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EXCHANGE RATE AND PRICE DYNAMICS WITH ASYMMETRIC INFORMATION*

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1. INTRODUCTION

Many recent contributions to the economics of exchange rates are based on the seminal model of Dornbusch [1976].[2] Despite these extensions, the basic model contains an awkward aspect which seems crucial for one of the major purposes of the model which was to explain the observed high volatility of exchange rates relative to the volatility of price levels. The awkward aspect is the asymmetric treatment of the domestic currency prices of domestically produced goods versus foreign produced goods. By predetermining domestic currency prices of domestic goods, the model forces asset market equilibrium to occur through fluctuations in interest rates and exchange rates producing the well-known overshooting result. Domestic prices of foreign goods, in contrast, are proportional to the current exchange rate. Since it is difficult to detect a substantial difference in the domestic pricing of domestic and foreign goods, this building block of the Dornbusch model is unappealing.[3] One solution to the asymmetry would be to make domestic prices of foreign goods an additional predetermined variable.

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[2] These works include Frankel [1979], Gray and Turnovsky [1979], Wilson [1979], Driskill [1981], Flood [1981], Frenkel and Rodriguez [1982], and Mussa [1982].

[3] While the predetermination of domestic goods prices is typical, it is not essential to the results of these models. The results would be robust to a pricing rule where some contemporaneous pricing disturbances are allowed as long as such diturbances are uncorrelated with contemporaneous shocks to good and asset markets. This point was made to us by Bennett T. McCallum. Meese [1983] investigates testing the assumption of predetermined prices within the context of particular models of exchange-rate and price determination.

Such a solution is also unappealing since it makes the domestic price level completely predetermined and removes the Dornbusch model's implications for the impact effects of monetary disturbances on the terms of trade. Instead, in this paper, both prices are current endogenous variables.

The unattractive feature of the standard model is driven by an assumed pricing rule which makes changes in nominal prices —from this period to the next period— a function of current excess demand. In this paper, we adopt an alternative pricing rule which requires firms to set prices prior to the realization of demand to them, but by allowing firms to see some current information, predetermined prices are avoided. Firms are required to set prices to equate expected demand to supply, and they rationally use their information about the economy in forming expectations.[4] In this model, prices are flexible in response to perfectly understood shocks, such as known changes in the money supply, yet prices are "sticky" in response to shocks that are less than fully perceived.[5]

The additional new aspect of our model is an assumed distribution of information about the innovations in exogenous macroeconomic processes. Firms are endowed with no aggregate information while some agents are endowed with complete aggregate information, and are allowed to dominate assets markets. This information assumption captures the notion that firms are continually faced with changes in their relative demands which are large in comparison to changes in aggregate demand.[6] Firms therefore find it more profitable to invest in direct acquisition of information about relative demand and are consequently less well informed than asset market specialists who rationally concentrate on aggregate variables which determine fluctuations in asset prices. Firms learn partial aggregate information from observing asset market equilibrium, but they remain

[4] McCallum [1977], Howitt [1981], and Brunner, Cukierman and Meltzer [1983] have investigated macroeconomic structures of this type.

[5] The pricing rule we use captures in a general tractable way the idea that information costs are the chief impediment to price flexibility. Alchian [1969] and Okun [1981] provide general discussions of the nature of information costs which may induce firms to keep prices fixed. While most sticky-price models merely postulate a pricing function with constant parameters, Barro [1972], Mussa [1981], and Rotemberg [1982] have derived price adjustment rules from microeconomic models in which agents incur real costs of changing prices. In the typical model, the firm balances the assumed lump-sum real cost of any price change against the cost of being away from the equilibrium price. It is hard to argue that no lump-sum cost exists, yet in our opinion the major component of these costs is the decision making or administrative cost that a firm bears in trying to determine what the equilibrium price really is. If this is true, such costs will be functions of the information environment and will not be constant, which is why we have adopted our alternative.

