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Relative Price Changes And Exchange Rate Determination With Slow Price Adjustment: An Empirical Analysis

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Relative Price Changes and Exchange Rate Determination with Slow Price Adjustment: An Empirical Analysis*

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I. Introduction

The general purpose of this paper is to analyze empirically sectoral price adjustment in the exchange rate adjustment process. Relative price changes may occur within a sector between countries, and within a country between sectors. Our main objective is to test the hypothesis that both kinds of relative price changes occur in the adjustment process to disturbances in money demand and supply. In particular, we expect that the relative prices among goods of different “tradedness”—ranging from perfectly traded to non-traded goods—are affected by such disturbances.

Our second objective is to test empirically whether the nature of exchange rate adjustment is affected by the average speed of sectoral price adjustment towards the “law of one price,” and whether the exchange rate “overshoots” purchasing power parity after monetary disturbances.

We build on a model developed by Dornbusch [6] and extended by Mussa [17]. They argue that the exchange rate may overshoot its purchasing power parity level after monetary disturbances as a result of slow price adjustment in the market for domestically produced goods. The price of imported goods follows the “law of one price.” We modify the Dornbusch-Mussa model to distinguish between domestically produced goods for which the “law of one price” may hold to different degrees.

Relative price changes in the adjustment process to monetary disturbances have gained

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attention in much of the theoretical literature on flexible exchange rate adjustment.¹ Kouri [14], Branson [3], Dornbusch and Fischer [7], and Stockman [20] have developed different models in which a relative price is correlated with the exchange rate. These models have in common that the terms of trade between two traded commodities are related to the exchange rate while the “law of one price” holds for both commodities. The substantial observed deviations from purchasing power parity on a quarterly and even a yearly basis can hardly be explained under the restriction that the law of one price holds, however. For empirical purposes, it seems therefore desirable to build on a model within which deviations from the “law of one price” may occur. The Dornbusch-Mussa model has this property. It is also well-accepted in the literature on monetary policy under flexible exchange rates and seems to be able to explain a number of “stylized facts” about exchange rate adjustment (see, for example, Engel and Flood, [9], and Buiter and Miller, [4]).

Empirical testing of the slow price adjustment model has been performed by Frankel [10] and Driskill [8]. These tests are indirect since they determine whether the behavior of real interest rates and the exchange rate are consistent with the predicted behavior in the Dornbusch model. Other models, such as Branson’s [3], incorporating imperfect substitutability between assets of different currency denomination and deviations from purchasing power parity for reasons other than differential adjustment speeds in goods markets, would explain the same pattern of exchange rate and interest rate behavior, however. It is therefore desirable to test the slow price adjustment model directly by estimating sectoral price adjustment behavior and thereafter test whether the adjustment coefficients contribute to the explanation of actual exchange rate behavior. These are the objectives of this paper.

In section II we restate the Dornbusch-Mussa model of exchange rate adjustment for a small country with two goods in a modified form. We assume that there are two sectors: a traded-good and a non-traded good sector. To test the model empirically, three extensions are necessary. First, real and monetary factors in *two countries* are taken into account to determine one exchange rate. Second, the *degree of tradedness* is not constrained to be “perfectly traded” or “perfectly non-traded,” and third, *more than two sectors* are explicitly included in the model. These extensions are explained in section III.

In section IV the sectoral price adjustment equations are estimated. Thereafter, we use the adjustment coefficients to derive what exchange rate changes would have been over the estimation period if the model contained all explanatory factors. Then we regress the actual exchange rate changes against these derived changes.

II. Determination of the Exchange Rate in a Small Country with Two Goods

The two-good model presented in this section is similar to Mussa’s extension [17] of the Dornbusch model in important respects. Overshooting of the exchange rate in response to monetary disturbances results from slow adjustment of the price level for domestically pro-

1. There is also a large literature on the relationship between the variance of relative prices and the rate of inflation in a country. (Cukierman and Wachtel [5], Hercowitz [13], Park [18], and Vining and Elwertowski [21].) The results of our paper have bearing on the issue raised in these papers, but our theoretical framework is different. Relative price changes after monetary disturbances can be caused only by exchange rate changes in our framework, while the papers referred to are testing implications of an island model such as Barro [1] for the relationship between inflation and relative prices.

duced goods in these models, while we assume that the price of non-traded goods relative to traded goods adjusts slowly. The price of traded goods obeys “the law of one price.” As Dornbusch and Mussa, we assume that asset markets adjust instantaneously and that the interest rate differential is equal to the expected rate of change of the exchange rate.

The price level (p in log form) is determined in the instantaneously adjusting money market. The money supply (m in log-form) is exogenous and determines the price-level at a certain interest rate and real national output (y in log form). Money market equilibrium is given by

$$m = p - \alpha r + \gamma y, \quad (1)$$

where r is the log of $(1 + \text{the nominal rate of interest})$. (Lower case letters denote log form in the following. A time subscript t is suppressed in equations in which all variables refer to the same period.)

Real national output is considered exogenous and determined by equilibrium in factor markets. Output consists in our model of traded and non-traded goods.

The nominal rate of interest is equal to the exogenous foreign rate of interest adjusted for the expected rate of change of the exchange rate. In other words, assets of different currency denomination are considered perfect substitutes and transactions costs are negligible. The following relationships in log form holds at all times:

$$r = r^F + (e_{t+1}^* - e_t) \quad (2a)$$

where

- r^F = log of $1 + \text{the foreign interest rate}$;
- e_{t+1}^* = the log of the anticipated exchange rate in period $t + 1$;
- e_t = the log of the exchange rate in period t (units of domestic currency per unit of foreign currency).

Equation (2a) implies if covered interest rate parity holds that the forward rate is an unbiased estimate of the expected future spot rate. Under this assumption it follows that:

$$e_{t+1}^* = f_{t+1,t} \quad (2b)$$

where $f_{t+1,t}$ = the log of the forward rate as of period t for $t+1$.

