, for the set of parameters used, the exchange rate falls as the price level rises, facilitating the desired real exchange rate appreciation.

5. Endogenous Price Rigidity

So far we have assumed that κ is fixed exogenously. In studies of the effects of monetary policy on U.S. data, most researchers have assumed a constant degree of nominal price rigidity. In the calibration above, we set κ equal to 0.75, implying that the median price is adjusted after four quarters. But when we wish to compare pass-through estimates in cross country data, it is highly unrealistic to assume a uniform value of κ. The underlying rationale for price rigidity is that firms incur some type of costs associated with price changes, either of the 'menu-cost' or 'contracting-cost' type (see Devereux and Yetman 2001). While these transactions costs are likely to be similar across countries, the benefits to firms from changing their prices may differ substantially. Moreover, they will differ in a systematic manner, depending on both the average inflation rate, and the variability of the exchange rate. The higher is the inflation rate, the more costly it is for a firm to set its price in terms of domestic currency, and have its real return eroded by exchange rate depreciation. The higher is the variance of the nominal exchange rate, the more variable is the firm's 'marginal cost' schedule, and the more the firm's price will depart from the efficient price, on average. Thus, we would anticipate that countries that have a) higher average inflation and b) higher variance of nominal exchange rates will have lower κ, because the menu costs of price change would tend to be more than offset by the losses the firm incurs from keeping its price fixed in domestic currency. But since κ represents the key determinant of nominal exchange rate pass-through, we may conclude that the same two factors should contribute to a higher value of pass-through.

Furthermore, in our model, both the mean inflation rate and the volatility of the exchange rate are related to the stance of monetary policy. For a higher value of δ, or a tighter monetary policy, the mean inflation rate is lower, and the variance of the exchange rate is lower. Hence, we would anticipate that countries that follow a more 'conservative' monetary policy would tend to have lower exchange rate pass-through.

We may illustrate this point as follows. Take a special case of the above model, where there are only interest rate (or monetary policy) shocks, and for simplicity, all shocks are i.i.d.. Then we may write the process for the exchange rate as

$$s_t = \mu + \frac{(1+\eta)\varepsilon_t}{\delta\eta+1} - \frac{\varepsilon_{t-1}}{\delta\eta+1} + s_{t-1},$$

where $\mu = \phi/(\delta-1)$ is the average rate of exchange rate depreciation, which is decreasing in δ, as we noted before. The variance of exchange rate changes is given by

$$\sigma_{ds}^2 = \left[\left(\frac{(1+\eta)}{\delta\eta+1}\right)^2 + \frac{1}{(\delta\eta+1)^2}\right]\sigma_\varepsilon^2,$$

which is also decreasing in δ. Hence, when we take the perspective that κ is endogenously determined on a country-by-country basis, then we may anticipate that it will be systematically related to the monetary policy followed by each country.

Continuing to focus on this special case, we may illustrate the solution for the optimal κ for each firm. Ignoring the constant mark-up, the firm has a desired price each period given by the exchange rate

$$\hat{p}_{t+j}(i) = \begin{cases} s_t, \ j=0 \\ s_t + j\mu + \dfrac{(1+\eta)\varepsilon_{t+j}}{\delta\eta+1} + \dfrac{\eta}{\delta\eta+1}\displaystyle\sum_{i=1}^{j-1}\varepsilon_{t+i} - \dfrac{\varepsilon_t}{\delta\eta+1}, \ \forall j>0 \end{cases}.$$

From equation (1), it is then straightforward to show that firms set prices according to

$$\tilde{p}_t(i) = s_t - \frac{\beta\kappa\varepsilon_t}{\delta\eta+1} + \frac{\beta\kappa\mu}{1-\beta\kappa}.$$

The optimal value of κ then determines the probability that the firm's price will be constant at each period in the future. We assume that the firm must decide on κ in advance of price setting for any period, so that κ minimizes $E_{t-1}L_t$. But since the environment is stationary, the firm will choose the same κ in each period. We may therefore think of the firm as choosing κ to minimize the stationary loss function,

$$L_t = \frac{(1-\beta\kappa)}{(1-\beta)}\left[F + E_{t-1}\sum_{j=0}^{\infty}(\beta\kappa)^j(\tilde{p}_t(i) - \hat{p}_{t+j}(i))^2\right].$$

Substituting the expressions for $\tilde{p}_t(i)$ and $\hat{p}_{t+j}(i)$ into the stationary loss function, we obtain

$$L_t = \frac{(1-\beta\kappa)}{(1-\beta)}\left[F + \frac{\beta\kappa\mu^2}{(1-\beta\kappa)^3} + \frac{\beta\kappa\sigma_\varepsilon^2}{(\delta\eta+1)^2(1-\beta\kappa)^2}\left((1-\beta\kappa)(2(1+\eta)-\beta\kappa)+\eta^2\right)\right]. \quad (10)$$

The individual firm chooses its pricing frequencyto minimize this stationary loss function, taking the κ's of all other firms as given. This means that it takes the stochastic process for the exchange rate, and therefore the values of μ and η, as given when choosing κ. A Nash equilibrium is defined as the value κ^N such that

$$\frac{\partial L}{\partial \kappa}(\kappa^N, \mu, \eta) = 0,$$

where $\mu = \mu(\kappa^N)$, $\eta = \eta(\kappa^N)$. The solution for κ^N is not in general analytical, but a simple numerical approach may be used. For this calculation, we use the following parameter values. The benchmark value of δ is set at 1.5, and the discount factor β is set at 0.95. If the benchmark value of κ is 0.75, this implies a value of η equal to 0.096. Setting ϕ equal to 0.015, steady state inflation is 3 per cent. The standard deviation of the exchange rate (σ_{ds}) is taken to be 5 per cent, in the range of OECD exchange rate estimates, implying a variance of the shock of $\sigma_\varepsilon^2 = 0.0015$. From equation (10), these parameter values, in turn, imply $F = 0.066$, so that changing price costs 6.6 per cent of steady-state profits. We then vary the δ parameter, which is equivalent to varying both the mean and variance of inflation, to investigate the dependence of κ on δ.