[6] Lucas [1976, p. 20] argues that changes in tastes and technology at the firm level dominate by far the relatively minor movements which constitute the aggregate business cycle. Our assumption that firms are endowed with no aggregate information while the asset markets are dominated by agents with complete aggregate information is obviously an extreme example of the informational asymmetry postulated above. We view it as a tractable, analytical simplification that should be robust to relaxation of the extreme nature of the asymmetry as long as agents in asset markets remain better informed about macro variables.

asymmetrically informed.

The paper contains four additional sections. In Section 2, we develop our model. In Section 3, we solve and interpret the model for two benchmark cases, full price flexibility and domestic price predetermined, as well as for the asymmetric-information version of the model. Section 4 presents a discussion of the volatility of exchange rates and prices and examines how the responses of exchange rates and prices to various shocks depend upon the variances of the exogenous processes. Section 5 provides some concluding remarks.

2. AN OPEN-ECONOMY MODEL WITH ASYMMETRIC INFORMATION

The model presented in this section is a logical development of the models and ideas presented in Dornbusch [1976], Flood [1981], and Mussa [1982]. It depicts an open economy which is assumed to be small in the world capital market but large in the market for the domestically produced goods. As with the other models, we abstract from variations in levels of national outputs and do not consider the effects of changes in asset stocks that occur through investment and through current account imbalances.

The principal aggregated equations of the model are the following:

THE MODEL

Asset Markets

(1) $$m_t - p_t = -\alpha i_t + z_t$$

(2) $$i_t = \bar{\imath}^* + E(s_{t+1} \mid I_t^A) - s_t$$

Commodity Markets

(3) $$\bar{Y} = \beta(q_t - p_t) + E(w_t \mid I_t^G)$$

(4) $$p_t = p_t^* + s_t$$

(5) $$q_t = \bar{q}^* + s_t$$

Exogenous Processes

(6) $$m_t = m_{t-1} + v_t$$

(7) $$w_t = w_{t-1} + u_t$$

Notation

- i_t = nominal interest rate
- m_t = logarithm of the money supply
- p_t = average of logarithms of the domestic prices of domestic goods
- q_t = logarithm of the domestic price of foreign goods
- s_t = logarithm of the spot exchange rate (domestic-currency price of foreign exchange)
- w_t = domestic demand disturbance

$\bar{Y}$ = level of domestically produced output

The disturbance terms u_t, v_t, and z_t are assumed to be serially uncorrelated and mutually orthogonal. Greek letters represent positive structural parameters; an asterisk indicates a foreign variable; exogenous variables with bars above them are assumed constant; and subscripts refer to the time dimension which takes integer values. Finally, the operation $E(x_t \mid \phi_t)$ denotes linear least squares prediction of x_t given the information set ϕ_t.

Equation (1) is money-market equilibrium; the supply of real money balances $(m_t - p_t)$ equals the demand for them $(-\alpha i_t + z_t)$. For simplicity, we have set the income elasticity of money demand at unity which allows us to avoid defining a price index for deflating the logarithms of nominal money (m_t) and nominal income $(p_t + \bar{y})$. Aggregate output is normalized to unity making $\bar{y}$, its logarithm, equal to zero.

Equation (2) is the assumption of uncovered interest parity which traditionally is used in models of this type to represent capital-market equilibrium.[7] The information set I_t^A contains the structure of the model and the values of all macro variables dated t or earlier. Since equations (1)–(7) are the aggregated equations of the model, (the disaggregated version of the goods market will be presented below), agents with information set I_t^A know all of the variables in these equations. We avoid discussions about the relative sizes of our two information groups by assuming that the agents possessing I_t^A are risk neutral and well financed. Since this group's information is superior concerning macro variables and since only macro variables are relevant to the asset market, it is in the interest of all agents to allow the group with superior macro information to dominate the forward market and to set the forward rate equal to their expected future spot rate, $E(s_{t+1} \mid I_t^A)$.