We turn now to the composition of the price level and the determination of the relative price between traded and non-traded goods. The price level is defined as

$$p \equiv \delta p_1 + (1-\delta)p_2 \quad (3)$$

where

- p_1 = the log of the domestic currency price of traded goods and
- p_2 = the log of the price of non-traded goods
- δ = the constant share of traded goods in the real value of total output.

The price of traded goods is determined by the “law of one price” in a perfectly competitive world market;

$$p_1 = p_1^F + e \quad (4)$$

where p_1^F is the exogenous foreign currency price of traded goods.

The price of non-traded goods (p_2) is determined in a domestic market. There is a long run *equilibrium* price \bar{p}_2 , toward which the actual price, p_2 , is assumed to adjust slowly

under certain conditions. The following expression defines how the price of non-traded goods adjusts from period t to period $t + 1$:

$$p_{2,t+1} - p_{2,t} = (p_{t+1}^* - p_t) + K(\bar{p}_{2,t} - p_{2,t}), \quad K \leq 1 \quad (5)$$

where an asterisk (*) denotes an anticipated price and a bar (-) denotes a long-run equilibrium price. Equation (5) states that there are two components to the change in the price of non-traded goods. First, the price adjusts *fully* to anticipated inflation ($p_{t+1}^* - p_t$). Second, the price adjusts with a fraction (K) of its deviation from long-run equilibrium in period t .

The price adjustment specified in equation (5) implies that the price of non-traded goods adjusts slowly only to the extent that a relative price change is required to restore long-run equilibrium. The adjustment equation (5) has the same properties as one for domestically produced goods in Mussa [17]. The first term keeps the price from diverging from its long-run equilibrium path in the absence of relative price disturbances and the second term reflects the slow adjustment of the relative price.²

The difference between the long run equilibrium price and the actual price of non-traded goods at the beginning of period t can be expressed in terms of the corresponding deviation between the actual and the long-run equilibrium price of traded goods ($p_{1,t} - \bar{p}_{1,t}$). Since the money market is always in equilibrium, the deviation from equilibrium price in one sector must correspond to a deviation (of the opposite sign) in the other sector.³ In other words, if there is excess supply of non-traded goods (e.g., inventory build-up) then there is excess domestic demand over output of traded goods (a current account deficit). Using this relationship between the two sectors' prices, and equation (4), we can write the price adjustment for non-traded goods as a function of the exchange rate's deviation from its long-run equilibrium ($e_t - \bar{e}_t$) and, the world traded goods price's deviation from long-run equilibrium ($p_{1,t}^F - \bar{p}_{1,t}^F$):

$$p_{2,t+1} - p_{2,t} = (p_{t+1}^* - p_t) + K_1(e_t - \bar{e}_t) + K_1(p_{1,t}^F - \bar{p}_{1,t}^F). \quad (6)$$

The price adjustment for non-traded goods has now been expressed as a function of the deviation from the long-run equilibrium of a macroeconomic variable—the exchange rate.

An expression for the rate of change of the exchange rate in the two-goods, small country case can be derived in terms of inflation and the relative price's deviation from equilibrium by noting that

$$p_{1,t+1} - p_{1,t} = e_{t+1} - e_t + p_{1,t+1}^F - p_{1,t}^F \quad (\text{from 4}), \text{ and} \quad (7)$$

$$p_{t+1} - p_t \equiv \delta(p_{1,t+1} - p_{1,t}) + (1 - \delta)(p_{2,t+1} - p_{2,t}) \quad (\text{from 3}). \quad (8)$$

We solve for the exchange rate change by inserting (6) and (7) into (8), also distinguishing between anticipated inflation ($p_{t+1}^* - p_t$) and unanticipated inflation ($p_{t+1} - p_{t+1}^*$):

2. Mussa explains the existence of slow relative price adjustment by reference to adjustment costs, as does Rotemberg [19]. Slow price adjustment as expressed in (5) may be explained by firms' inventory behavior as well. Inventory, output and price behavior has been analyzed by, for example, Blinder [2] for a monopolistic firm, and by Glick and Wihlborg [12]. In these models, characterized by rational expectations, the relative price of a commodity and output adjusts slowly towards a long-run equilibrium in response to disturbances. Note also that prices may adjust slowly in *both* the traded and the non-traded sectors. In the traded sector the domestic currency price is determined as by equation (4) in this case as well, while the foreign currency price is determined in world markets.

3. The price level p can be expressed as $p = \delta \bar{p}_1 + (1 - \delta) \bar{p}_2 + \delta(p_1 - \bar{p}_1) + (1 - \delta)(p_2 - \bar{p}_2)$. In money market equilibrium $p = \bar{p} = \delta p_1 + (1 - \delta) p_2$. Thus $(p_2 - \bar{p}_2) = -(\delta / (1 - \delta))(p_1 - \bar{p}_1)$.

$$e_{t+1} - e_t = (p_{t+1}^* - p_t) + [(p_{t+1} - p_{t+1}^*)/\delta] - [(1 - \delta)/\delta] K_1[(e_t - \bar{e}_t) + (p_{1,t}^F - \bar{P}_{1,t}^F)] - (p_{1,t+1}^F - P_{1,t}^F). \quad (9)$$

The first term in (9) shows that the exchange rate adjusts by the full amount of anticipated inflation. Similarly, the last term reveals that it adjusts fully to changes in the foreign currency price of traded goods. Thus, relative purchasing power parity continues to hold after these disturbances. The second term on the right hand side of (9) shows that the exchange rate changes by more than the price level when inflation is unanticipated. The coefficient $1/\delta$ is greater than one and greater the share of traded goods in the price index.

The third term in (9) implies that when the exchange rate or the foreign currency price of traded goods deviate from their long-run equilibrium, there is a partial adjustment of the exchange rate. Equations (5) and (6) show that this partial adjustment of the exchange rate corresponds to partial adjustment of the relative price between traded and non-traded goods.