Figure 5 illustrates the dependence of κ^N on the monetary policy rule. As δ falls below 1.5, κ falls sharply. For δ below 1.06 price rigidity is completely eliminated, as all firms adjust prices each period. As δ rises above 1.5, κ rises, but flattens out quickly at values higher than 0.8. Note that the results can be also be stated in terms of the average 'contract length,' or the average time between price adjustment, given by $1/(1-\kappa)$. As δ falls, the average contract length falls, so when $\delta = 1.06$, adjustment takes place every period. But as δ rises, prices become fixed for increasing intervals.

Figure 6 shows the relationship between κ and average inflation rates, given by $\phi/(\delta-1)$. For the parameterization we use, as the inflation rate rises above 25 per cent, all prices become flexible.

Finally, Figure 7 gives the exchange rate pass-through estimates, as a function of the monetary policy rule, implied by the model.[5] Consistent with the implications of the previous figures, we find that the short-run pass-through of exchange rates to prices is very low for our benchmark calibration - less than 10 per cent. But as inflation rises progressively, pass-through increases, and is complete for inflation rates exceeding 25 per cent.

[5] Pass-through in this special case is given by $\eta/(\eta+1)$.

6. Empirical Implementation

While our theoretical model is too simple to be directly estimated, we may take a more indirect approach to testing the implications of the model. Broadly, our model points to the role of menu-costs of price change in determining the speed with which changes in exchange rates pass-through to domestic price levels. For countries with low inflation and low exchange rate volatility, we should anticipate pass-through to be quite low. In this case, in the presence of macro shocks that require adjustment of the real exchange rate, we should not expect to find any strong statistical relationship between changes in the exchange rate and changes in domestic price levels. But for countries with much higher inflation rates, and higher exchange rate volatility, we would expect to find higher exchange rate pass-through, as firms find that the menu costs of price change are more than offset by the loss from having prices far from their desired level. Moreover, this relationship should be non-linear: as inflation rises above some threshold, there should be no further impact of inflation on pass-through, as all prices are adjusted continually, so that pass-through is complete.

Our more fundamental hypothesis is that the rate of pass-through is ultimately related to the stance of monetary policy. Excessively loose monetary policy will imply a higher average rate of inflation, and a higher level of exchange rate volatility.

We investigate the hypothesis by estimating a regression of the form

$$\Delta P_{tj} = \beta_{1j}\Delta S_{t\text{-}1j}+\beta_{2j}\Delta P^*_t,$$

where P_t is the CPI of country j, S_t is the U.S. dollar exchange rate of country j, and P^*_t is the U.S. CPI.[6] Data are annual, to smooth out high frequency fluctuations in the exchange rate, and are taken from the IMF International Financial Statistics.[7]

Although this equation is not likely to represent a full specification for inflation determination, it should capture the aggregate influence of exchange rate movements on changes in national price levels.[8] For example, while both contemporaneous and lagged exchange rate changes may be expected to influence inflation, only lagged exchange rate changes are included in the regression to avoid any reverse endogeneity from domestic inflation rates to exchange rates biasing the estimates.

Our measure of exchange rate pass-through is the coefficient β_1. The estimates of β_1 for the full sample (given in Appendix) are quite sensible, in most cases lying between zero and one. Figures 8 and 9 contain scatter plots of the β_1 estimates against the mean inflation rate for each country. Figure 8 contains the estimates for all countries (excluding a few outliers), while Figure 9 contains only those countries for which β_1 was significant at the 5% level.

6 Similar results to those reported below are obtained if we include an intercept.

7 All countries for which there are at least 10 annual observations in the post-Bretton Woods period (1970-2001) are included in the sample, with the exception of Hong Kong, for which there is virtually no nominal exchange rate volatility.

8 A similar approach is taken by Choudhri and Hakura (2001).

We follow the methodology of Ball, Mankiw and Romer (1988) in investigating a relationship between the estimates of exchange rate pass-through and trend inflation. The presence of menu costs suggests that exchange rate pass-through should be positively related to mean inflation, but with a non-linear relationship, since for inflation above a certain threshold, further increases in mean inflation should have no effect on pass-through. In addition, according to our model, exchange rate volatility should increase the measured rate of pass-through. Hence, we could run the regression

$$\hat{\beta}_{1j} = \alpha_1 \pi_j + \alpha_2 \pi_j^2 + \alpha_3 \operatorname{var}(\Delta S_j),$$

where π is the mean inflation rate for country j and $\operatorname{var}(\Delta S_j)$ is the variance of the exchange rate change vis-à-vis the U.S. dollar.[9]

In the model, firms should adjust their frequency of price change in response to changes in the mean rate of exchange rate depreciation. While the model implies that this is the same as the mean inflation rate, in reality, the two numbers may differ considerably. As an extra possibility, we estimate the equation adding on mean exchange rate depreciation, and its square, as well as the standard deviation of domestic inflation, both separately and in combination.

Table 3A contains the results including all 122 countries in the sample. First, there is strong evidence that mean inflation tends to increase the rate of exchange rate pass-through,[10] and that this effect dwindles as inflation rises. There is evidence of a similar effect for mean exchange rate depreciation. Inflation variance also has a positive and significant effect on the degree of pass-through, even once we control for the mean inflation and inflation squared. When we include *both* mean inflation and mean exchange rate depreciation as separate variables, as well as inflation variance, all variables are highly significant. In particular, there is clear evidence that both inflation and mean exchange rate depreciation separately impact on the degree of pass-through, increasing pass-through, but in a non-linear fashion.

