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# Exchange Rate Volatility, Pricing to Market and Trade Smoothing

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## Abstract

This paper investigates the consequences of exchange rate volatility on the variability of export prices and quantities in the presence of market segmentation and pricing to market. Firms stabilize destination prices through systematic price discrimination, limiting the degree of exchange rate pass-through. Consequently, the variability of exchange rates is not fully translated into prices and quantities at the point of destination. Empirical estimates using aggregate price data for the G-7 industrial countries show incomplete pass-through in variances, with considerable variation among these countries. U.S. industry specific data also indicate incomplete pass-through in most cases, with considerable variation across industries.

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**SUMMARY**

Since the breakdown of the Bretton Woods fixed exchange rate system in 1973, there has been a substantial increase in nominal and real exchange rate volatility, with little adverse effect on the level of international trade. To understand why the prices and quantities of traded goods may be relatively insulated from short-term variations in exchange rates, this paper develops a model of pricing-to-market behavior based on the assumption of market segmentation, where economic forces and structural rigidities limit convergence in the prices of the same goods across different markets, so the law of one price does not hold.

The paper develops a two-country model of monopolistic competitors who set prices for their differentiated products and choose production levels depending on the demand for their individual products. The analysis focuses on the consequences of pricing to market for the degree of pass-through of exchange rate changes on the levels and variances of export prices and quantities. It finds that this pass-through, which depends importantly on the convexity of costs and the openness of the economy, is incomplete and that unpredictable movements in exchange rates have a relatively small effect in raising the level of export prices and thereby in reducing the volume of international trade.

The paper provides some illustrative empirical estimates of the variance pass-through, i.e., the extent to which the variance of the exchange rate is reflected in the variance of import prices, using aggregate price data for the G-7 countries and industry-specific data for the United States. The variance pass-through is incomplete except in industries with homogenous products where pricing to market is unlikely to hold. Overall, the theoretical implications of pricing-to-market behavior, as well as the illustrative empirical results, suggest that the substantial short-run volatility of nominal exchange rates over the last 25 years has not adversely affected economic performance.

## I. INTRODUCTION

Following the collapse of the Bretton Woods exchange rate system in 1973, there has been a considerable increase in the short–term variability of exchange rates. This is clearly evident in Figure 1, which shows the month–to–month percentage changes in the bilateral exchange rates of the three major industrial countries. As prices tend to be sticky in the short run, this rise in nominal exchange rate variability has also been associated with a roughly comparable increase in the volatility of real exchange rates.[2] Moreover, the greater variability in exchange rates has been matched by a rise in uncertainty, as short–run movements in exchange rates tend to be unpredictable. This unpredictability has been manifested in the relative lack of success of exchange rate models in explaining month–to–month and quarter–to–quarter changes in exchange rates as well as tests of bias in the forward exchange market which show that exchange rates do not vary as predicted by the forward rate or the interest rate differential.[3]

The large short–run movements are generally seen as a consequence of the fact that exchange rates behave as forward–looking asset market prices. As foreign exchange activity is dominated by financial transactions rather than generated by international flows of goods and services, exchange rates react quickly to news about current and prospective monetary and fiscal policies as well as other economic fundamentals. As this news is unpredictable and random, so are short–run changes in exchange rates.

The high degree of volatility in the floating exchange rates of the industrial countries is viewed by many as a key defect in the current international monetary system.[4] It is viewed as costly because it increases uncertainty about relative prices and therefore unnecessarily restricts otherwise profitable international investment and flows of goods and services. McKinnon (1988), for example, believes that uncertainty about the future relative purchasing

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[2]See Table 2 in Mussa et al. (1994), which shows that the standard deviation of month–to–month changes in the real exchange rate between the U.S. dollar, the yen and the deutsche mark since 1973 has risen over threefold, from under 1 percent per annum prior to 1992 to over 3 percent subsequently.