To clarify the adjustment path and the long-run equilibrium exchange rate further, we denote by u_t a real (demand or cost) disturbance in period t . This term represents a shift in the long-run equilibrium price of non-traded goods (\bar{p}_2 in log) relative to the average price level (p in log). Thus, in each period the long-run equilibrium price $\bar{p}_{2,t} = p_t + u_t$. In (5) it can be seen that the actual price adjusts slowly after a change in u_t . In the empirical section below we impose restrictions on the time series properties of u_t since an empirical proxy for this variable is lacking.

Using (3) and (4) the long-run equilibrium exchange rate is:

$$\bar{e}_t = p_t - \bar{p}_{1,t}^F - [(1 - \delta)/\delta]u_t, \quad (10)$$

Expression (10) says that the change in the long-run equilibrium exchange rate is the change in the purchasing power parity rate in the absence of real disturbances at home ($u = 0$) or abroad ($p_{1,t}^F = p_t^F$).

Deviations from relative purchasing power parity occurs for three reasons in this model. First, as shown by (10) there are equilibrium deviations when real disturbances occur. Second, an unanticipated change in the price level due to a change in the money supply or national income (in eq. (3)) induces an exchange rate change in excess of the price level change as shown in (9). We may call the “excess” exchange rate change overshooting. It corresponds to a relative price change and occurs as a result of the rigidity of the price of non-traded goods. For the money market to remain in equilibrium after such a disturbance the price of traded goods (and the exchange rate) must change by more than the average price level. The third source of deviations from relative purchasing power parity occurs in the adjustment process in periods after unanticipated price level changes. Since the relative price between traded and non-traded goods has changed with the disturbance, the exchange rate changes with the adjustment of the relative price to its long-run equilibrium level as shown by (6).⁴

4. The overshooting here occurs for a somewhat different reason than in Mussa [17]. Both Mussa and Dornbusch [6] assume that prices for all domestically produced goods adjust slowly, while the price of imported goods follows the “law of one price.” Only the former goods’ prices affect money demand. After an increase in the money supply, there is an incipient excess supply of money which is not immediately absorbed by a price level increase for domestic goods. Instead, the interest rate must fall. This fall is consistent with an expected appreciation of the exchange rate caused by an immediate depreciation relative to equilibrium. Money market equilibrium can be retained only by means of interest rate

In the following we mean by *monetary* disturbances shifts in the aggregate price level due to shifts in the money supply, national income or the interest rate in (3). To simplify the empirical work we view the price level as exogenous even though the interest rate and therefore exchange rate expectations affect the price level. However, endogenous shifts in the price level due to expectations only dampen price level effects of changes in m and y . Furthermore, this endogenous effect is likely to be small since empirical evidence indicates that the interest rate elasticity of the demand for money is low.⁵

III. Extending the Model

Two Countries

Extensions of the model are necessary before empirical tests can be performed. First, since one exchange rate depends on monetary and real factors in two countries, we include prices and disturbances in two countries. Second, in the second subsection below, the price adjustment is specified for any sector i that may produce goods of any degree of "tradedness." Third, the model must be expressed in terms of observable variables. In the third subsection we show how the forward rate may substitute for unobservable anticipated inflation in price and exchange rate equations.

The model can easily be extended to allow explicitly for two countries in which there are perfectly traded and non-traded goods. First, we postulate a price adjustment for non-traded goods in the foreign country analogously with the domestic price adjustment for non-traded goods in (6). The foreign country is for simplicity assumed to be large. Then, the exchange rate does not affect the foreign currency price of traded goods.

$$p_{2,t+1}^F - p_{2,t}^F = (p_{t+1}^{*F} - p_t^F) + K_1 (p_{1,t}^F - \bar{p}_{1,t}^F). \quad (11)$$

We assume for simplicity that the adjustment coefficient K_1 in (11) is equal to the corresponding coefficient in equation (6) for domestic non-traded goods.

The long run equilibrium price of traded goods in the foreign currency can be expressed in the following way in analogy with (10):

$$\bar{p}_{1,t}^F = p_t^F - [(1-\delta)/\delta] u_t^F \quad (12)$$

where u_t^F shows how much the foreign price of non-traded goods would have to change in period t for equilibrium to be restored after a foreign demand or cost disturbance. Though not essential, the expressions below are simplified by the assumptions that the share of traded goods in output is the same in the two countries (δ), and that adjustment coefficients are equal.

Next, we express the *differential* price change for non-traded goods between the two countries and currencies. For this purpose, we use (6), (11), (10) and (12);

$$(p_{2,t+1} - p_{2,t}) - (p_{2,t+1}^F - p_{2,t}^F) = (p_{t+1}^* - p_t) - (p_{t+1}^{*F} - p_t^F) \quad (13)$$

where $e_t - \bar{e}_t = e_t - (p_t - p_t^F) - [(1-\delta)/\delta](u_t - u_t^F)$.

adjustment in the Mussa model, while in our model the increase in the price of traded goods along with the depreciation raises money demand. In spite of these differences between our model and Mussa's, the models predict similar time paths of adjustment of all variables.

5. Elasticity estimates are often in the range of $(-).15 - (-).30$.

The *differential* price change is equal to the differential anticipated inflation minus an adjustment to the exchange rate's deviation from its equilibrium value. This value depends on relative price levels and the relative real disturbance between traded and non-traded goods.