In the above results, the dependent variable includes estimated pass-through coefficients for all countries, including those that may be poorly identified. To confirm the robustness of the results, the estimation was repeated including only those 75 countries for which the estimated pass-through coefficient is significant at the 5% level. The results are displayed in Table 3B, and are very similar to those outlined above, clearly demonstrating the explanatory power of both the level and volatility of inflation and exchange rate depreciation for exchange rate pass-through.[11]

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9 If an intercept is included, it is nearly always statistically insignificant, and the estimation results are virtually identical to those reported here.

10 This is also shown in Choudhri and Hakura (2001).

11 While the coefficients on inflation and inflation volatility are highly robust to different formulations of the model, those on exchange rates and exchange rate volatility are less so. For example, including a constant in the first stage of the estimation, while statistically insignificant for the majority of countries, results in estimated coefficients on exchange rates and exchange rate volatility in the second stage of the estimation that frequently have the ‘wrong’ sign. This anomaly can be explained by the high collinearity between the inflation and exchange rate variables (correlation coefficients of 0.83, 0.81, and 0.77 between the levels, levels squared, and standard deviations respectively). Replacing each exchange rate variable with its component that is orthogonal to the comparable inflation variable completely eliminates the anomaly in this case.

Separate estimates done on high inflation and low inflation countries (not reported) suggest that the influence of mean inflation and mean exchange rate depreciation on exchange rate pass-through is much weaker. But this is what we should anticipate since, for countries with generally low (or high) rates of inflation, there should be little difference in pass-through. In general, the results support the hypothesis that sticky prices are an important factor in determining exchange rate pass-through at the aggregate level.

7. Conclusions

This paper makes two major arguments. First, the rate of pass-through from exchange rates to prices is at least partly determined by macroeconomic factors, in particular the presence of sticky prices. Second the rate of pass-through is sensitive to the monetary policy regime, precisely because the degree of price stickiness itself is endogenous to the monetary regime. The theoretical model shows how pass-through in a small open economy is determined by structural features of the economy, such as the persistence of shocks, and the degree of price stickiness. When firms can adjust their frequency of price changes, we find that 'looser' monetary policy leads to more frequent price changes, and higher pass-through. Our empirical results provide strong support for the presence of price stickiness in determining the degree of pass-through. In particular, both mean inflation and mean exchange rate depreciation tend to increase pass-through, but in a non-linear fashion, as suggested by the model. For sufficiently high inflation rates (or mean exchange rate depreciation rates), price changes occur every period, and exchange rate pass-through is complete.

Overall, the evidence strongly points to the need to take into account the endogenous nature of exchange rate pass-through in designing monetary policy for a small open economy.

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Table 1.

a_1	$\dfrac{\eta}{\left[(\delta-\rho)\eta+(1-\rho)(1-\beta\rho)\right]}$	b_1	$\dfrac{(1-\beta\rho)}{\left[(\delta-\rho)\eta+(1-\rho)(1-\beta\rho)\right]}$
a_2	$\dfrac{\eta}{\left[(\delta-\gamma)\eta+(1-\gamma)(1-\beta\gamma)\right]}$	b_2	$\dfrac{(1-\beta\gamma)}{\left[(\delta-\gamma)\eta+(1-\gamma)(1-\beta\gamma)\right]}$
a_3	$\dfrac{\eta(1-\mu)}{\left[(\delta-\mu)\eta+(1-\mu)(1-\beta\mu)\right]}$	b_3	$\dfrac{-\eta(\delta-\mu)}{\left[(\delta-\mu)\eta+(1-\mu)(1-\beta\mu)\right]}$

Table 2. Exchange Rate Pass-through

	Baseline	Transitory	Low Price Rigidity
t=1	0.28	0.12	0.89
t=2	0.47	0.41	0.95
t=5	0.76	0.98	0.99
t=10	0.81	1.00	1.00

Table 3A. Dependent Variable: Estimated Pass-through Coefficient (All Countries)

	(1)	(2)	(3)	(4)	(5)	(6)
Inflat	1.68***	1.19***	1.09***	1.54***	1.11***	1.20***
	(0.11)	(0.07)	(0.11)	(0.19)	(0.11)	(0.12)
Inflat sq.	-0.08***	-0.11***	-0.11***	-0.07***	-0.10***	-0.11***
	(0.010)	(0.006)	(0.008)	(0.01)	(0.008)	(0.008)
Ex Rate Depr				1.07	1.47***	2.41***
				(0.83)	(0.46)	(0.71)
Ex. Rate Dep Sq.				-1.02	-2.46***	-3.29***
				(1.27)	(0.71)	(0.85)
St.Dev. Inflat		0.30***	0.30***		0.31***	0.31***
		(0.02)	(0.02)		(0.02)	(0.02)
St. Dev. Ex Rate			0.29			-0.60*
			(0.23)			(0.35)
R^2	0.85	0.95	0.95	0.86	0.96	0.96

Standard errors are given in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels respectively.

Table 3B. Dependent Variable: Estimated Pass-through Coefficient (Significant Coefficients)

	(1)	(2)	(3)	(4)	(5)	(6)
Inflat	2.29***	1.45***	1.19***	3.42***	2.16***	2.16***
	(0.13)	(0.14)	(0.18)	(0.19)	(0.28)	(0.28)
Inflat sq.	-0.16***	-0.13***	-0.12***	-0.24***	-0.17***	-0.17***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Ex Rate Depr				0.48	1.54***	1.68*
				(0.61)	(0.54)	(0.88)
Ex. Rate Dep Sq.				-8.02***	-5.72***	-5.79***
				(0.97)	(0.91)	(1.00)
St.Dev. Inflat		0.26***	0.26***		0.19***	0.19***
		(0.03)	(0.03)		(0.03)	(0.04)
St. Dev. Ex Rate			0.68**			-0.09
			(0.32)			(0.43)
R^2	0.88	0.94	0.94	0.95	0.96	0.96

Standard errors are given in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels respectively.