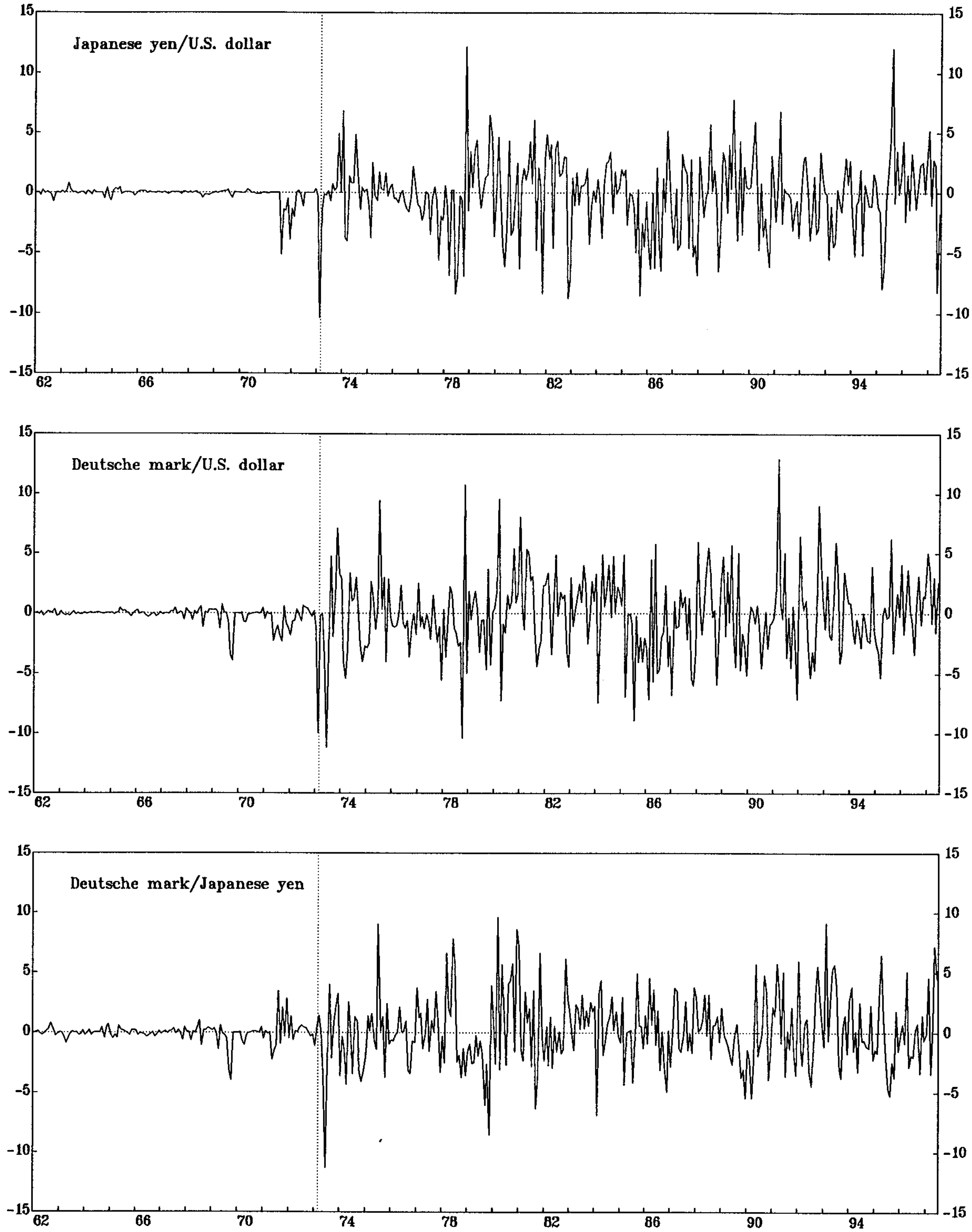
[3]See Meese and Rogoff (1983) and (1984), and Frankel and Rose (1995). However, it should be noted that there is now growing evidence that over longer time periods nominal and real exchange rates display a systematic relationship to fundamental economic variables. This evidence relates both to the long–run PPP, which has recently been surveyed by MacDonald (1995) and Rogoff (1996), and to changes in the real exchange rate, which has been analyzed in several papers in Williamson (1994) and by Faruqee (1995) and Stein et al. (1995). See also Mark (1995).

[4]For a recent and comprehensive discussion and analysis of recent international currency experience, see Obstfeld (1995).

Figure 1.

## Germany, Japan, and the United States:
## Volatility of Nominal Exchange Rates, January 1962 - June 1997

*(Percentage changes from previous month)*




Dotted line indicates approximate date of breakdown of Bretton Woods System.
Source: IMF, International Financial Statistics.

powers of national fiat monies of the three major industrial countries interferes with international investment decisions, so that pegging the nominal exchange rates of these three countries at approximate purchasing power parities would be beneficial. The Bretton Woods Commission (1994) also argues that the costs of exchange rate volatility are high and concludes that international policy coordination is needed to stabilize exchange rates. In a similar vein, Williamson has for some time recommended target zones as a means to reduce the degree of exchange rate volatility and misalignments, most recently in Williamson and Henning (1994).