We next derive the rate of change of the exchange rate as a function of differential anticipated and unanticipated inflation, and of differential real disturbances. Following the procedure for the one country case where equations (6)–(8) were used, we now use (13) instead of (6) and the definition of differential inflation instead of (8). The equation for the rate of change of the exchange rate becomes:

$$\begin{aligned} e_{t+1} - e_t &= (p_{t+1}^* - p_t) - (p_{t+1}^{*F} - p_t^F) \\ &\quad + [(p_{t+1} - p_{t+1}^*) - (p_{t+1}^F - p_{t+1}^{*F})]/\delta \\ &\quad - [(1 - \delta)/\delta] K_1 [e_t - (p_t - p_t^F)] - [(1 - \delta)/\delta] (u_t - u_t^F). \end{aligned} \quad (14)$$

The rate of change in the exchange rate is equal to the *differential* anticipated inflation, plus the *differential* unanticipated inflation divided by the share of traded goods, minus an adjustment term. The latter consists of an adjustment towards purchasing power parity [$e - (p_t - p_t^F)$] and an adjustment towards equilibrium relative prices after a differential real disturbance ($u_t - u_t^F$).

Equations (13) and (14) show that the differential price change on non-traded goods and the exchange rate change depend only on differential inflation rates and differential real disturbances. In the following, we analyze only differential price changes. Then the degree to which countries are price takers or price makers is irrelevant. The notation can also be simplified by suppressing the price term for the foreign country. Therefore, in the following, the variables p , p_1 , p_2 and u represent the *differential* price changes ($p - p_1^F$), ($p_1 - p_1^F$), ($p_2 - p_2^F$), and ($u - u^F$), respectively.

Many Sectors and Different Degrees of "Tradedness"

So far, only two goods have been considered, one of which is perfectly traded—the “law of one price” holds in each period—and one which is non-traded—its price in a period does not directly depend on the exchange rate. We will now allow for a large number of sectors and for any possible degree of “tradedness.”

The (differential) price adjustment for any sector i is specified in the following way:

$$\begin{aligned} p_{i,t+1} - p_{i,t} &= (p_{t+1}^* - p_t) + \theta_i^1 (e_{t+1} - p_{t+1}^*) \\ &\quad + \theta_i^2 (e_t - p_t) + \theta_i^3 (u_{i,t}). \end{aligned} \quad (15)$$

This adjustment equation for the domestic currency price change on good i relative to the foreign currency price change on good i should be compared to equation (13) for the price change on non-traded goods. The first term on the right hand side captures the assumed complete adjustment to anticipated inflation. The second term did not appear in (13). The coefficient θ_i^1 captures the degree of “tradedness” of good i . It shows the extent to which the differential price of good i adjusts to exchange rate changes *in excess of* the anticipated rates of inflation from one period to another. For a perfectly traded commodity the coefficient θ_i^1 equals unity. In this case the “law of one price” holds at all times. For a non-traded commodity the coefficient θ_i^1 equals zero. It can be seen that in these extreme

cases the adjustment equation (15) reduces to those postulated in section II for non-traded goods (13) and (implicitly) for traded goods.

The third and the fourth terms in (15) appeared in equation (13) as well. In the third term, $(e_t - p_t)$ is the exchange rate's deviation from purchasing power parity in period t . As in the two-good models this deviation is proportional to the deviation between each sector's actual price and its long-run equilibrium price during the adjustment process in the absence of cost and demand disturbances.⁶ The fourth term in (15) represents the adjustment to a *differential* real disturbance for sector i .

Next we derive the exchange rate change from period t to period $t + 1$ in the same way equations (9) and (14) were derived above. Define the relative price level between the countries (p_t) in the following way:

$$p_t = w_1 p_{1,t} + \dots + w_n p_{n,t} = \sum_{i=1}^n w_i p_{i,t} \quad (16)$$

where w_i represents sector i 's share in the price index ($\sum_{i=1}^n w_i = 1$) of each country. By assuming that sector shares are the same across countries we are able to work with *relative* price levels and *differential* changes in prices.

The exchange rate change *in excess of anticipated relative inflation rates* can be solved for by using equations (15) and (16):

$$(e_{t+1} - p_{t+1}^*) = (p_{t+1} - p_{t+1}^*)/A_1 - (A_2/A_1)(e_t - p_t) + \sum_{i=1}^n w_i \theta_i^3 u_{i,t}/A_1 \quad (17)$$

where $A_1 = \sum_{i=1}^n w_i \theta_i^1$, and $A_2 = \sum_{i=1}^n w_i \theta_i^2$.

The coefficient A_1 can be interpreted as the *average degree of tradedness*. The average adjustment speed of sectoral prices towards their equilibria *and* the adjustment speed of the exchange rate to purchasing power parity is captured by the coefficient A_2 . The last term in (17) equals zero in the absence of differential cost and demand disturbances across *all* sectors.

Equation (17) shows that the exchange rate will overshoot its purchasing power parity level in response to an unanticipated change in the price level between periods t and $t + 1$ if $A_1 < 1$. The adjustment of *each sector's price* to such an unanticipated price level change depends on the degree of tradedness of each sector's goods, i.e., on the coefficient θ_i^1 in (15). The exchange rate change consistent with a certain unanticipated change in the price level between periods t and $t + 1$ causes the weighted *average* of sectoral prices to rise with the amount of the unanticipated disturbance to the price level. Thereafter, each sector's price adjusts from period $t + 1$ to $t + 2$ by the amount of $\theta_i^2(e_{t+1} - p_{t+1})$ as shown by (15).⁷

6. This assertion rests on the assumption that adjustment coefficients are stable over time. See also note 7 below for the relationship between individual sector price deviation from long-run equilibrium and the exchange rate's deviation from purchasing power parity.