The goods market is described by equations (3)–(5) which result from the following aggregation. There are n markets in which home goods are produced, and in each market, the price, p_t^i, $i = 1, \ldots, n$, is set at the level expected by price setters to clear the market. Prices of all goods are known to the price setters in each market. Equation (3) results from summing the following condition across markets

$$\bar{Y}^i = (\beta_1/n)(q_t - p_t) + \beta_2(p_t - p_t^i) + E[(w_t/n) \mid I_t^G] \tag{3a}$$

where $\bar{Y}^i$ is the fixed level of output in market i, $(\beta_1/n)(q_t - p_t) + (w_t/n)$ is market i's share of aggregate demand for the home goods, and $\beta_2(p_t - p_t^i)$ reflects the change in demand in market i due to deviations of its price, p_t^i, from the average price of

[7] We view equation (2) as a useful simplifying assumption that allows us to focus directly on the determination of exchange rates and prices without complicating the theory with a discussion of time-varying risk premiums. There is considerable controversy regarding the empirical validity of the expression. The evidence in Hansen and Hodrick [1983] suggests that statistically significant risk premiums may characterize the relationship between forward exchange rates and expected future spot rates. Their evidence also indicates that the risk premiums are small in comparsion to unanticipated changes in spot rates which are the focus here.

home goods, $p_t=(1/n)\sum_{i=1}^{n} p_t^i$. Since firms do not observe w_t directly, they must infer its value from available information, I_t^G, which is common to all firms. This information set contains the past history of all macroeconomic aggregates but only current information about all prices in the economy including interest rates and exchange rates. Summing equation 3a across the n markets produces equation 3 with $\beta_1=\beta$ and $\bar{Y}=\sum_{i=1}^{n} \bar{Y}^i$.

Equations 4 and 5 are the arbitrage conditions for domestic and foreign goods. The foreign price of foreign goods is assumed to be fixed at $\bar{q}^*$, and the average foreign price of the domestic good is $p_t^*=p_t-s_t$. Since s_t and $\bar{q}^*$ are in I_t^G, domestic price setters know that q_t-p_t is the relative price of the product although they do not know if they have charged the price which will actually clear the market.

Our model is completed by the specification of processes on the exogenous variables in equation 6 and 7. We work with simple time series processes whose innovations are uncorrelated which keeps the inference problems tractable. Equation 6 is the money-supply process. We view the random element in 6 as an inherent result of the interaction of the central bank with the commercial banks and the public in producing the medium of exchange called money. Equation (7) is the aggregate goods market disturbance which can be thought of as influences of fiscal policies such as tariffs and changes in domestic and foreign demand. For notational simplicity, we have suppressed all constant terms in equations 1 and 3. In addition, we will ignore the constants $\bar{Y}$, $\bar{q}^*$, and $\bar{i}^*$ in presenting the solutions to the model.

3. SOLUTIONS TO THE MODEL

To highlight the difference between our asymmetric information model and typical exchange rate models, we present in this section solutions of the model under three different assumptions about the information sets of agents. These assumptions are

ASSUMPTION (1). All agents possess full information making $I_t^A=I_t^G$, and this information set includes all variables dated t and earlier. This assumption makes prices fully flexible as in the work of Frenkel [1976].

ASSUMPTION (2). Goods market agents possess only information pertaining to variables dated $t-1$ and earlier while in asset markets agents act with full information of variables dated t and earlier. This assumption makes p_t predetermined and corresponds to the work of Dornbusch [1976].

ASSUMPTION (3). Our asymmetric information assumption where I_t^A contains all variables dated t and earlier and I_t^G contains all variables dated $t-1$ and earlier as well as all period t prices.