Figure 1. Impulse Responses to Foreign Interest Rate Shock

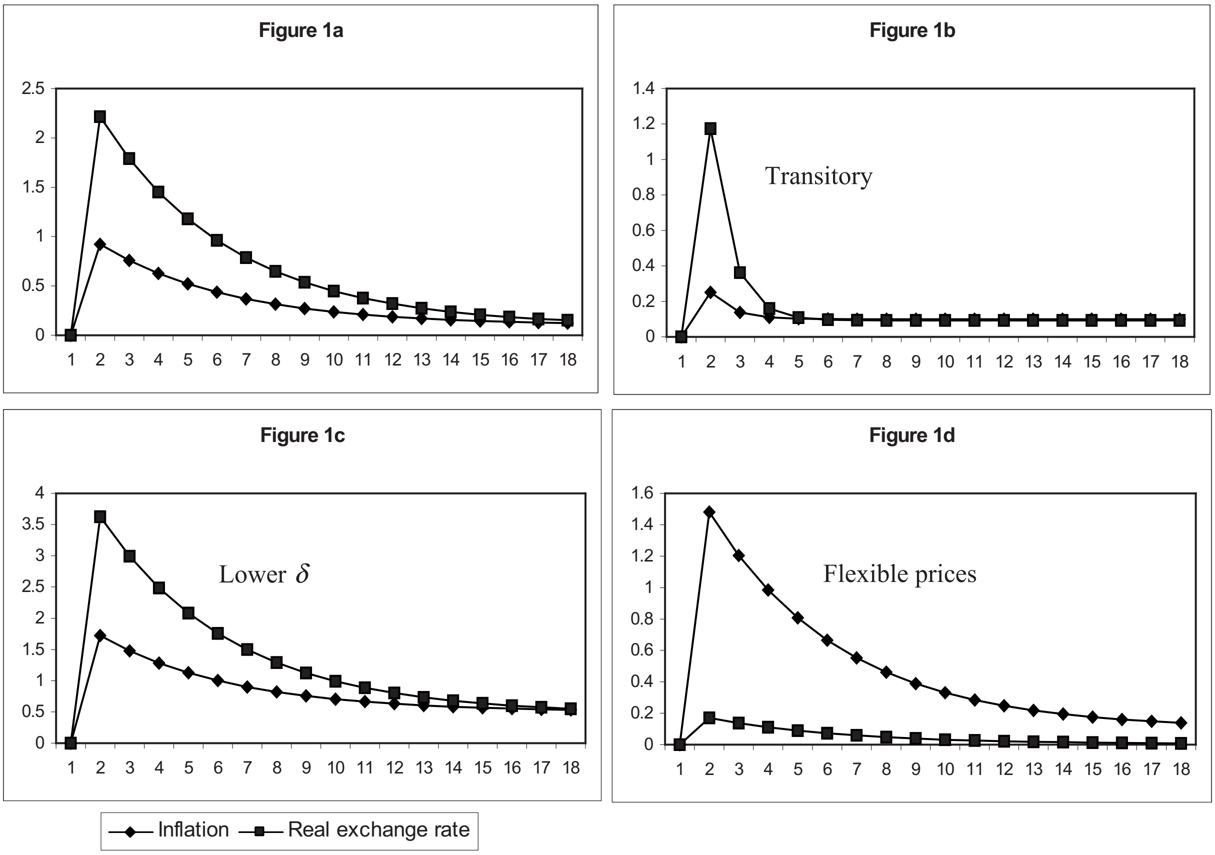


Figure 2. Impulse Responses to a Transactions Technology Shock

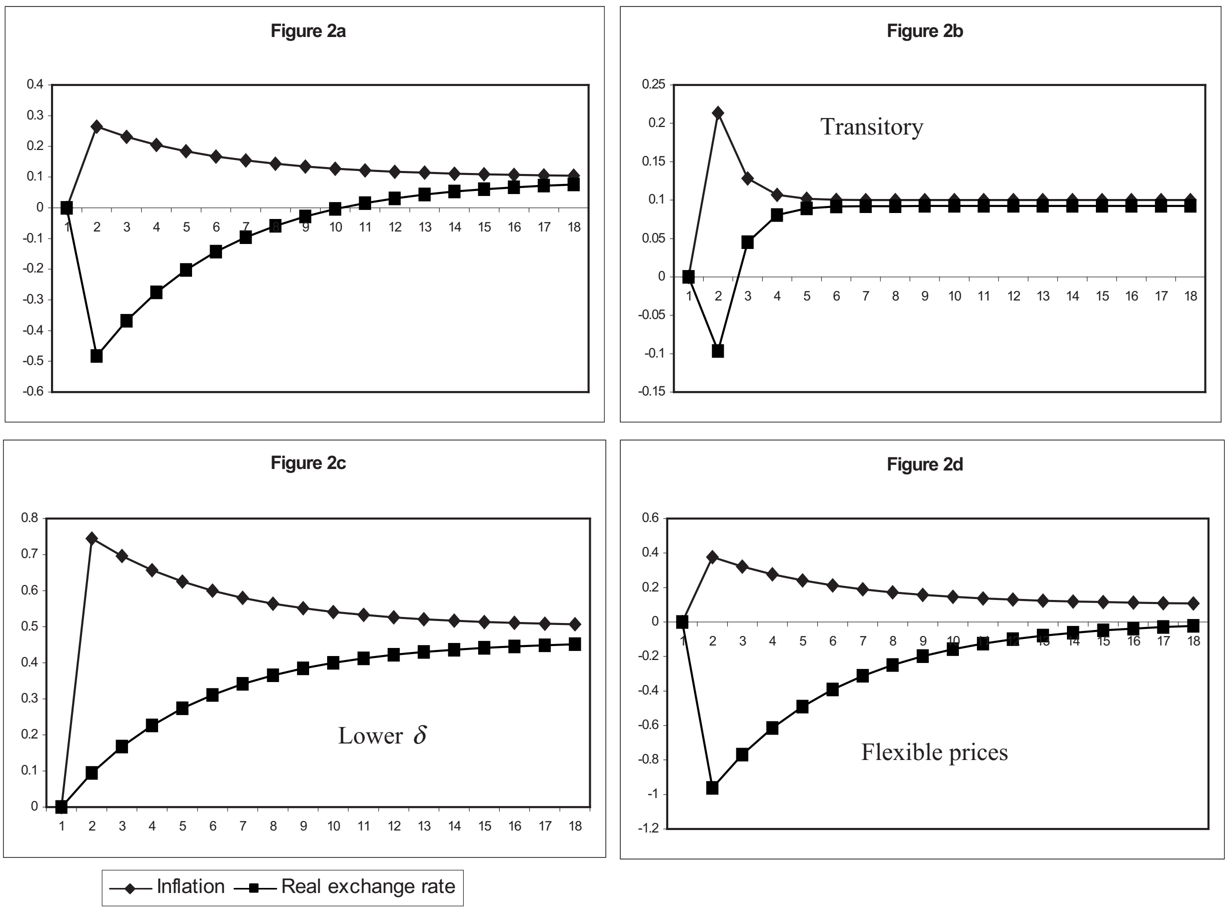