7. The exchange rate's deviation from purchasing power parity $(e_{t+1} - p_{t+1})$ in the period after an unanticipated disturbance has occurred is $[(1 - A_1)/A_1](p_{t+1} - p_t)$. For sector i the price in the period after the disturbance is $\theta_i^1(e_{t+1} - p_t) = \theta_i^1[e_{t+1} - p_{t+1}] + (p_{t+1} - p_t) = [\theta_i^1/A_1](p_{t+1} - p_t)$, or in terms of the exchange rate's deviation from purchasing power parity, $\theta_i^1(e_{t+1} - p_t) = [\theta_i^1/(1 - A_1)](e_{t+1} - p_{t+1})$. The deviation of sector i 's price from equilibrium in the same period is $\theta_i^2(e_{t+1} - p_t) - (p_{t+1} - p_t) = [(\theta_i^2 - A_1)/(1 - A_1)](e_{t+1} - p_{t+1})$. The coefficient θ_i^2 in (15) includes, therefore, the term $(\theta_i^1 - A_1)/(1 - A_1)$ as well as the adjustment speed of goods prices towards equilibrium in each sector. Thus, θ_i^2 is negative in (15) if $\theta_i^1 > A_1$, i.e., for goods with relative high degree of tradedness. The reason is that relatively traded goods' prices overshoot the actual price level.

The coefficient θ_i^2 is negative for goods with relatively high tradedness since the price of such goods changed between t and $t + 1$ by more than the average price level (see note 7). When the sectoral prices adjust towards their long-run equilibria the exchange rate adjusts according to (17) towards its purchasing power parity rate by an amount that depends on the average adjustment speed of relative prices (A_2).

Finally, it should be noted that an *anticipated* price level disturbance does not cause any relative price changes, since each sector's price and the exchange rate would change by the amount of the anticipated change in the price level.

Expectations and the Forward Exchange Rate

In (17) we solved for the exchange rate in excess of anticipated inflation. Since unanticipated inflation is unobservable, the model cannot be tested in this form. However, we can rewrite (17) and the sectoral price adjustment in (15) in terms of observable variables, since the forward rate contains information about anticipated inflation.

The forward exchange rate ($f_{t+1,t}$) is equal to the anticipated future spot rate under the assumption of perfect asset substitutability across currencies and zero transactions costs (see eq. (2b)). Using (17) and assuming that firms and individuals form expectations consistent with the model, the expected rate of change in the exchange rate i.e., the forward premium on the foreign currency can be written in the following way:

$$f_{t+1,t} - e_t = (p_{t+1}^* - p_t) - [A_2/A_1][e_t - p_t]. \quad (18)$$

Equation (18) is derived by evaluating from (17) the expected exchange rate change *in excess of* anticipated inflation. Thereafter to obtain the expected rate of change in the exchange rate in (18) we add anticipated inflation since within the model such inflation causes an exchange rate change of the same magnitude. The first term on the right hand side of (17) represents unanticipated inflation and is not observed in period t . Variables e_t and p_t in (17) can be observed. The third term in (17) is the average differential real disturbance. We assume that this term *cannot* be observed.

Equation (18) is used to derive an expression for the relative anticipated inflation as the forward premium minus expected adjustment due to deviations from long-run equilibrium. The expression for anticipated inflation so derived is substituted for $(p_{t+1}^* - p_t)$ in (17). Then the following expression for the exchange rate change in excess of the forward premium is derived:

$$(e_{t+1} - f_{t+1,t}) = (p_{t+1} - p_t) / A_1 - (f_{t+1,t} - e_t) / A_1 \\ - [1 + (A_2/A_1^2)][e_t - p_t] + \sum w_i \theta_i^3 u_{i,t} / A_1. \quad (19)$$

Equation (19) *cannot* be used for forecasting purposes, since it is based on the assumption that the forward rate is an unbiased estimate of exchange rate expectations at time t . It is also important to note that the negative coefficient of $(f_{t+1,t} - e_t)$ does not imply a negative correlation between anticipated and unanticipated exchange rate changes. Components of the anticipated exchange rate change appears in the first, third, and fourth terms on the right-hand side. Therefore, to test whether the model in hindsight explains unanticipated exchange rate changes, these changes should not be regressed against the four right-hand side variables, but only against the *constrained sum* of the four variables. The constraints depend on the values of coefficients A_1 and A_2 . Estimates of these coefficients are obtained from regressions of sectoral price adjustment equations.

Table I. Sectors Included in Tests (all weights in US GNP)

USA—Canada	Weights	USA—Germany	Weights
Furniture	.006	Leather	.002
Leather	.002	Minerals (Non-Metallic)	.022
Wood	.006	Rubber and Plastic	.017
Minerals (Non-Metallic)	.022	Textiles	.023
Rubber and Plastic	.017	Metals	.047
Paper and Paper Products	.013	Chemicals	.045
Fuel	.030	Machinery	.081
Textiles	.023		
Metals	.047		
Chemicals	.045		
Machines (1975–1980)	.081		

Sources:

Canada: Industry Price Indexes, Statistics Canada 62011

Germany: The Economic Situation in the Federal Republic of Germany, Monthly Review. The Federal Minister of Economics.

USA: Labor Review, Monthly. Bureau of Labor Statistics.

Consumer Price Indexes: International Financial Statistics*Exchange Rate Data:* Harris Bank

The sectoral price adjustment equation (15) can be reformulated in terms of observable variables by incorporating the expression for the anticipated inflation rate from equation (18). We derive:

$$(p_{i,t+1} - p_{i,t}) = \theta_i^1 (e_{t+1} - f_{t+1,t}) + (f_{t+1,t} - e_t) + [(A_2/A_1)(1 - \theta_i^1) + \theta_i^1 + \theta_i^2](e_t - p_t) - \theta_i^3 u_{i,t}. \quad (20)$$

All right-hand side variables in (20) are not independent, when the expression for anticipated inflation from (18) has been substituted for $p_{t+1}^* - p_t$ in (15). Specifically, the term $(f_{t+1,t} - e_t)$ contains $(e_t - p_t)$ which appears as a separate term in (20). It will therefore be estimated below with the coefficient for $(f_{t+1,t} - e_t)$ constrained to be unity as the theoretical specification suggests.