In each case, the solution is readily obtained by the method of undetermined coefficients. The average price of domestic output and the exchange rate are postulated to be linear functions of the underlying state of the economy, which is a vector of market fundamentals $(m_{t-1}, v_t, w_{t-1}, u_t, z_t)$, and the equations representing the money market and the goods market are solved simultaneously using the exogenous processes and the following postulated solutions:

(8a) $$s_t = \lambda_{i1} m_{t-1} + \lambda_{i2} v_t + \lambda_{i3} w_{t-1} + \lambda_{i4} u_t + \lambda_{i5} z_t$$

(8b) $$p_t = \phi_{i1} m_{t-1} + \phi_{i2} v_t + \phi_{i3} w_{t-1} + \phi_{i4} u_t + \phi_{i5} z_t,$$

where $i = 1, 2, 3$ indexes the flexible-price, predetermined price and asymmetric-information models referred to as Assumptions 1–3 above. The solutions for the λ and ϕ coefficients are presented in Table 1.[8]

TABLE 1

REDUCED FORM COEFFICIENTS

Endogenous Variable	Model Type	Coefficients on Reduced Form Variable: m_{t-1}	v_t	w_{t-1}	u_t	z_t
Exchange Rate	Flexible	1	1	$-1/\beta$	$-1/\beta$	$-\delta$
Price	Flexible	1	1	0	0	$-\delta$
Exchange Rate	Predetermined	1	$1+(1/\alpha)$	$-1/\beta$	$-1/\beta$	$-1/\alpha$
Price	Predetermined	1	0	0	0	0
Exchange Rate	Asymmetric	1	$1+\delta\sigma_u^2\sigma_z^2/\psi$	$-1/\beta$	$-1(1/\beta)+(1/\beta)\delta\beta^2\sigma_v^2\sigma_z^2/\psi$	$-\delta+\delta\sigma_u^2\sigma_v^2/\psi$
Price	Asymmetric	1	$1-\alpha\delta\sigma_u^2\sigma_z^2/\psi$	0	$-(1/\beta)\cdot\alpha\delta\beta^2\sigma_v^2\sigma_z^2/\psi$	$-\delta-\alpha\delta\sigma_u^2\sigma_v^2/\psi$

Note: $\delta \equiv [1/(1+\alpha)]$, $\psi \equiv (\beta^2\sigma_v^2\sigma_z^2+\sigma_u^2\sigma_z^2+\sigma_u^2\sigma_v^2)$

Before conducting the comparison of the three regimes, it is useful to provide precise definitions of two concepts. First, a variable is said to *overshoot* (undershoot) when its immediate response to a disturbance is greater (less) in absolute value than the response of the variable in some appropriate benchmark model. We will use the full-information flexible-price model as our benchmark. Second, we define the terms of trade as the relative price of imports, $q_t - p_t$. Since we have held q_t^* constant and normalized it to zero, the terms of trade is merely $s_t - p_t$. We turn now to the comparison of the effects of the state variables on the exchange rate, the domestic price, and the terms of trade.

[8] An earlier draft of this paper contains explicit derivations of the solutions to all versions of the model and is available from the authors. The solution of the asymmetric information model involves signal extraction which is explained by Sargent [1979]. Our Appendix provides some details of the solution. See Harris and Purvis [1981] and Harkness [1982] for other international economic models using this technique.

3.1. *Effects of* m_{t-1}. In all versions of the model past money, m_{t-1}, has a unit coefficient in both the exchange-rate and domestic-price solutions. Past money is neutral in that it does not affect the terms of trade.[9]

3.2. *Effects of* v_t. Unanticipated increases in the money supply are permanent in this model. Hence, with flexible prices and full information, the domestic price and the exchange rate respond equiproportionately to an innovation in money, v_t. Notice that when prices are predetermined they cannot respond to v_t, but the response of the exchange rate is greater than unity, which is the classic Dornbusch overshooting result.

The asymmetric-information model produces exchange-rate overshooting and domestic-price undershooting in response to an innovation in the money supply. Consequently, a monetary disturbance causes the terms of trade to overshoot since the effect of v_t on the terms of trade is positive, and there is no effect in the flexible-price model. The mechanism which produces overshooting of exchange rates here though, is somewhat different from the mechanism in the Dornbusch model since it rests on the informational asymmetries across asset and goods markets.