Figure 3. Impulse Responses to Foreign Interest Rate Shock

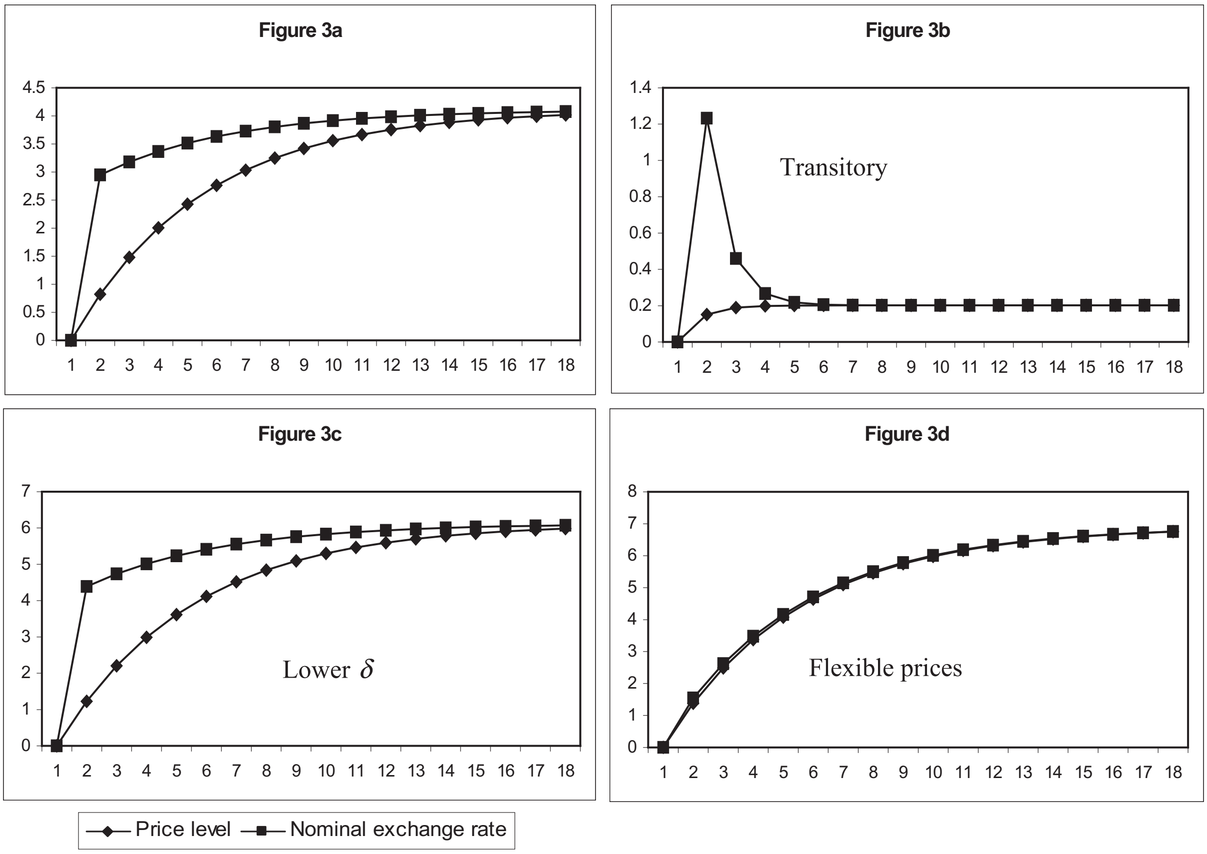


Figure 4. Impulse Responses to a Real Exchange Rate Shock

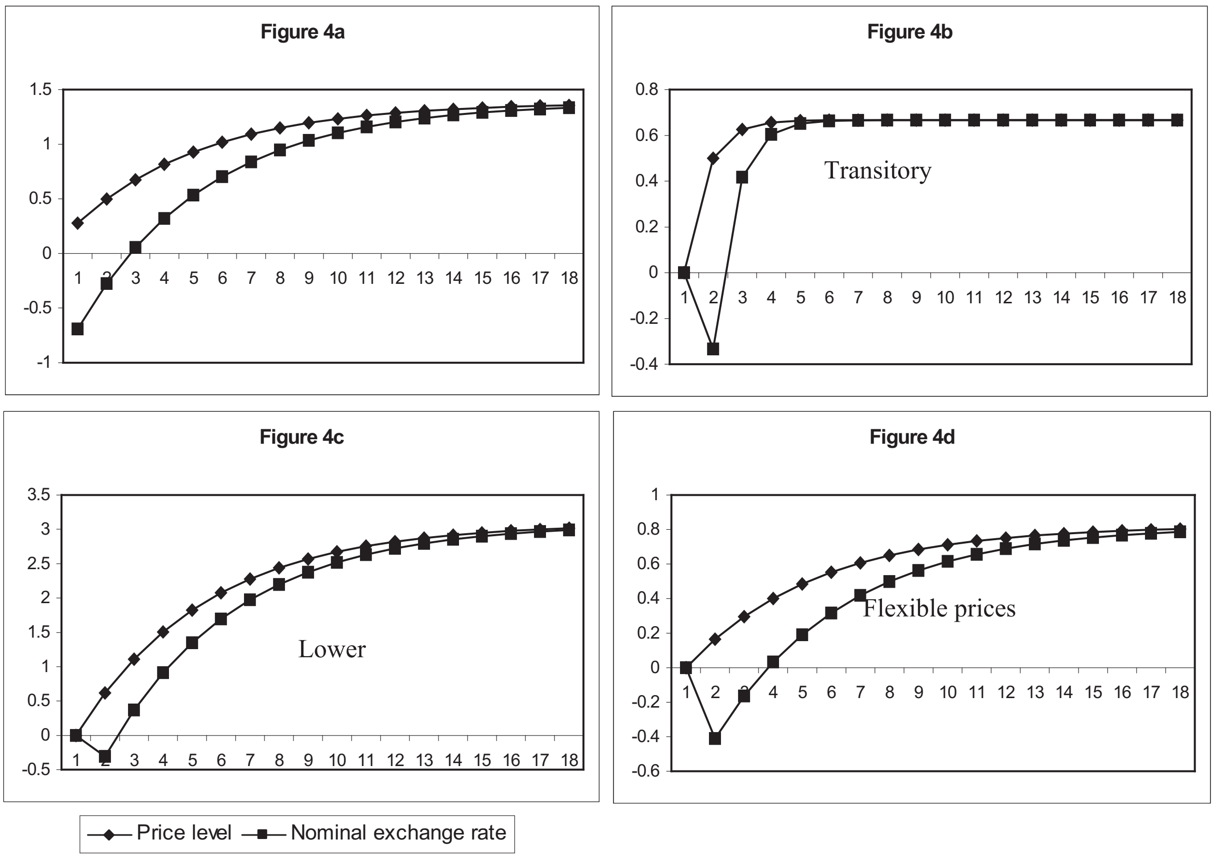