IV. Data, Testing Procedures and Results

The equations for sectoral price adjustment (20) and the rate of change of the exchange rate (19) are estimated for USA-Canada and USA-Germany. Estimation of sectoral price adjustment is limited by data availability to manufacturing sectors. Thus, constraints on the economy-wide sum of the coefficients cannot be imposed. Quarterly sectoral producer price indexes are used for the period 1974I–1980I. Table I shows the sectors and their relative weights in US GNP. These weights are assumed to apply in Canada and Germany as well. As we noted above by applying equal sector weights in all countries we reduce the number of independent variables in the regressions. For countries with similar levels of output per capita the assumption is realistic.

We test for the sectoral price adjustment under the assumption that for each sector the exchange rate and the price level are exogenous variables. This assumption seems reasonable, since each sector's contribution to the price index is only a small fraction of the total index (see Table I).

Table II. Sectoral Price Adjustment Equation

$(p_{i,t+1} - p_{i,t}) = \beta_0 + \beta_1(e_{t+1} - f_{t+1,t}) + (f_{t+1,t} - e_t) + \beta_2(e_t - p_t) - \beta_3(p_{i,t} - p_t)^a$	
Coefficient	Interpretation
β_1	$\theta_i^1 =$ adjustment to exchange rate change in excess of anticipated inflation
for $(f_{t+1,t} - e_t) = 1$	this coefficient equals one, if adjustment to anticipated inflation is assumed to be complete. Coefficient is constrained. (See Section IIC).
β_2	$[(A_2/A_1)(1 - \theta_i^1) + \theta_i^1 + \theta_i^2]$, where $\theta_i^2 =$ adjustment to deviation from purchasing power parity exchange rate.
β_3	If significant and if \bar{R}^2 improves relative to regressions without the term $(p_{i,t} - p_t)$, then differential real disturbances have contributed to the differential relative price adjustment during the period.

a. p_t , the purchasing power parity exchange rate, was calculated by estimating a coefficient for the average deviation from purchasing power parity during 1974–1980. The relative price index for each period was thereafter multiplied by this coefficient.

Table II shows the form of the tested price adjustment equation and the interpretation of the coefficients. Since $u_{i,t}$ —the shift in the equilibrium relative price in (20)—cannot be directly observed unless prices have adjusted, this variable was neglected in one set of regressions.⁸ We assume in effect that differential cost and demand disturbances have a mean zero and are randomly distributed. In another set presented below, we substituted the term $(p_{i,t} - p_t)$ for $u_{i,t}$ in order to analyze whether cost and demand disturbances have affected differential price changes *within* a sector. The reasoning behind this procedure is the following: The term $(p_{i,t} - p_t)$ is the price ratio between the countries for *sector i* relative to the ratio between the countries' price levels. If price adjusts slowly toward an equilibrium relative price after a real disturbance, relative prices are serially correlated among periods after the disturbance. Since the relative price captured by the term $(p_{i,t} - p_t)$ is correlated with the exchange rate's deviation from purchasing power parity, $(e_t - p_t)$, during the adjustment to *monetary* disturbances (note 7), the inclusion of $(p_{i,t} - p_t)$ in the regression would not add to its explanatory value *in the absence of* differential cost and demand disturbances. However, if differential cost and demand disturbances occurred, then the explanatory value of the regression including $(p_{i,t} - p_t)$ would be superior to the regression without this term.

A comparison of the results for sectoral price adjustment presented in Table III, *including* the term $(p_{i,t} - p_t)$, with results of tests *excluding* this term reveals that R^2 and F -values generally increase somewhat when the term is included. Coefficients for other variables do not change substantially. Coefficients for $(e_t - p_t)$ in Table III are therefore not distorted by the inclusion of the term $(p_{i,t} - p_t)$.

Table III shows the results of the sectoral regressions for differential price changes. The $\beta_1 (= \theta_i^1)$ coefficients indicate that between the USA and Canada more than 50% of the adjustment towards the "law of one price" occurs within a quarter for 10 of the 11 sectors. Between the USA and Germany the corresponding figure is zero out of seven. One of the β_1 coefficients for USA-Canada is larger than unity, while one coefficient for USA-Germany is

8. Real aggregate disturbances (in national output) are considered disturbances to money market equilibrium and therefore included in changes in p .

Table III. Sectoral Adjustment Equations for USA-Canada and USA-Germany
(Underlined coefficients are significantly different from zero at the 90% level, $t > 1.65$)