Despite the observed fact of higher nominal and real exchange rate volatility under current international monetary arrangements than under the Bretton Woods system, there is little evidence that this has adversely affected economic performance. The literature on the issue has recently been exhaustively surveyed by Goldstein (1995). He finds little evidence of a robust cause and effect relationship and in the relatively few instances where a statistically significant impact of exchange rate volatility on economic performance has been found, the effect is typically small and generally declining over time. He concludes that the principal shortcoming of the current exchange rate system—at least regarding the key currencies at the center of the system—involves misalignments of real exchange rates, not the volatility of these rates. This view is also shared by Obstfeld (1995, p. 144).

It thus appears that the level of international transactions is relatively insulated from the variability of one of the key determining variables. In particular, both the quantities and the prices of exports and imports (except possibly for homogeneous internationally traded commodities) are much less variable than exchange rates. For example, Engel (1993) presents evidence showing that the relative price of different goods in the same market tends to be much less variable than the relative price of the same good across different markets.[5] This situation is hard to reconcile with the standard paradigm of perfect competition and costless price adjustment, which implies that the law of one price holds between prices of the same or similar goods across different markets characterized by different currencies. Indeed, there is now considerable evidence that the law of one price does not hold, at least in the short run. Consequently it is necessary to explore alternative approaches to explain this failure.

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[5]Much of the empirical evidence on departures from one price across countries has drawn from the experience of the United States in the 1980s and focused on the behavior of U.S. import prices during the period of massive U.S. dollar appreciation and subsequent depreciation. For example, Krugman (1987) finds that more than 30 percent of the real appreciation of the dollar between 1980 and 1984 was reflected in the divergence between prices of U.S. imports and the dollar prices of the same goods in other markets. See also Dornbusch (1987) and Hooper and Mann (1987) for an analysis of import prices during this episode. Goldberg and Knetter (1997) provide a useful survey of the literature on the relationship between exchange rates and prices of traded goods.

In an attempt to understand why the prices and quantities of traded goods are relatively insulated from short–run variations in nominal exchange rates, this paper develops a model of market segmentation which draws out some of the economic implications of pricing–to–market behavior. With pricing to market, i.e., with firms taking explicit account of conditions specific to particular export markets, the economic forces that would normally assure continuous spatial arbitrage are absent. This approach essentially breaks from standard models based on the law of one price by highlighting market segmentation and thereby acknowledging the presence of economic forces and structural rigidities that limit convergence in the prices of the same goods across different markets.

Recent papers have examined some of the macroeconomic implications of market segmentation and pricing to market. For example, Faruqee (1995) shows that, in the presence of nominal rigidities, pricing to market allows for greater local price stability (in local currency terms), which leads to further persistence in real exchange rates than under price stickiness alone. Betts and Devereux (1996) also find that under pricing to market, consumption across countries tend to be less correlated (as shown empirically) than what a model of integrated markets would suggest.

This paper by contrast, investigates the consequences of pricing to market for the *variability* of prices and quantities of traded goods in the face of nominal exchange rate fluctuations. On the assumption that imperfectly–competitive producers can discriminate on the basis of price between local and foreign markets, i.e., that market segmentation is possible, the model is used to examine the degree of pass–through of predictable exchange rate changes to the levels and variances of export prices and quantities. The extent of pass–through on the level of export prices, which depends importantly on the convexity of costs and the openness of the exporting economy, is shown to be incomplete. As a consequence the pass–through of exchange rate volatility on the variance of export prices is also incomplete. The analysis also explores the effects of exchange rate uncertainty, i.e., unpredictable movements in exchange rates, on the level of trade flows. Such uncertainty is shown in the context of the model to have a very small impact in raising the level of export prices and thereby in reducing the volume of international trade.

The paper also provides some illustrative empirical estimates of the variance pass–through , that is, the extent to which the variance of the exchange rate is reflected in the variance of import prices. Using aggregate price data for the G–7 countries, where it is possible to take account of the effect of changes in costs, it is found that there is incomplete pass–through, although there is significant variation in the extent of such pass–through across these countries. Using industry specific data for the United States, where it is not possible to take account of changes in costs, also reveals incomplete pass–through in many industries. There is, however, considerable variation across industries, and in a number of cases the variance of import prices exceeds that of the exchange rate by a significant margin. This is found to be the case for those industries characterized by homogenous products where the law of one price is more likely to hold and where there is considerable cyclical variability in prices that is unrelated to exchange rate changes. In these industries, therefore, the conditions for pricing–to–market behavior would not be expected to hold.

