Price-Setting and Exchange Rate Pass-Through: Theory and Evidence

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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, 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 countries, has 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 indexes, has been extensively documented.[1]

A debate on the causes of low exchange rate pass-through has recently 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

1. See, for instance, Engel (2002b).

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between goods in response to exchange rate changes (Burstein, Eichenbaum, and Rebelo 2002). Others argue, however, that the failure of pass-through is more of a macroeconomic phenomenon, related to the slow adjustment of goods prices at the consumer level (Engel 2002 a, b). 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 they ultimately come down on the side of a microeconomic explanation, based on the changing composition of import goods.

Whether the behaviour 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 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 empirical approach closely follows 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 because of the presence of "menu costs." Modelling 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. Exchange rate pass-through is determined by the types of shocks in the economy, and their persistence. But with a constant frequency of price changes, pass-through is independent of monetary policy.

We go on to allow firms to determine the frequency with which prices change. This frequency is chosen as a result of the trade-off between the menu costs of price change and the loss from being away from the optimal desired price. In general, the optimal frequency of price changes 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 the average rate of inflation, the more volatile the nominal exchange rate; and the higher the frequency of price changes, the greater the 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 that case, the pass-through from exchange rate changes to prices is complete.

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, that aggregate pass-through is very high, and in many cases statistically indistinguishable from unity. 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.

The rest of the paper is arranged as follows. Section 1 documents the price-setting problem facing a single firm. Section 2 integrates this into a model of exchange rate determination. Section 3 investigates the determinants of exchange rate pass-through within the model. Section 4 allows for an endogenous frequency of price adjustment. Section 5 presents the empirical results, and the final section concludes.

1 The Importing Firm

In this section, we derive the optimal pricing policy for a firm, given an exogenous frequency of price-setting. This essentially follows the Calvo (1983) model, save for the fact that the firm is an importer rather than a producer. Consider a set of domestic firms that import a consumer good from abroad and sell it to local consumers. Each firm has marginal costs of P_t^* in terms of foreign currency. Suppose that each individual firm, i, selling to the domestic market faces demand given by

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

where $P_t(i)$ is the firm's price, and P_t is the composite price index for foreign goods sold on the domestic market (this demand function will be derived from the domestic country's utility maximization—see below). The firm's profit at any period t is then given by

$$\Pi_t(i) = P_t(i)C_t(i) - S_t P_t^* C_t(i).$$

Here, S_t is the exchange rate. 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 equal to the desired price, $\hat{P}_t(i)$, given by

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

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 of κ that the firm's price will remain unchanged, *no matter how long* it has been fixed. In section 4, 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 papers (e.g., Walsh 1998), the intertemporal 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 a *loss function*, given by

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

where lower-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, including the menu cost of price change, F.[2] The total loss, L_t, comprises the immediate loss of F, interpreted as the share of average profits going to price adjustment, 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

2. In this section, the menu cost is irrelevant to the firm's decision-making. But when κ is endogenous, the menu cost becomes critical.

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

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

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

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, 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 equation (1) gives the newly set price as a function not just of the current exchange rate but of 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 holding p_t^* constant, changes in exchange rates have one-for-one effects on the domestic price level.[3]

We may combine equations (1) and (2) to derive an inflation equation for imported goods prices,

$$\pi_t = \eta(\hat{\lambda} + q_t) + \beta E_t \pi_{t+1}, \tag{3}$$

where $\pi_t = p_t - p_{t-1}$ is the imported goods 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.[4] Imported goods inflation will be higher when the real exchange rate is higher than its flexible-price equilibrium level, given by $-\hat{\lambda}$. 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 fundamental falls.

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3. We will show that, 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.
4. As applied to exchange rate pass-through, see Devereux (2001) and Monacelli (2001).