When a positive money supply disturbance occurs, s_t, p_t and $E(s_{t+1} \mid I_t^A)$ must move to eliminate the incipient excess supply in the money market while leaving the capital market in equilibrium. The conditional expectation of next period's exchange rate moves by the full amount of the shock because asset markets have full information, but price setting agents rationally attribute part of this movement to a fall in real demand for goods. They allow the terms of trade to deteriorate which increases real balances and necessitates exchange rate overshooting.

3.3. *Effects of* w_{t-1}. Our assumed information structure makes w_{t-1} an observable variable for all agents in all versions of the model. A positive w_{t-1} reflects a permanent positive component in demand for the home good. Given the fixed supply of the product, its relative price must rise with an increase in w_{t-1}, that is, the terms of trade must improve. As a result of the assumed unit elasticity of money demand, the improvement in the terms of trade occurs entirely through an appreciation of the exchange rate. An increase in w_{t-1} lowers the exchange rate by the proportion $1/\beta$ in all three models.

3.4. *Effects of* u_t. Unanticipated increases in real aggregate demand are also assumed to be permanent in this model. Consequently, expected rates of return in asset markets need not change in reestablishing equilibrium after a demand shock which is why domestic prices need not change. In all versions of the model, the demand shock requires a reduction in the terms of trade, and the exchange rate falls by $1/\beta$ to affect the change in the flexible price case. In the predetermined-price version, the fall in the exchange rate is also $1/\beta$. Domestic

[9] We assume that all agents obtain full information about the state of the economy with a one-period lag. Modifying this assumption as in Chari [1980] would lengthen the state vector, delay the advent of monetary neutrality, and increase the persistence of shocks.

prices need not change and do not when they are predetermined.

In the asymmetric-information model, an aggregate demand disturbance causes exchange-rate undershooting since the absolute value of the response is less than $1/\beta$. Further, innovations in real demand cause the domestic price to overshoot since the effect on prices is negative in the asymmetric model and zero in the flexible-price solution. The combined effect of u_t on the terms of trade is undershooting since it falls by less than $1/\beta$.

A positive disturbance to the demand for goods is misinterpreted by goods market agents partly as a fall in the nominal money supply. Nominal goods prices are decreased in proportion to the perceived amount of the decrease in the money supply. This increases real balances which dampens the appreciation of the current exchange rate relative to the expected exchange rate to allow equilibrium in the asset markets to obtain.

3.5. *Effects of* z_t. Under full information, a positive temporary disturbance to money demand causes the domestic price and the exchange rate to fall equiproportionately which increases real balances and the opportunity cost of holding money. The latter effect arises because the expected future exchange rate does not change. Both effects offset the increased demand for money allowing asset markets to reequilibrate. With no correlation between the disturbances in the money market and the goods market, the innovation in the demand for money does not affect the terms of trade if it is fully perceived. The transitory money demand disturbance produces exchange-rate overshooting in the predetermined price case. Under asymmetric information, the model exhibits exchange-rate undershooting, domestic price overshooting, and terms of trade overshooting. These responses are produced by the following sequence of events. Under the assumed information structure, the expected future exchange rate does not change with an innovation in money demand because asset market specialists know the shock is transitory. Price-setting agents, on the other hand, think that the lack of change in the expected future spot rate is consistent with either a money-demand shock or offsetting money-supply and goods-market disturbances. Consequently, the observed fall in the spot exchange rate with no change in the future exchange rate signals to price-setting agents the possibility of a fall in the money supply that is offset by a decrease in demand for goods. Price setters lower the nominal price of goods and allow the terms of trade to deteriorate.