Sector	β_0	β_1	β_2	β_3	\bar{R}^2	F	D.W
<u>USA-Canada</u>							
Furniture	-.004 (-.45)	<u>.511 (3.45)</u>	1.0	.079 (.99)	<u>-.078 (-.64)</u>	.29	4.14 .97
Leather	.022 (2.57)	<u>.690 (4.25)</u>	1.0	-.013 (-.26)	<u>-.177 (-2.20)</u>	.51	8.88 1.53
Wood	.022 (.77)	<u>.956 (4.30)</u>	1.0	.063 (.85)	<u>-.070 (-.60)</u>	.44	7.11 1.96
Minerals	.022 (1.07)	<u>.535 (2.42)</u>	1.0	.002 (.02)	<u>-.072 (-.78)</u>	.15	2.37 1.58
Paper	.005 (1.5)	<u>.711 (5.21)</u>	1.0	.063 (1.01)	<u>-.118 (-1.20)</u>	.53	9.75 1.49
Rubber	.021 (.87)	<u>.823 (3.46)</u>	1.0	.089 (1.34)	<u>-.073 (-.54)</u>	.33	4.72 1.68
Fuel	.287 (3.83)	.111 (.10)	1.0	.102 (.34)	<u>-.894 (-3.91)</u>	.36	5.36 2.10
Textile	.007 (.70)	<u>.535 (3.37)</u>	1.0	.103 (1.08)	<u>-.108 (-.81)</u>	.28	4.02 1.54
Metal Primary	.008 (.31)	<u>3.37 (2.96)</u>	1.0	<u>.203 (1.82)</u>	<u>-.052 (-.33)</u>	.35	5.20 1.56
Chemicals	.46 (2.13)	<u>.536 (3.71)</u>	1.0	<u>.244 (3.75)</u>	<u>-.284 (-1.78)</u>	.55	10.45 1.73
Machines	-.45 (-.94)	<u>.540 (3.77)</u>	1.0	.263 (1.51)	<u>.293 (1.18)</u>	.40	5.23 1.57
<u>USA-Germany</u>							
Leather	.210 (1.61)	-.032 (1.15)	1.0	.191 (1.48)	<u>-.233 (-1.54)</u>	0	.97 1.36
Minerals	.208 (2.29)	<u>.211 (1.67)</u>	1.0	.086 (1.05)	<u>-.181 (-2.17)</u>	.27	3.78 2.34
Rubber/Plastic	.114 (.99)	<u>.326 (1.85)</u>	1.0	-.056 (.60)	<u>-.097 (-.95)</u>	.26	3.72 1.83
Textile	-.063 (-.70)	.087 (.63)	1.0	-.023 (-.42)	.074 (.72)	0	.38 1.88
Metal	.524 (3.53)	.091 (.51)	1.0	<u>.313 (2.62)</u>	<u>-.433 (-3.43)</u>	.29	4.19 1.89
Chemicals	.334 (4.25)	.066 (.42)	1.0	.0062 (.081)	<u>-.257 (-4.08)</u>	.56	10.81 2.20
Machines	.56 (1.90)	.167 (-.40)	1.0	.279 (1.61)	<u>-.578 (-1.87)</u>	.10	1.84 2.27

negative. In both cases, the explanation may be that the sectors are not sufficiently homogeneous among the countries.⁹

The large differences among the β_1 coefficients indicate that exchange rate changes are associated with very substantial relative price changes among sectors. This conclusion is strengthened by the fact that the sectors included are likely to be producing relatively highly tradeable goods as compared to sectors not included.

The β_2 and β_3 coefficients capture adjustments to deviations from the monetary and real long-run equilibrium, respectively. The β_3 coefficient is significant only for few sectors. Thus for most sectors differential real disturbances explain little of differential price changes.

The θ_i^2 coefficient in equation (20) can be derived as shown in Table II, from the β_2 coefficients in Table III. First an estimate of A_2/A_1 must be obtained. We note that the coefficient for $(e_t - p_t)$ in (18) may provide this estimate. However, we have no proxy for

9. An anonymous referee noted that Canadian prices in the statistics sometimes are calculated as the foreign price multiplied by the exchange rate. High adjustment coefficients would then follow definitionally. We may hope, however, that this procedure is used only for goods that are highly tradeable.

Table IV. Sectoral Coefficient of Adjustment to Exchange Rate's Deviation from Purchasing Power Parity

$\theta_i^2 = \beta_2 - [(A_2/A_1)(1 - \theta_i^1) + \theta_i^1]$ where $A_1/A_2 = -.03$ for Canada and $-.05$ for Germany		
	Canada	Germany
Furniture	-.44	
Leather	-.71	-.17
Wood	-.90	
Minerals	-.55	-.16
Paper	-.66	
Rubber	-.04	-.42
Fuel	-.04	
Textiles	-.45	-.16
Metal	-3.07	-.11
Chemicals	-.31	-.06
Machines	-.29	.39

the first term i.e., anticipated inflation in (18). Nevertheless, provided anticipated inflation and $(e_t - p_t)$ are independent, unbiased estimates of A_2/A_1 can be obtained. There is in the theory no grounds for suspecting any correlation between the two variables. We therefore regress the forward premium on $(e_t - p_t)$ and present the values of the coefficients (A_2/A_1) in Table IV. R^2 and Durbin Watson statistics are poor for this regression (not presented), but since its purpose is limited to providing a coefficient these statistics are irrelevant.

Table IV shows the θ_i^2 coefficients. These coefficients represent each sector's price adjustment when the exchange rate deviates from purchasing power parity in the adjustment process after unanticipated monetary disturbances. Nearly all the calculated θ_i^2 coefficients are negative. This indicates that the degree of tradedness for sectors included here is relatively high (footnote 7). The reason is that sectors with relatively high θ_i^1 coefficients are expected to be characterized by relatively much price "overshooting," and therefore, prices in these sectors have to adjust relatively more back to equilibrium (relatively large negative θ_i^2 coefficients). Calculating rank correlation coefficients between θ_i^1 and θ_i^2 coefficients indicates that for USA-Canada, the rank correlation is .59 (significantly different from zero at the 90% level). For USA-Germany the estimated rank correlation is .70 (significant at the 90% level).

We turn now to the test of equation (19) for the unanticipated exchange rate change. The purpose of this test is to evaluate whether the model in hindsight explains unanticipated exchange rate changes as defined by the prediction error of the forward rate.¹⁰ The equation cannot be used for prediction.

We noted in section III that for the purpose of testing the model's explanatory power for the exchange rate, the right-hand side of (19) must be constrained and treated as one independent variable. Thus, the regression we run is:

10. There is some doubt about the unbiasedness of the forward rate as a prediction of the future spot rate [15]. On the other hand, there is no model that consistently seems to outperform the forward rate over long periods and across several time horizons and currencies. Furthermore, even if other models may outperform the forward rate for some time, we cannot think of a better proxy than the forward rate for the market's expectations.