The paper is organized as follows. Section II develops an illustrative two–country model of monopolistic competition and market segmentation. Section III derives the degree of exchange rate pass–through implied by the pricing–to–market behavior in the model as well as the link between the variability of exchange rates and export prices and quantities. Section IV provides some empirical estimates based on aggregate data for the G–7 industrial countries and disaggregated SIC data for the United States. Finally, Section V offers some concluding remarks.

## II. A Model of Pricing to Market

The model consists of two countries—home and foreign—with each country composed of *n* producer-consumers. These individual agents produce and sell a differentiated product in order to purchase and consume the products produced by all other agents. Each agent acts as a monopolistic competitor, setting its price, taking others' prices as given, and choosing a level of production depending on the demand that the individual producer faces. Using these basic assumptions, the appendix lays out the set–up of the model the builds on the constant elasticity of substitution (CES) approach developed by Dixit and Stiglitz (1977) and used by Blanchard and Kiyotaki (1987).

The home and foreign, i.e., export demand functions for an individual home producer $I$ are given in Table 1, corresponding to markets 1 and 2, respectively.[6] The foreign money stock, $M^*$, is expressed in units of foreign currency, and $E$ is the nominal exchange rate expressed as the home currency price of foreign currency. The constant elasticity of substitution between any two varieties from the same industry is denoted by $\epsilon$, with $\epsilon > 1$. The extent to which residents in each country favor their own goods in consumption is given by $\alpha$, which represents the nominal expenditure shares allocated to locally-produced goods in each country. Assuming that consumers have a preference for the goods that they produce themselves, we specify that $0.5 < \alpha < 1$. Solving the producer's problem by maximizing real revenues from domestic and export sales minus the utility costs of production, yields the optimal price for each producer for each market. These equations are shown in the second row of Table 1, where lowercase letters denote logarithms of variables.

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[6]See the appendix for the derivation of these equations.

Table 1. Demand Functions and Price Setting Rules
under Monopolistic Competition

| | Home Market | Foreign Market |
|---|---|---|
| Demand Functions (levels) | $Y_i^1 = \left(P_i^1/P^1\right)^{-\epsilon}\left(\alpha M/P^1\right)$ | $Y_i^2 = \left(P_i^2/P^2\right)^{-\epsilon}\left((1-\alpha)EM^*/P^2\right)$ |
| Optimal Price (log levels) | $p_i^1 = \pi m + \theta q + (1-\pi-\theta)p^1$ | $p_i^2 = \pi(e+m^*) + \theta q + (1-\pi-\theta)p^2$ |

Demand for output $Y_i$ in each market is a function of relative prices and aggregate demand. Demand for a particular variety is a decreasing function of its price $P_i$ relative to other prices in the industry, where $P$ is the relevant industry index of producer prices set by producer $I$ and his $(n-1)$ fellow producers in each market. Second, product demand for each variety depends on aggregate demand facing the industry in each market, where real money balances measure real aggregate demand in each market through a simple quantity equation relationship.

Note that foreign prices in each market do not enter the relative–price term. This result reflects the simplifying assumption that countries engage in one–way trade between industries, with complete country specialization at the industry level. With this type of *interindustry* trade, the complete absence of import–competing firms in the industry severely limits home producer sensitivity to foreign producer prices and the exchange rate. However, this extreme assumption about the pattern of trade places a *lower* bound on the degree of pricing–to–market behavior. Incorporating the effects of two–way, *intraindustry* trade would only increase the incentives for, and the degree of, pricing to market, leading to significantly lower pass–through in export prices and, hence, greater stability in destination prices and quantities.[7] With greater interactions between domestic and foreign producers under

[7]Recent empirical evidence documenting the degree of cross–sectional variation in pricing-to-market behavior across industries is reported by Knetter (1992). Examining various export prices for Germany, Japan, the United Kingdom, and the United States, Knetter (1992) finds that *industry* is the critical dimension explaining the variation in the pattern of pricing–to–market practices within *and* across countries. Much of this variation can be explained by trade pattern differences.

intraindustry trade, relative country size also becomes a factor in affecting the degree of pass-through in export prices.[8]

The optimal price-setting rules (ignoring constants) for both markets in the case of interindustry trade are given in Table 1 from the perspective of the representative home producer. The constant terms (not shown) are basically composed of technology parameters, and changes in the constant would represent shifts in the cost schedule (supply shocks) which are not explicitly considered here.[9]

Reflecting demand–side considerations, the optimal (log) price $p_i$ expressed in units of the home, i.e., exporter's currency, is a weighted average of the local money stock, consumer prices at home, $q$, and producer prices for the industry prevailing in that destination ($p^1$ or $p^2$), with all weights being strictly positive.[10] For example, the price rule for the home destination places a weight $\pi$ on the domestic money stock which represents nominal aggregate demand in the home market.[11] The corresponding component and weight appear in the optimal export price rule with regards to foreign nominal aggregate demand (expressed in units of home currency). With an increase in aggregate demand, there is an increase in demand for each individual variety, which generates a rise in price with convex costs.