4. EXCHANGE-RATE AND PRICE VOLATILITY

Our theory was constructed to meet the criticisms outlined in the introduction while remaining consistent with the stylized facts of high exchange-rate volatility and exchange-rate volatility in excess of domestic-price volatility. In this section, we examine the predictions of our model for the volatility of the two variables and examine how the volatilities and responses of the endogenous variables change with changes in the variances of the underlying exogenous stochastic processes.

We define volatility of a variable, x_t, to be the variance of its one-step-ahead prediction error. The definition of volatility is

$$V_i(x_t) = E\{[x_t - E(x_t \mid I^A_{t-1})]^2 \mid I^A_{t-1}\}\,. \tag{9}$$

Letting $i=1, 2, 3$ index the flexible-price, predetermined-price, and asymmetric information versions of our model as before, we find that prices are "sticky" in our asymmetric-information model in the sense that the volatility of prices is less than under full information:

$$V_1(p) - V_3(p) = [\alpha^2/(1+\alpha)^2]\sigma_u^2\sigma_v^2\sigma_z^2/\psi > 0. \tag{10}$$

Increasing the variance of one of the fundamental state variables increases the volatility of prices under both solutions, but the right-hand side of equation (10) also increases indicating that prices become more "sticky" even as they increase in volatility.[10]

All three versions of the model produce exchange-rate volatility in excess of domestic-price volatility:

$$V_1(s) - V_1(p) = (1/\beta^2)\sigma_u^2 \tag{11}$$

$$V_2(s) - V_2(p) = [1+(1/\alpha)]^2\sigma_v^2 + (1/\beta^2)\sigma_u^2 + (1/\alpha^2)\sigma_z^2 \tag{11b}$$

$$V_3(s) - V_3(p) = (1/\beta^2)\sigma_u^2\{1-[(1-\alpha)/(1+\alpha)](\beta^2\sigma_v^2\sigma_z^2/\psi)\}\,. \tag{11c}$$

When $\alpha > 1$, our model of asymmetric information produces a greater volatility of exchange rates relative to domestic prices than under the full information solution even though $\lambda_{35}^2 < \phi_{35}^2$. If any of the variances of the fundamental processes increases, the volatility of exchange rates also increases, and from equation (11c) we see that the increase in the volatility of exchange rates exceeds the increase in the volatility of domestic prices.

An interesting aspect of our model of exchange-rate and price determination is that overshooting and undershooting change with changes in the stochastic environment of the economy. These changes occur because agents interpret the signals they receive from their observations of s_t and $E(s_{t+1} \mid I_t^A)$ in different ways depending on their stochastic environment. As the variance of a particular exogenous variable approaches zero, the effects of the other two disturbances on the exchange rate and the domestic price converge to their full-information values. This is true since uninformed agents continue to observe two separate pieces of information which they know are caused only by two shocks in the limit. Given the structure of the economy, they become fully informed. The behavior of the

[10] In both models, the volatility of prices goes to infinity as one of the variances goes to infinity. Hence, it may be appropriate to examine the ratio

$$[V_1(p) - V_3(p)]/[V_1(p)] = [\alpha^2/(1+\alpha)^2]/\{1+\beta^2(\sigma_v^2/\sigma_u^2)+[\beta^2/(1+\alpha)^2](\sigma_z^2/\sigma_u^2) + [1/(1+\alpha)^2](\sigma_z^2/\sigma_v^2)+(\sigma_v^2/\sigma_z^2)+[1/(1+\alpha)^2]\}$$

which goes to zero whenever any variance goes to zero or to infinity. Since the volatilities are the same when any one of the variances equals zero or infinity, there will be a maximum deviation that occurs as a variance is increased, ceteris paribus.

coefficient whose variance is going to zero, on the other hand, is quite different. As its variance becomes small, agents attribute less and less of any of their observations to that particular source. Hence, the responses of exchange rates and prices to a shock from that source under asymmetric information show an increasing deviation from their full information values as the variance goes to zero. We now turn to a discussion of the effects of changes in σ_u^2, σ_v^2, and σ_z^2 on the coefficients of u_t, v_t, and z_t in the solutions for prices and exchange rates.