2 Determination of the Exchange Rate

The previous section derived a relationship between the inflation rate in imported goods and the current and expected future exchange rate (equation (3)). We now derive a separate condition that will combine with equation (3) to jointly determine both the exchange rate and the inflation rate of imported goods. The underlying assumption behind the model is that the economy is so small and open that its total consumption basket consists of imported goods.[5] Hence, the inflation rate of imported goods is the same as CPI inflation. Then, we may assume that the monetary rule used by the central bank takes the form

$$i_t = \phi + \delta\pi_t + u_t, \tag{4}$$

where i_t is the nominal interest rate, and the parameter δ captures the stance of monetary policy. Based on the principle of the Taylor rule, we assume that $\delta \geq 1$, so that the monetary authority follows a policy of increasing the ex post real interest rate in response to a rise in current inflation. A lower value for δ indicates a "looser" monetary policy. The parameter ϕ measures the target nominal interest rate set by the monetary rule. When $\phi > 0$, the authorities attempt to keep the interest rate systematically low. Finally, u_t is a random shock to the interest rate, representing uncertainty in the monetary rule. This could capture uncertainty about the type or preferences of the monetary authority.

The second condition that we use is the familiar relationship of uncovered-interest-rate parity (UIRP), given by

$$i_t = i_t^* + E_t s_{t+1} - s_t. \tag{5}$$

This will hold (up to a linear approximation) in any environment where asset-holders in the home economy have access to an internationally traded, foreign-currency-denominated bond.

Now, combining equations (4) and (5) gives

$$\phi + \delta\pi_t + u_t = r_t^* + E_t q_{t+1} - q_t + E_t \pi_{t+1}, \tag{6}$$

where $r_t^* = i_t^* - E_t(p_{t+1}^* - p_t)$ is the exogenous foreign real interest rate. Equation (6) implies equality between the nominal interest rate rule followed by the monetary authority, and the UIRP-determined nominal

5. In particular, there are no non-traded goods.

interest rate facing domestic agents. It gives a relationship between the inflation rate and the current and expected future real exchange rate.

Equations (3) and (6) form a simple dynamic system in domestic inflation and the real exchange rate. To solve these equations, we must be more specific about the shock processes. For the purposes of this paper, we focus exclusively on domestic monetary shocks.[6] Assume that the monetary shock is governed by the following process:

$$u_t = \rho u_{t-1} + \varepsilon_t,$$

where $0 \le \gamma \le 1$, and ε_t is an i.i.d., mean-zero disturbance. Using these assumptions, it is easy to establish that the solutions for inflation and the real exchange rate are as follows:

$$\pi_t = \frac{(r^* - \phi)}{(\delta - 1)} - a u_t, \tag{7}$$

$$q_t = \frac{(r^* - \phi)(1 - \beta)}{\eta(\delta - 1)} - \hat{\lambda} - b u_t, \tag{8}$$

where $a = \frac{\eta}{[(\delta - \rho)\eta + (1 - \rho)(1 - \beta\rho)]}$,

and $b = \frac{(1 - \beta\rho)}{[(\delta - \rho)\eta + (1 - \rho)(1 - \beta\rho)]}$.

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, i.e., if $r - \phi > 0$, then steady-state inflation is positive. The steady-state real exchange rate is then determined by the steady-state inflation rate, and the steady-state price markup on imported goods. 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, $r^* - \phi$, a "tighter" monetary policy (a higher δ) implies a lower mean inflation rate. While the monopoly markup $\hat{\lambda}$ affects the steady-state real exchange rate, it has no implications for the average inflation rate.

An expansionary money shock (which is equivalent to a fall in u_t) 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 the shock, but lower the higher the interest rate elasticity of the monetary rule.

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6. In particular, we assume that the foreign real interest rate is constant.

Figure 1 illustrates some of the dynamic properties of the model's response to a money shock.[7] Three parameters are important in the analysis. First, the monetary policy stance δ affects the scale of the response of π and q, but it does not affect the *relative* response of the two variables. A tighter monetary rule (a higher δ) reduces the response of both inflation and the real exchange rate to a monetary shock, but the response of both variables falls by the same proportion.

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, since when prices are more sticky, it takes longer for the price level to adjust to a shock. 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.

3 Exchange Rate Pass-Through

We now focus on the main issue of interest. How do nominal exchange rate changes pass through into changes in the domestic price level? In our framework, the failure of immediate pass-through can be solely ascribed to the presence of slow price adjustment. Since our focus is on domestic monetary policy shocks alone, if prices could adjust instantaneously, the real exchange rate would be constant, and the law of one price would hold continuously. The main objective of the investigation here is to isolate the structural determinants of low pass-through resulting from slow price adjustment.