Table V. Actual against Calculated in Sample Unanticipated Exchange Rate Changes

$e_{t+1} - f_{t+1,t} = a_0 + a_1(e_{t+1} - f_{t+1,t})_c$, where $(e_{t+1} - f_{t+1,t})_c$ is calculated using (19)	a_0	a_1	\bar{R}^2	F	D.W.
USA-Canada:					
1. Complete adjustment to anticipated inflation	-.007 (-1.8)	.25 (4.5)	.47	20.2	1.17
2. Unconstrained adjustment to anticipated inflation	-.001 (.025)	.10 (1.8)	.09	3.26	1.48
USA-Germany:					
1. Complete adjustment to anticipated inflation	.008 (.91)	.018 (2.5)	.18	6.04	1.90
2. Unconstrained adjustment to anticipated inflation	.006 (.58)	-.03 (-1.4)	.04	1.84	1.68

$$e_{t+1} - f_{t+1,t} = a_0 + a_1(e_{t+1} - f_{t+1,t})_c, \quad (21)$$

where $(e_{t+1} - f_{t+1,t})_c$ is the in sample, calculated unanticipated exchange rate change. The right-hand side of (19) is used to calculate $(e_{t+1} - f_{t+1,t})_c$. A_1 is obtained by the weighted sum of θ_i^1 (β_1) coefficients in Table III. A_2 is estimated by the weighted sum of θ_i^2 coefficients in Table IV. The last term in (19) is neglected in the absence of a proxy for aggregate differential demand and cost disturbances. The results are presented in Table V, and denoted by a 1/.

The regressions denoted by a 2/ in Table V are included in order to test whether different sets of coefficients in A_1 and A_2 would affect the ability of the model to explain the unanticipated exchange rate change. If a different set of coefficients is used to constrain the right-hand side of (19) without affecting the explanatory value of (19), then we would tend to reject the hypothesis that the nature of goods market adjustment affects the exchange rate. The exchange rate change could still be explained by the variables in (19), but specific values of coefficients relating to goods market adjustment would be irrelevant.

The second set of coefficients included in A_1 and A_2 was obtained by testing the sectoral adjustment equation in Table II without constraining the coefficient for $(f_{t+1,t} - e_t)$, i.e., without constraining the price adjustment to anticipated inflation.¹¹

Before discussing the results it should be noted that we lack estimates of adjustment coefficients for a large part of the economy. Implicitly we assume that all coefficients are zero for these sectors. Though this cannot be the case, it is of no serious consequence if the relative coefficients are stable over time. It implies, however, that we cannot expect coefficient $a_0 = 0$ and $a_1 = 1$ when estimating (21).

The results in Table V indicate that nearly half of the variation in the unanticipated exchange rate between the USA and Canada is explained, when the coefficients presented in Table III are used. The corresponding figure for the exchange rate change between the

11. The in sample, calculated unanticipated exchange rate change was also calculated based on a third set of adjustment coefficients estimated under the assumption that $\theta_i^2 = \beta_2$. The prediction obtained in this way performed worse than those presented in Table V.

USA and Germany is 18%. The table also shows the drastic deterioration of the predictions when the other set of sectoral price adjustment equations is used to calculate exchange rate changes. These results lend strong support to the hypothesis that the speed of goods market adjustment matters for exchange rate adjustment to monetary disturbances. The results also indicate that the particular price adjustment assumption made with respect to anticipated inflation is sensible.

The behavior of the exchange rate in response to an unanticipated monetary disturbance (in the form of an unanticipated change in the price level) can be calculated using equation (19), the results in Table V, and the calculated value of A_1 — the average degree of tradedness. A one percent unanticipated change in the relative price level causes theoretically a $(1/A_1)$ percentage change in the exchange rate. Table V shows that, if we were to use our calculated values of A_1 , the exchange rate change would be exaggerated by a factor of $(1/.25)$ and $(1/.018)$, respectively. Taking these coefficients into account, the results imply that a one percent change in the relative price levels leads to a .9 percent change in the USA-Canada exchange rate and a .8% change in the USA-Germany exchange rate. These somewhat crude estimates do not support the hypothesis that the exchange rate “overshoots” unanticipated price level disturbances, though at the same time the results support the hypothesis that the average degree of tradedness is important for exchange rate adjustment to such disturbances. These seemingly inconsistent results can be explained if financial capital is *not* perfectly mobile. Then, interest rate differentials (adjusted for expected exchange rate changes) may carry part of the adjustment burden in goods markets assigned to the exchange rate in our theoretical model. This proposition cannot be tested without using a measure other than the forward premium for expected exchange rate changes. Such a measure is not available (see note 10).¹²

IV. Conclusion

We have developed and tested a model of relative price and exchange rate changes incorporating different degrees of “tradedness” and slow relative price adjustment towards equilibria.

The degree of tradedness between the USA and Canada and between the USA and Germany varies widely among manufacturing sectors. We conclude, therefore, that substantial relative price changes among sectors as well as between countries occur in response to unanticipated disturbances in money supply and demand.

The negative relationship between sectoral coefficients for the degree of tradedness and coefficients for adjustment to the exchange rate deviation from purchasing power parity supports the view that prices on relatively traded goods overshoot equilibrium after unanticipated monetary disturbances.

Though price adjustment towards the “law of one price” seems to occur faster than commonly thought for manufacturing goods between the USA and Canada, our results indicate that the average degree of tradedness and slow price adjustment play important roles in exchange rate determination. The results also indicate that the assumption about complete price adjustment in response to anticipated price level changes is valid. Therefore, such changes would not cause deviations from purchasing power parity.

12. If capital is not perfectly mobile, the forward rate is a biased predictor of the anticipated exchange rate.

18% of the variation of unanticipated exchange rate changes between the USA and Germany is explained by our model, while the corresponding figure between the USA and Canada is 50%. Thus, it seems as if the nature of goods market adjustment is more important for the exchange rate between the latter two countries on a quarterly basis, though in neither case could exchange rate overshooting be substantiated. The data do not allow us to test whether goods market adjustment between the USA and Germany contributes more to longer term exchange rate changes. The very small adjustment within a quarter to the "law of one price" between the USA and Germany may imply that there is simply not sufficient adjustment for it to have a measurable impact on exchange rate adjustment over this time horizon. Other variables may then dominate quarterly exchange rate movements.

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