4.1. *Effect of* σ_u^2. The variance of the goods-market disturbance is σ_u^2. When $\sigma_u^2=0$, the coefficients of the money-supply disturbance for the exchange rate and domestic price, λ_{32} and ϕ_{32}, are at their full information values of unity. As σ_u^2 rises monotonically, λ_{32} falls exacerbating exchange-rate overshooting and domestic-price undershooting in response to money-supply shocks. The coefficients of the money-demand shocks are also at their full information value when $\sigma_u^2=0$, but as σ_u^2 increases, the response of the exchange rate to a money-demand shock decreases while the response of the domestic price increases. As σ_u^2 goes to infinity, the coefficients of the real shock go to their full information values, but as the variance of the real shock shrinks, the coefficients converge to the same value since in the limit when real shocks are not entering the system, price setters think that relative prices should not change.

4.2. *Effect of* σ_v^2. The variance of the money-supply disturbance is σ_v^2. As σ_v^2 rises, the coefficient of the money-supply disturbance in the exchange-rate equation, λ_{32}, falls and that in the price equation, ϕ_{32}, rises. Both approach unity as the variance of v_t goes to infinity. As σ_v^2 grows, agents know that monetary shocks are becoming a relatively more important part of their stochastic environment, and they appropriately attribute more of their observations on the changes in their environment to that source. This causes the real effect of a monetary shock to be dampened. In the limit, as the variance of v_t goes to infinity, agents fully perceive a monetary shock through its influence on s_t and $E(s_{t+1} \mid I_t^A)$.[11] It is interesting to note that if a monetary authority is successful at reducing the variance of v_t, it will find that exchange rates fluctuate more for any given disturbance to v_t. Maximum overshooting in our model of asymmetric information is $1/(1+\alpha)$ which is never greater than the amount of overshooting in the predetermined-price model. Maximum overshooting or undershooting for all other cases is similarly dampened relative to the predetermined-price solution since we allow agents to see some contemporaneous information.

The behavior of the coefficients of the goods-demand disturbance and the money-demand disturbance as σ_v^2 increases demonstrates that less information about these shocks is conveyed to the uninformed agents, the larger is the variance of the money supply. The absolute values of the coefficients on the two shocks

[11] The analogous result in the rational expectations business cycle literature is that the slope of the Phillips curve goes to infinity as the variance of monetary shocks becomes infinite. Output no longer responds to innovations in nominal prices.

fall in the exchange-rate and rise in the price equation which exacerbates exchange-rate undershooting and domestic-price overshooting.

4.3. *Effect of* σ_z^2. The variance of the money-demand disturbance is σ_z^2. The larger are money-demand disturbances, the more exacerbated are exchange-rate overshooting and domestic-price undershooting with respect to money-supply shocks. As σ_z^2 rises, the response of the exchange rate to real goods-market disturbances is muted while the response of prices to these shocks is exacerbated. The change in the terms of trade in response to a real shock is smaller than would take place under full information because agents misinterpret part of any positive shock to the real goods market as a positive money-demand shock or a negative money supply shock. As σ_z^2 grows, the deviation of the terms of trade from its full information value asymptotically approaches its maximum error which is $(1/\beta)[\beta^2\sigma_v^2)/(\beta^2\sigma_v^2+\sigma_u^2)]$.

As σ_z^2 approaches infinity, the responses of exchange rates and prices to money-demand shocks, λ_{35} and ϕ_{35}, approach their full information values $[-1/(1+\alpha)]$. In contrast, as σ_z^2 goes to zero, the response of λ_{35} goes to zero while ϕ_{35} goes to minus unity. When a positive money-demand shock occurs, price-setting agents misinterpret it as an offsetting decrease in both the money supply and real demand.

5. CONCLUSIONS

The purpose of this paper was to present a model of exchange-rate and price determination that overcomes a deficiency we perceived in the standard specification of the Dornbusch [1976] model while remaining consistent with that model's primary implications. By redesigning the pricing rule, we have met our objective and derived additional insights.