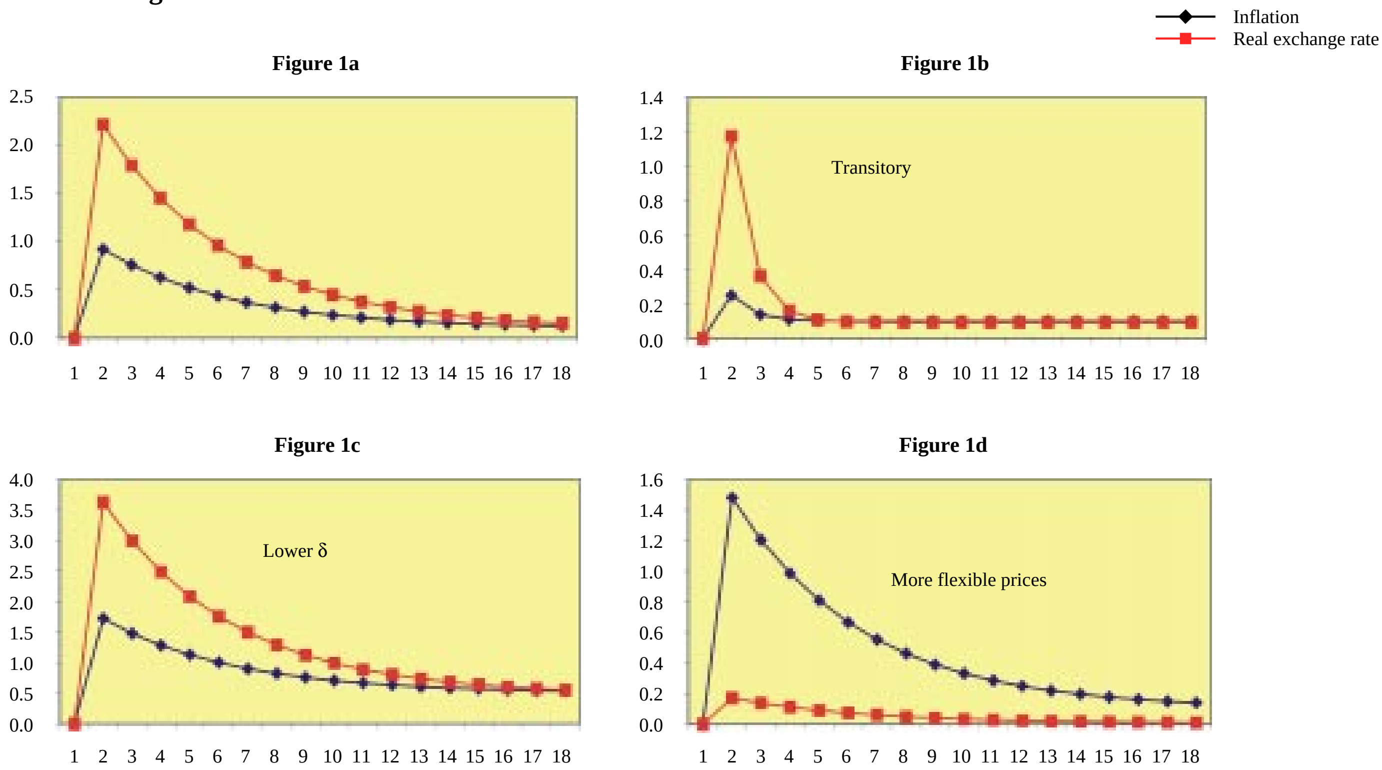
Pass-through is defined as a relationship between the nominal exchange rate and the domestic price level. From the inflation equation (6), we can write the domestic price level as

$$p_t = \frac{(r^* - \phi)}{(\delta - 1)} - au_t + p_{t-1}.$$

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

7. The parameter values used in the figure are outlined in section 4.

Figure 1
Real exchange rate and inflation



$$s_t = \frac{\phi}{(\delta - 1)} + (b + a)u_t - bu_{t-1} + s_{t-1}.$$

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. We see that the exchange rate will always respond by more than the domestic price level in the short run, since such shocks cause an immediate real depreciation as well as domestic inflation. Thus, generically, short-run pass-through is incomplete in this economy. But, since the real exchange rate converges back to its equilibrium, the subsequent rise in the nominal exchange rate is slower than the rise in the price level.