The weight placed on domestic consumer prices, $q$, captures a real income effect.[12] As each producer is also a consumer—ultimately concerned with utility—an increase in local consumer prices translates into a loss of real purchasing power and a desire to raise nominal prices in response. Note that changes in the exchange rate, an hence import prices, will affect domestic prices through this channel, depending on the degree of openness of the economy.

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[8]See Faruqee (1995).

[9]An important distinction is implicitly made here between supply–side considerations leading to *shifts* in marginal costs curves and pricing–to–market factors which are associated with movements *along* marginal cost curves.

[10]Krugman (1984) finds that most countries invoice exports in terms of domestic currency when relative country-size differences are not significant. LDC exports, which are predominantly invoiced in U.S. dollars, are an exception.

[11]Based on taste and technology parameters, the coefficients in Table 1 are given by: $\pi = \frac{\gamma - 1}{\epsilon(\gamma-1)+1}$ and $\theta = 1 - \epsilon\pi$, where both coefficients and their sum are between (0,1) and where $\gamma$ represents the degree of convexity in costs (see appendix).

[12]More precisely, with interindustry trade, the level of the domestic CPI, $Q$, which is a function of prevailing home and foreign producer prices is given by:

$$Q = (P)^{\alpha}(EP*)^{1-\alpha}$$

where $\alpha$ is the exact expenditure share on home goods.

On the production side, the weight placed on the prices of other industry producers, $1-\pi-\theta$, captures a relative-price effect; an increase in the prices of other producers in the industry lowers producer $I$'s relative price, thereby raising the demand for its output and its price.

With goods market segmentation, producers can in fact systematically discriminate on the basis of price across market destinations if this raises profits. In other words, unlike the case of the law of one price, $p_i^1$ need not equal $p_i^2$ as long as the arbitrage mechanisms which normally assure the law of one price remain absent. Consequently, under segmented markets each home and foreign producer can price to each market separately, depending on the market conditions that prevail in each location.

In standard models of market segmentation, firms price to market by making destination-specific adjustments to price-cost margins in response to exchange rate changes. In this CES framework, however, markups are constant, closing the usual channel through which prices may systematically differ between markets. Hence, to ensure that producers have an incentive to discriminate on the basis of price, given that they have the ability to do so, we assume that costs are separable and convex in the production of domestic and export goods. There are many justifications for the premise of differential costs. For example, if there exist market–specific costs in transportation, distribution, production, or servicing, then costs can differ at the margin for the home and exported good. These and similar explanations may also help explain why markets are actually segmented in the first place. For further discussion, see Krugman (1987), Knetter (1993), and Faruqee (1995).[13]

Pricing decisions under cost separability and convexity are qualitatively similar to the pricing-to-market responses under differential and variable markups. In the latter case, firms usually reduce markups in markets where the currency has depreciated in order to stabilize their prices in terms of the destination currency.[14] In the case considered here, exchange-rate movements elicit a very similar response. For example, a depreciation of the foreign currency lowers demand for home exports which are now more expensive in the foreign market. Consequently, faced with reduced demand and production costs, home producers respond by lowering export prices in units of the home currency, i.e., the seller's currency, in order to offset the price increase in terms of foreign currency, i.e., the buyer's currency. Producers still desire destination price stability, although now through a marginal-cost channel rather than the markup channel, where the degree of convexity in costs affects the extent to which firms pursue foreign price and market–share stability.

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[13]If costs were the same, producers would always choose the same price for each market. Constant differential markups could of course be introduced into this CES framework by assuming differential elasticities of substitution across markets $(\epsilon^1 \neq \epsilon^2)$. In that case, there would exist a constant price differential across markets.

[14]Typically, with differential markups, demand is *less* convex than the constant elasticity case. See, for example, Marston (1990).