Our model was designed to overcome our concerns regarding price determination in the standard model. In stochastic presentations of that model, domestic prices of domestic goods are typically treated asymmetrically from domestic prices of foreign goods by making the prices of domestic goods predetermined variables while allowing domestic prices of foreign goods to jump with the exchange rate. Neither the predetermination nor the asymmetry is consistent with our view of the world. In addition, the explicit models of price setting which have been offered in support of the standard pricing rule are based on menu cost considerations rather than information costs which we believe to be the quantitatively more important cost.

Our pricing scheme required firms to set prices prior to the realization of demand to them, but we allowed firms to base their prices on an information set that included observations on economy-wide interest rates and exchange rates. As a consequence, prices in our model are "sticky" only in the sense that they are less flexible than the prices which would be set if firms had full information. This type of stickiness increases with increases in the variances of the fundamental processes even though prices become more volatile. Since firms are engaged in a signal extraction problem, the amount of overshooting or undershooting of exchange rates and prices in response to a current unperceived shock to the economy is a function of the relative variances of those shocks. One of our major findings in this regard was that exchange rates would overshoot their full-information change responding more than proportionately to an innovation in the money supply, but the amount of overshooting decreased with an increase in the variance of the money supply.

We also demonstrated that the volatility of exchange rates relative to the volatility of domestic prices increased with an increase in any of the fundamental variances of the model. In implementing our model empirically it would be important that we characterize how the conditional variances of the shocks evolve over time if indeed they do change. We demonstrate in the model that the responses of exchange rates and prices to innovations in all of the state variables of the economy are functions of the relative variances of these variables. Hence, assuming a constant response in estimating the model when the conditional variances were not constant would lead to imprecise, inaccurate inference about the validity of the model. Indeed, Cumby and Obstfeld [1983] have provided evidence against the hypothesis that price-level and exchange-rate forecast errors are characterized by conditional homoscedasticity. Considerations such as these may be partly responsible for the empirical failure of popular exchange-rate models, as documented by Meese and Rogoff [1983].

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APPENDIX

The solution to the asymmetric information version of the model involves signal extraction by firms who infer expected values of aggregate disturbances from their observations on market clearing prices in asset markets. In this appendix, we outline the solution technique.

Since firms have complete time $t-1$ macroeconomic information, we need only consider the innovations to the firms' information set provided by asset markets. The money market equilibrium (1) may be written as

$$m_{t-1} + v_t - p_t = -\alpha i_t + z_t. \tag{A1}$$

Because prices and interest rates are in the information set, the money market equilibrium provides information about the linear combination of disturbances $g_{1t} = v_t - z_t$. Also, since firms observe the capital market equilibrium (eq. 2), they observe the well-informed agents expected future spot rate. Given the postulated solution for the exchange rate (eq. 8a), firms learn the linear combination of the disturbances $g_{2t} = \lambda_{31} v_t + \lambda_{33} u_t$. Firms then employ signal extraction techniques to infer an expected value for the demand disturbance given by

$$E(u_t \mid I_t^g) = \gamma_{u1} g_{1t} + \gamma_{u2} g_{2t} \tag{A2}$$

where
$\gamma_{u1} = -\lambda_{31}\lambda_{33}\sigma_u^2\sigma_v^2/\Delta$ and $\gamma_{u2} = (\sigma_v^2+\sigma_z^2)\lambda_{33}\sigma_u^2/\Delta$ are the linear least squares coefficients, and $\Delta = \lambda_{31}^2\sigma_v^2\sigma_z^2 + \lambda_{31}^2\sigma_u^2\sigma_v^2 + \lambda_{33}^2\sigma_u^2\sigma_z^2$. By substituting (A2) into (eq. 3) and solving the model with the method of undetermined coefficients, one generates the solution given in Table 1.

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