Figure 2 describes the response of the nominal exchange rate and the price level following a monetary policy shock. 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.

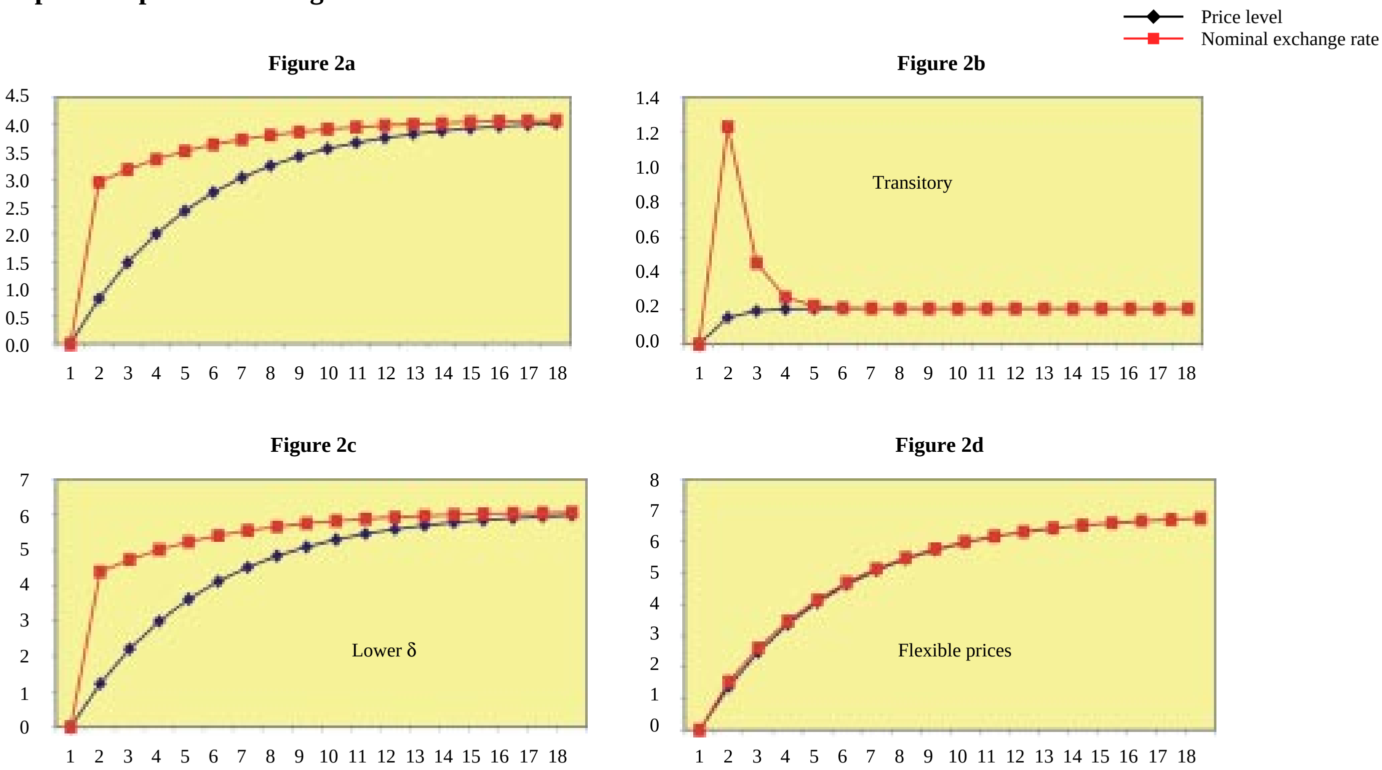
How does monetary policy affect pass-through? The answer is that, for given values of κ and given persistence, monetary policy has no effect. A tighter monetary policy (higher δ) reduces both the price and the exchange rate response to the shock, but the relative price to exchange rate response is unchanged. 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 $a/(a+b) = \eta/(\eta + (1 - \beta\rho))$. Therefore, for given η, this is independent of the monetary rule. However, as we will see, when we allow the frequency of price adjustment to be determined endogenously, the monetary rule may have a substantial impact on pass-through.

Table 1 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.