Explaining pricing to market through costs has been emphasized elsewhere in the literature. It has been argued that market–specific distribution costs may play an important role in explaining observed pricing–to–market practices. For example, Baldwin and Foster (1986) posit a "marketing bottlenecks" hypothesis and suggest that the presence of (possibly binding) capacity constraints facing distribution outlets provide an important incentive for firms to stabilize destination price and output.[15]

Other possible factors explaining an exporter's desire to stabilize his export price and market share include the threats of protectionism stemming from a protracted depreciation of the exporter's currency, or the presence of sunk costs—associated, for example, with irreversible investments initially required to penetrate the export market—which may motivate firms to sustain their foreign market presence even during extended appreciations of their currency.[16] In the context of this paper, the general preference for trade smoothing is introduced very simply through the convexity and separability of costs which provide the basic driving force behind pricing–to–market behavior.[17]

We should also note that the simple representation of systematic price discrimination in the model places no boundaries on the extent of divergence between prices for the same good. Clearly, this is an extreme assumption. More likely, there would exist a band—likely based on the level of transport or adjustment costs—within which price differentials would persist. Beyond this range "gray markets" would emerge as agents found it profitable to circumvent the producer's own distribution channels. However, for small enough fluctuations in demand and large enough adjustment costs, this representation is a reasonable assumption.

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[15]See also Krugman (1987). For a broad review of various explanations for pricing to market, see Knetter (1992).

[16]See Baldwin (1988) and Dixit (1989) for hysteresis models of trade where the market structure itself depends upon currency fluctuations by affecting the exit/entry decisions of firms.

[17]The model in this paper assumes that prices change continuously in response to variations in the exchange rate. For an analysis that provides a rationale for sticky prices in the face of exchange rate fluctuations, see Delgado (1991), which develops a model where destination prices change only when the expected revenue is large enough to take account of menu costs and the possibility of a reversal of the exchange rate.

## III. PRICING TO MARKET AND VARIANCE PASS–THROUGH

Using the analytical framework outlined above, the effects of exchange rate volatility on nominal prices can be determined for a particular calibration of the model. This involves comparative static exercises in which we calculate the variability of the optimal export price ($p^2$), given the behavior of local ($p^1$) and import ($p^{1*}$) prices in the face of exchange rate variations.[18] The export price response function for the industry in symmetric equilibrium based on the individual export price rules in Table 1 is given by:[19]

$$p^2 = \frac{\pi}{\pi+\theta}(e+m^*) + \frac{\theta}{\pi+\theta}q. \tag{1}$$

Based on the industry response function in equation (1), one can calculate both the level and variance effects of exchange rate fluctuations on export prices and quantities. We consider first the case under certainty where fluctuations in the exchange rate, which here are the sole source of variability, are either perfectly predictable or at least realized in advance of pricing decisions. We then consider the level effects of uncertainty when agents make their pricing and output decisions prior to the realization of the exchange rate based on their rational expectations.

### A. Level Effects

Given that industry relative prices are unity in symmetric equilibrium, both the export demand for a particular variety and aggregate home exports are in general directly proportional to foreign real aggregate demand, expressed in units of purchasing power for the export industry's product: $e+m^*-p^2$ (in logs). Hence, for a given foreign money supply, the change in the level of home exports depends upon the degree of *pass–through* in home export prices. "Pass-through" is defined as the percentage change in the price of domestic goods (usually exports)—measured in terms of foreign currency that results from a change in the nominal exchange rate. For example, if the foreign-currency price of the home export changes one–for–one with the exchange-rate, the degree of pass-through is unity. In other words, the exchange rate change is fully reflected in the destination price while the home-currency price,

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[18]The analysis proceeds on the assumption that home goods prices in the home market remain unchanged in terms of home currency (full exchange rate pass–through). This would be an *equilibrium* response if the (separable) costs for the home good lacked the convexity assumed in the production of the export good. Otherwise, it serves an approximation to the general equilibrium case. See Faruqee (1995) for further analysis regarding general equilibrium dynamics.

[19]In general equilibrium, identical producers in the industry choose the same export price: $p_i^2 = p^2$.

$p^2$, remains unaffected. At the other extreme, if the home price responds to fully offset the change in the exchange rate, leaving the foreign-currency price unaffected, the degree of pass–through is zero. Mathematically, this elasticity measure for the home export price is calculated (in absolute value) by $|\partial p^2/\partial e - 1| \in (0,\ 1)$.