Figure 5. Probability of Not Adjusting Price as A Function of Monetary Policy

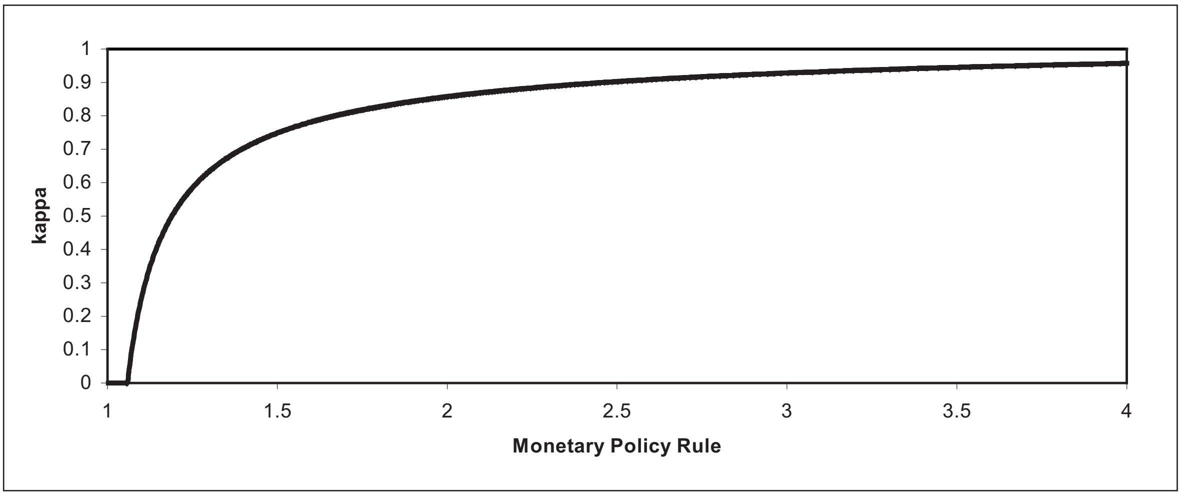


Figure 6. Probability of Not Adjusting Price as A Function of Inflation

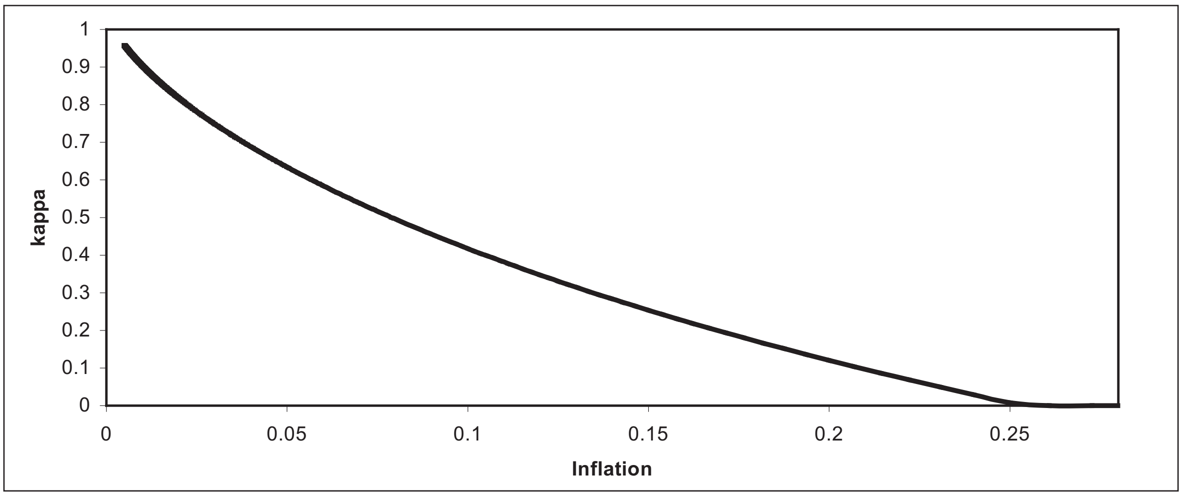