Figure 2
Impulse responses to foreign interest rate shock



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.

Table 1
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

4 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 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 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. But the higher the inflation *variance*, the higher will be the expected losses from having prices preset for long periods of time. Finally, the higher the variance of the nominal exchange rate, the more variable 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 i) higher average inflation and higher volatility of inflation, and ii) 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 inflation and 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. From this point on, to maintain tractability, we assume u_t shocks are i.i.d. Then we may write the process for the price level and the exchange rate as

$$p_t = \frac{(r^* - \phi)}{(\delta - 1)} - \frac{\eta}{\delta\eta + 1}u_t + p_{t-1}$$

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

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 inflation is

$$\sigma_\pi^2 = \left(\frac{\eta}{\delta\eta + 1}\right)\sigma_u^2,$$

and the variance of exchange rate changes is given by

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

Both σ_π^2 and $\sigma_{\Delta s}^2$ are decreasing in δ. Hence, when we take the perspective that κ is endogenously determined on a country-by-country basis, we may anticipate that it will be systematically related to the monetary policy followed by each country.

We may illustrate the solution for the optimal κ for each firm. Ignoring the constant markup, the firm has a desired price each period given by the exchange rate

$$\hat{P}_{t+j}(i) = \left\{ \begin{array}{c} s_t,\ j = 0 \\ s_t + j\mu + \dfrac{(1+\eta)u_{t+j}}{\delta\eta + 1} + \dfrac{\eta}{\delta\eta + 1}\displaystyle\sum_{i=1}^{j-1} u_{t+i} - \dfrac{u_t}{\delta\eta + 1},\ \forall j > 0 \end{array} \right\}.$$

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

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

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

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

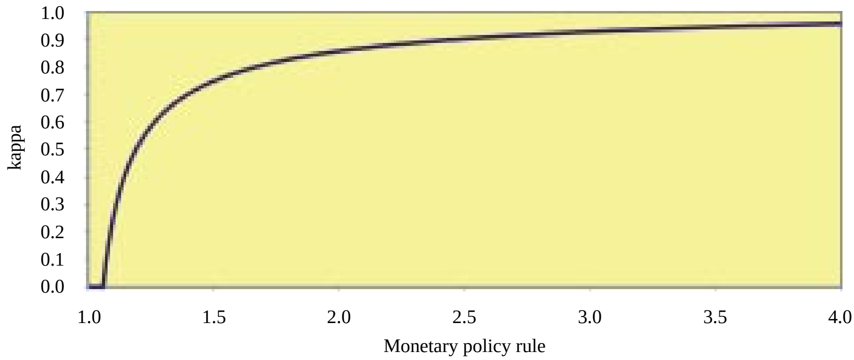
The individual firm chooses its pricing frequency κ to minimize this stationary loss function, taking the κ's of all other firms as given. This means that it takes the stochastic process for the exchange rate, and therefore the values of μ and η, as given, when choosing κ. A Nash equilibrium is defined 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 3 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

Figure 3
Probability of not adjusting price as a function of monetary policy



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

Finally, Figure 5 gives the exchange rate pass-through estimates implied by the model as a function of the monetary policy rule.[8] 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 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. In a broad sense, 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