Figure 1 shows how the degree of pass–through varies with respect to openness, whereby an increasing import share, $1 - \alpha$, represents increasing openness in the home country. The two lines seen in Figure 1 reflect two polar assumptions regarding the responsiveness of *foreign* export prices, i.e., home import prices, used in calculating the *home* export price response. The upper line represents the case where home import prices remain unchanged in terms of home currency, i.e., zero pass–through in imports. In this case, there is no CPI effect from an exchange rate change, as $q$ is fixed in equation (1), and the line measures the production-side impact alone. In this case we see that half of an exchange rate change is reflected in the destination export price in percentage terms regardless of the degree of openness, i.e., the domestic expenditure pattern.[20]

At the other extreme, if foreign export prices remain unchanged at the *source*, there is full pass–through allowing both home import prices and the CPI to move with the exchange rate. The resulting production and consumption effects taken together are captured by the lower line which shows lower pass–through in Figure 1. As owner–operators of firms are concerned with their real consumption and utility, the CPI effect generates a greater price response to offset the exchange rate change. Moreover, with the added consumption effect, a more open economy displays greater sensitivity to currency fluctuations and responds with a lower pass–through in prices.

Endogenizing foreign export prices and allowing for general equilibrium interactions between prices set at home and abroad, one can show by symmetry that the equilibrium level of pass–through must lie in between the two lines shown in the figure.[21] Finally, note that the sensitivity of pass–through to exchange rate changes shown in the figure assume quadratic costs ($\gamma$=2). With a greater degree of convexity in costs, a stronger production effect would lead to a lower degree of pass–through than shown in Figure 2.

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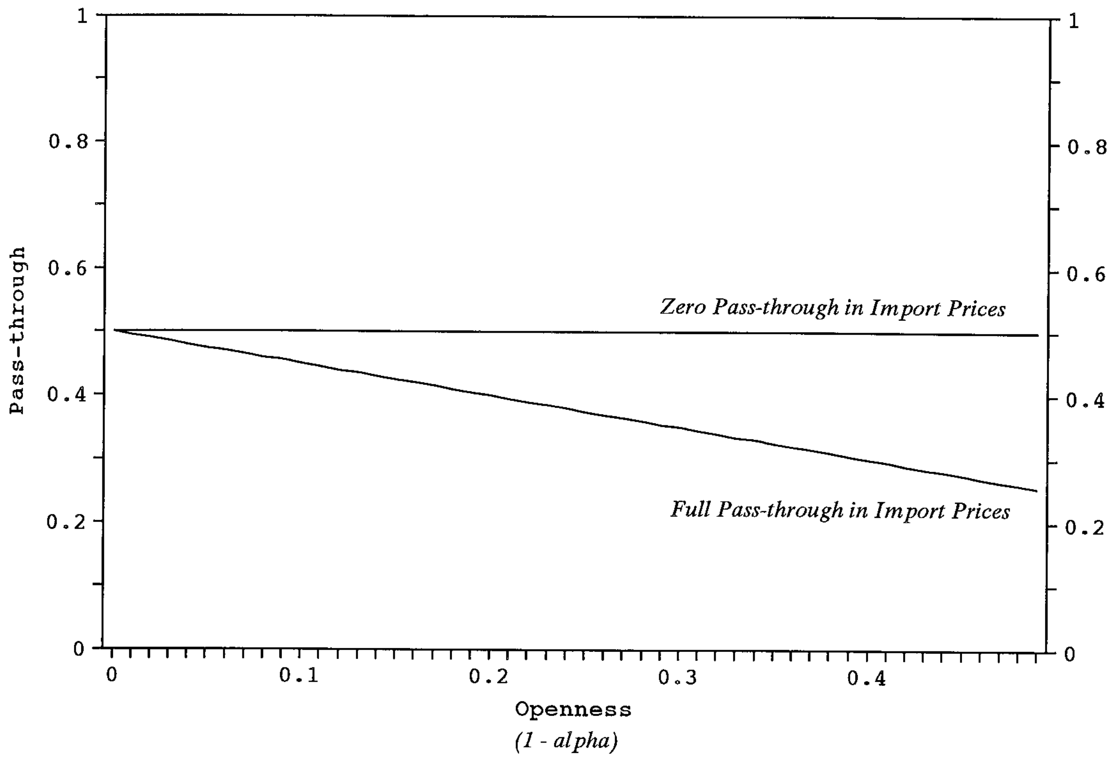
[20]In the absence of a CPI effect, the degree of pass-through —reflecting only production–side incentives—is given by $\frac{\theta}{1+\theta} = \frac{1}{\gamma}$. In Figure 2, we assume quadratic costs ($\gamma$= 2) and, hence, obtain a pass-through of ½.