Figure 7. Exchange Rate Pass-through as A Function of Inflation

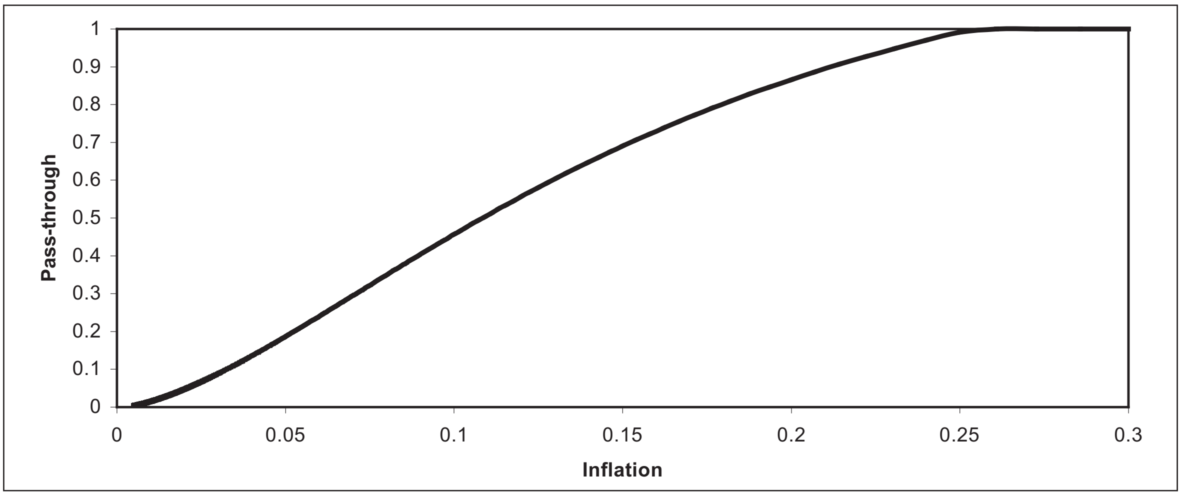


Figure 8. Pass-through (All Countries)

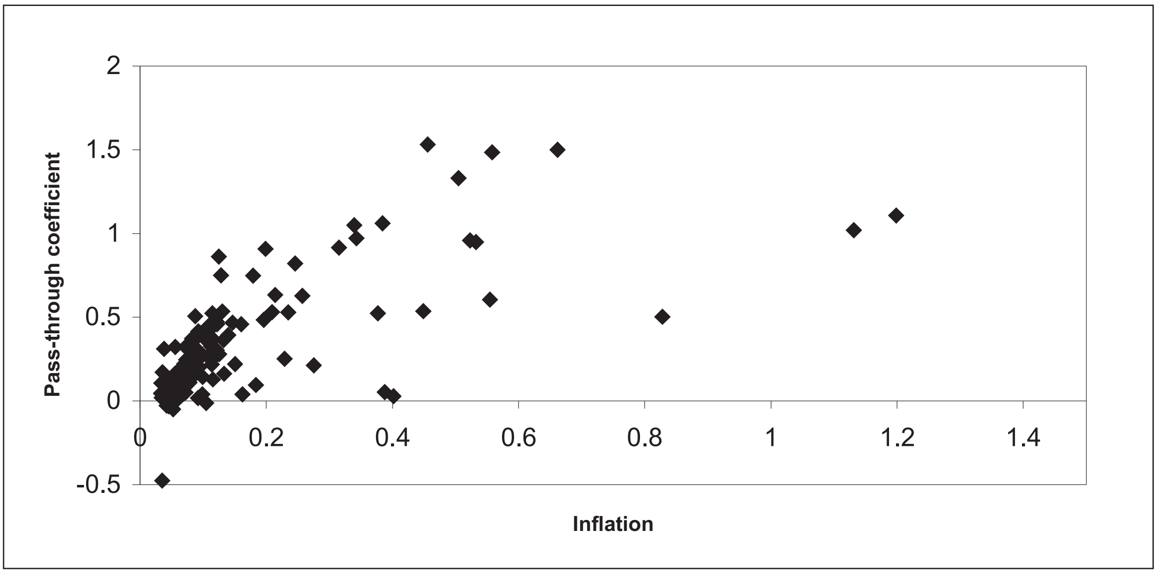
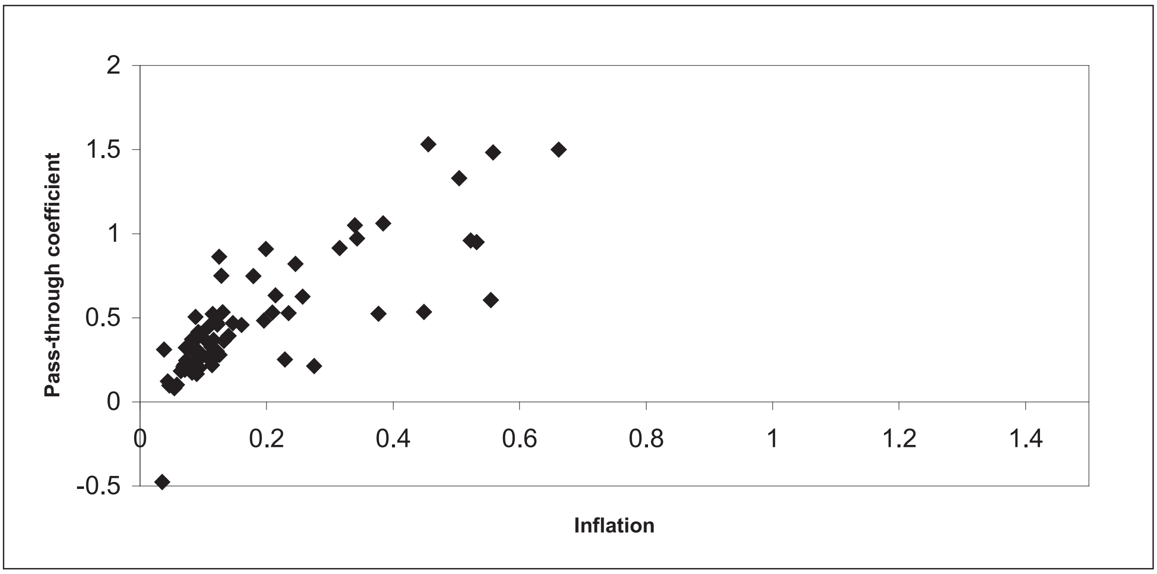