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

Figure 4
Probability of not adjusting price as a function of inflation

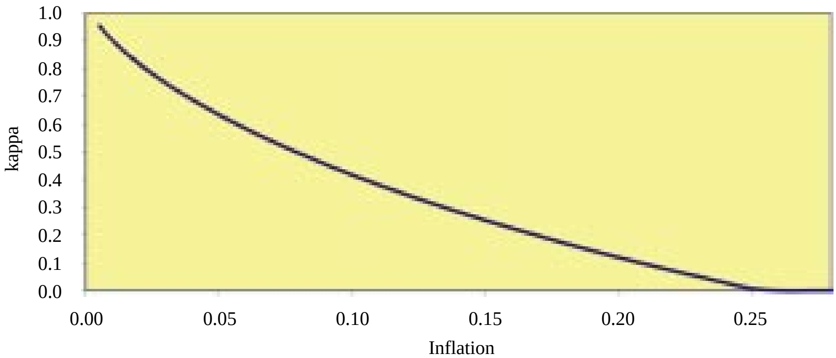
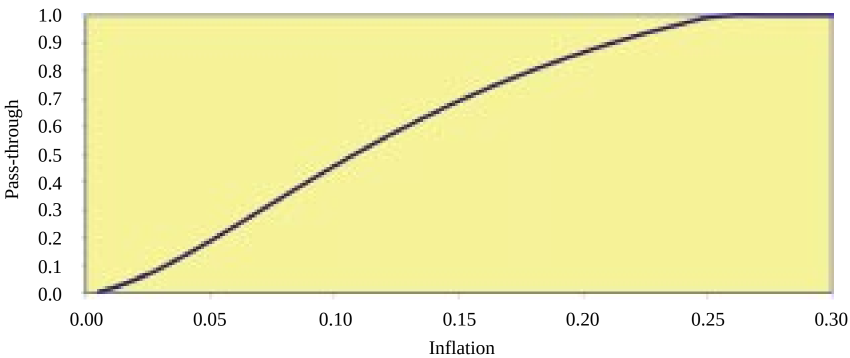


Figure 5
Exchange rate pass-through as a function of inflation



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'd 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, since all prices are adjusted continually and 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

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

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.[9] Data are annual, to smooth out high-frequency fluctuations in the exchange rate, and they are taken from the IMF International Financial Statistics.[10]

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.[11] 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 the Appendix) are quite sensible, in most cases lying between zero and one. Figures 6 and 7 contain scatter plots of the β_1 estimates against the mean inflation rate for each country. Figure 6 contains the estimates for all countries (excluding a few outliers), while Figure 7 contains only those countries for which β_1 was significant at the 5 per cent level.

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

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

10. The IFS codes are ..RF.ZF… and 64..XZF… for the exchange rate and the inflation rate, respectively. 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.

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

Figure 6
Pass-through (all countries)

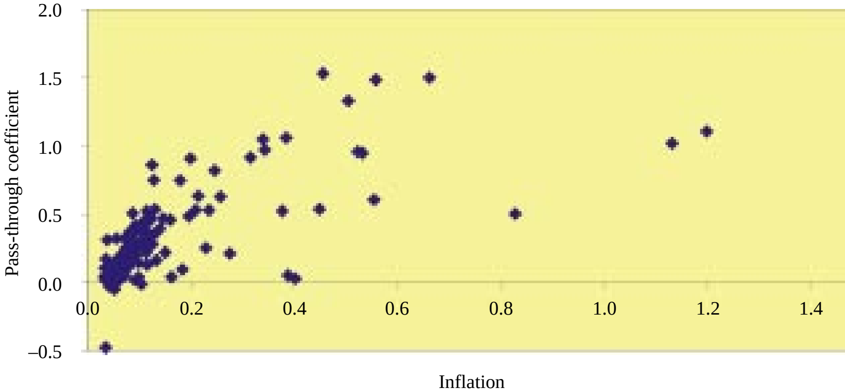
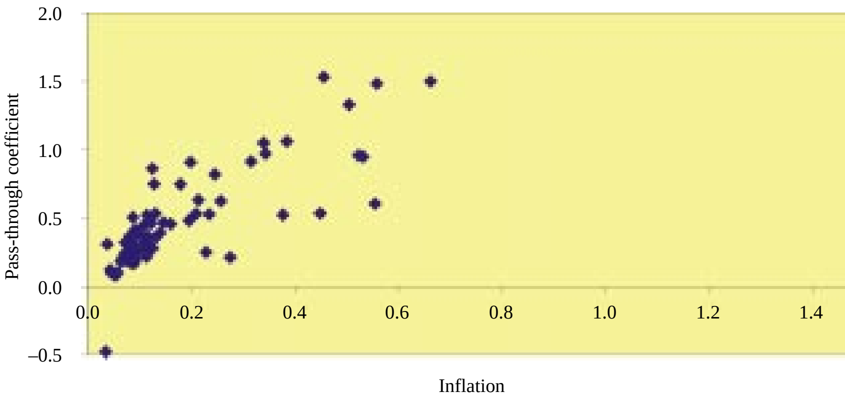


Figure 7
Pass-through (significant coefficients)



$$\hat{\beta}_{1j} = a_1\pi_j + a_2\pi_j^2 + a_3\text{var}(\Delta S_j),$$

where π is the mean inflation rate for country j and $\text{var}(\Delta S_j)$ is the variance of the exchange rate change vis-à-vis the U.S. dollar.[12]

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

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

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 2 contains the results of all 122 countries in the sample. First, there is strong evidence that mean inflation tends to increase the rate of exchange rate pass-through,[13] 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 when 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 increase the degree of 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 per cent level. The results are displayed in Table 3, and are very similar to those outlined in Table 2, clearly demonstrating the explanatory power of both the level and volatility of inflation and exchange rate depreciation for exchange rate pass-through.[14]

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.