Figure 9. Pass-through (Significant Coefficients)



Appendix 1. Pass-through Coefficients

Country	Obs.	B[1]	Signif.
Algeria	29	0.47	0.000
Angola	11	5.86	0.029
Argentina	25	4.02	0.000
Australia	31	0.10	0.177
Austria	28	0.03	0.339
Bahrain, Kingdom of	11	-1.24	0.038
Bangladesh	15	0.32	0.224
Belgium	28	0.10	0.018
Bhutan	20	0.41	0.003
Bolivia	24	9.22	0.010
Botswana	27	0.27	0.000
Brazil	21	4.82	0.001
Bulgaria	16	1.11	0.233
Burkina Faso	18	0.11	0.199
Burundi	23	0.37	0.025
Cameroon	31	0.14	0.119
Canada	31	-0.05	0.535
Cape Verde	18	0.09	0.314
Central African Rep.	19	0.31	0.001
Chad	18	0.16	0.311
Chile	30	1.50	0.000
China, P.R.: Mainland	13	0.19	0.335
Colombia	31	0.63	0.000
Congo, Dem. Rep. of	22	10.81	0.059
Congo, Republic of	15	0.13	0.397
Costa Rica	26	0.75	0.000
Côte d'Ivoire	31	0.11	0.126
Cyprus	31	0.08	0.041
Denmark	31	0.05	0.188
Dominican Republic	17	0.22	0.071
Ecuador	21	0.92	0.000
Egypt	16	0.13	0.103
El Salvador	11	0.28	0.020
Ethiopia	14	0.04	0.765
Fiji	31	0.05	0.618
Finland	28	0.03	0.592
France	28	0.10	0.004
Gabon	30	0.22	0.036
Gambia, The	30	0.45	0.003
Germany	28	0.05	0.129
Ghana	25	0.05	0.736
Greece	28	0.39	0.000
Guatemala	16	0.30	0.025
Guinea-Bissau	14	0.52	0.035
Haiti	11	0.75	0.000
Honduras	12	0.52	0.000
Hungary	29	0.86	0.000
Iceland	30	0.53	0.000
India	31	0.36	0.011
Indonesia	26	0.16	0.075
Iran, I.R. of	28	0.09	0.054
Ireland	28	0.19	0.004
Israel	31	1.48	0.000
Italy	28	0.17	0.001
Jamaica	26	0.48	0.001
Japan	30	0.05	0.422
Jordan	24	0.25	0.009
Kenya	29	0.53	0.000
Korea	27	0.02	0.783
Kuwait	29	-0.03	0.842
Lao People's Dem. Rep	13	0.97	0.002

Country	Obs.	B[1]	Signif.
Lebanon	24	1.33	0.002
Lesotho	24	0.30	0.002
Luxembourg	28	0.12	0.002
Madagascar	31	0.47	0.000
Malawi	20	0.82	0.000
Malaysia	29	-0.03	0.669
Maldives	12	0.42	0.138
Mali	13	0.17	0.123
Malta	31	0.06	0.305
Mauritania	16	0.04	0.606
Mauritius	31	0.04	0.684
Mexico	26	1.05	0.000
Morocco	31	0.18	0.002
Mozambique	13	0.03	0.848
Myanmar	31	0.04	0.927
Namibia	21	0.22	0.001
Nepal	27	0.51	0.000
Netherlands	28	0.05	0.198
New Zealand	31	0.17	0.031
Nicaragua	18	7.14	0.005
Niger	31	0.16	0.130
Nigeria	29	0.25	0.044
Norway	31	0.07	0.289
Pakistan	23	0.30	0.000
Papua New Guinea	30	0.31	0.001
Paraguay	17	0.46	0.000
Peru	27	8.63	0.000
Philippines	31	0.46	0.001
Poland	26	1.53	0.001
Portugal	28	0.36	0.000
Romania	11	1.02	0.074
Rwanda	22	0.40	0.002
Samoa	31	0.24	0.027
Saudi Arabia	17	-1.77	0.003
Senegal	31	0.21	0.021
Seychelles	31	0.32	0.038
Sierra Leone	31	1.06	0.000
Singapore	31	-0.48	0.006
Slovenia	10	0.21	0.000
Solomon Islands	28	0.36	0.002
South Africa	29	0.33	0.000
Spain	28	0.20	0.002
Sri Lanka	31	-0.01	0.922
Sudan	20	0.54	0.001
Swaziland	29	0.26	0.001
Sweden	31	0.05	0.252
Switzerland	31	0.02	0.601
Tanzania	29	0.53	0.000
Thailand	27	0.03	0.702
Togo	31	0.19	0.049
Tonga	26	0.37	0.008
Trinidad and Tobago	19	0.14	0.064
Tunisia	18	-0.01	0.926
Turkey	30	0.96	0.000
Uganda	21	0.61	0.044
United Kingdom	31	0.11	0.080
Uruguay	30	0.95	0.000
Vanuatu	25	0.04	0.785
Venezuela, Rep. Bol.	24	0.63	0.001
Zambia	12	0.50	0.196
Zimbabwe	31	0.91	0.000