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

14. 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.

Table 2
Dependent variable:
Estimated pass-through coefficient (all countries)

	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	1.68***	1.19***	1.09***	1.54***	1.11***	1.20***
	(0.11)	(0.07)	(0.11)	(0.19)	(0.11)	(0.12)
Inflation squared	–0.08***	–0.11***	–0.11***	–0.07***	–0.10***	–0.11***
	(0.010)	(0.006)	(0.008)	(0.01)	(0.008)	(0.008)
Exchange rate				1.07	1.47***	2.41***
depreciation				(0.83)	(0.46)	(0.71)
Exchange rate				–1.02	–2.46***	–3.29***
depreciation squared				(1.27)	(0.71)	(0.85)
Standard deviation		0.30***	0.30***		0.31***	0.31***
inflation		(0.02)	(0.02)		(0.02)	(0.02)
Standard deviation			0.29			–0.60*
exchange rate			(0.23)			(0.35)
R^2	0.85	0.95	0.95	0.86	0.96	0.96

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

Table 3
Dependent variable:
Estimated pass-through coefficient (significant coefficients)

	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	2.29***	1.45***	1.19***	3.42***	2.16***	2.16***
	(0.13)	(0.14)	(0.18)	(0.19)	(0.28)	(0.28)
Inflation squared	–0.16***	–0.13***	–0.12***	–0.24***	–0.17***	–0.17***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Exchange rate				0.48	1.54***	1.68*
depreciation				(0.61)	(0.54)	(0.88)
Exchange rate				–8.02***	–5.72***	–5.79***
depreciation squared				(0.97)	(0.91)	(1.00)
Standard deviation		0.26***	0.26***		0.19***	0.19***
inflation		(0.03)	(0.03)		(0.03)	(0.04)
Standard deviation			0.68**			–0.09
exchange rate			(0.32)			(0.43)
R^2	0.88	0.94	0.94	0.95	0.96	0.96

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

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, sticky prices. Second, the rate of pass-through is sensitive to the monetary policy regime, precisely because the degree of price stickiness 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.

Appendix
Pass-Through Coefficients

Table A1

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
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

(continued)

Table A1 (continued)

Country	**Obs.**	**B_1**	**Signif.**	**Country**	**Obs.**	**B_1**	**Signif.**
Haiti	11	0.75	0.000	Swaziland	29	0.26	0.001
Honduras	12	0.52	0.000	Sweden	31	0.05	0.252
Hungary	29	0.86	0.000	Switzerland	31	0.02	0.601
Iceland	30	0.53	0.000	Tanzania	29	0.53	0.000
India	31	0.36	0.011	Thailand	27	0.03	0.702
Indonesia	26	0.16	0.075	Togo	31	0.19	0.049
Iran, Islamic Rep. of	28	0.09	0.054	Tongo	26	0.37	0.008
Ireland	28	0.19	0.004	Trinidad and Tobago	19	0.14	0.064
Israel	31	1.48	0.000	Tunisia	18	–0.01	0.926
Italy	28	0.17	0.001	Turkey	30	0.96	0.000
Jamaica	26	0.48	0.001	Uganda	21	0.61	0.044
Japan	30	0.05	0.422	United Kingdom	31	0.11	0.080
Jordan	24	0.25	0.009	Uruguay	30	0.95	0.000
Kenya	29	0.53	0.000	Vanuatu	25	0.04	0.785
Korea	27	0.02	0.783	Venezuela	24	0.63	0.001
Kuwait	29	–0.03	0.842	Zambia	12	0.50	0.196
Lao People's Dem. Rep.	13	0.97	0.002	Zimbabwe	31	0.91	0.000

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