[21]Viewing equation (1) as an optimal response function, and using its foreign counterpart, one can show that the pass–through response of prices for the home and foreign export industry are downward–sloping (monotonic declining) functions of the degree of pass–through in the other country and must cross in $\mathbb{R}^2$:[0,1]x[0,1]. The intersection of the home reaction function with the foreign one represents the Nash equilibrium outcome.

*Figure 2. Pass-through in Export Prices*



It should be realized that less than full pass–through is *not* sufficient evidence of pricing to market. As limited exchange rate pass–through may hold even under the law of one price, pricing to market requires the stronger condition that *differential* rates of pass–through exist across markets, reflecting systematic divergences in intermarket prices for a particular good.[22] In this setting, given full pass–through in corresponding local prices, e.g., if domestic goods prices in the domestic market are unchanged in terms of domestic currency, less than full pass–through in export prices also reflects price discrimination.[23] Hence, the implied degree of pricing to market that measures the degree of price divergence, in response to exchange rate changes, is given by 1 minus the level of pass–through shown in Figure 2.

### B. Variance Effects

Variance pass-through is defined as the extent to which exchange rate variability translates into the variability of the foreign–currency price of home goods. For export prices, this type of pass–through in the second moment of the distribution can be expressed as the ratio of the variance of the destination price to that of the exchange rate: Var $(p^2–e)$/Var$(e)$.

Two extreme cases are worth noting. When export prices are completely fixed in terms of the seller's currency, there is full pass–through in variances (variance ratio = 1, $p^2$ constant). At the other end of the spectrum, if destination prices are completely fixed in terms of the buyer's currency, there is zero pass–through in variances (variance ratio = 0, $p^2$–e constant).

It is instructive to examine the definition of the variability of destination prices, which is given by:

$$\mathrm{Var}(p^2-e) = \mathrm{Var}(p^2) + \mathrm{Var}(e) - 2\mathrm{Cov}(p^2,e). \tag{2}$$

In equation (2), the covariance term reflects the efforts on the part of exporters to stabilize destination prices and quantities in the face of exchange rate volatility. If the presumably positive covariance between the exchange rate and home export prices at the point of origin is sufficiently large, then the export prices measured at the point of destination will be less variable than the exchange rate and the variance ratio will be less than unity.[24]

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[22]See, for example, Krugman (1987) and Faruqee (1995) for discussion of this point.

[23]See Faruqee (1995) for analysis of pass–through in *both* local and export prices, and the corresponding degree of pricing to market. There it is shown that pass–through in local prices under interindustry trade is less than (but close to) one, and greater than the degree of pass–through in export prices.

[24]As with pass–through in levels, limited variance pass–through by itself is not, in general, a (continued...)

Figure 3a displays the degree of variance pass–through in export prices across different degrees of openness. Once again, two extreme responses for foreign export prices are used to trace the impact of exchange rate variability on home export prices. In the case where home import prices remain unchanged (i.e., no CPI effect) due to zero variance pass–through abroad, the production–side impact of exchange rate variability is captured by the top line in the figure. At the other extreme, if foreign export prices remain unchanged at the source so that home import prices display full variance pass–through, both production and consumption effects are captured by the lower line (lower variance pass–through) in Figure 3a. As before, allowing for endogenous foreign price responses, the degree of variance pass–through in home (and foreign) export prices would lie somewhere between these bounds.

Figure 3b shows the changing degrees of variance pass–through across various degrees of convexity in the export cost function. With more sharply increasing costs (e.g., quadratic costs), exporters have a greater incentive to stabilize their foreign market share. Consequently, the degree of exchange rate variability passed–through to destination prices is smaller.

It is important to note that the analysis here has exclusively focused on price responses and price variability stemming from changes in export demand resulting from changes in the exchange rate. In practice, however, the variance of export prices reflects not only demand factors (i.e, movements along given cost curve), but supply factors as well (i.e., shifts in the cost curve)—with both sources contributing to Var($p^2$) in equation (2). Consequently, we need to adjust for these latter effects in the empirical analysis below to better isolate the quantitative impact of pricing to market on smoothing the impact of exchange rate changes on prices of traded goods.

## C. Uncertainty Effects

Before turning to the empirical analysis of variance pass-through in export prices, we can also use the model to examine the effects of exchange rate uncertainty on the level of export prices and quantities. As noted at the outset, there has been concern that the considerable nominal and real exchange rate volatility in the post Bretton Woods system may have adversely affected the level of international trade. However, the discussion above has indicated that destination market prices of goods purchased from abroad may be relatively

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[24](...continued)
segmentation. However, with a high degree of variance pass–through in local prices (we assume full variance pass–through), the variance of home prices in the home market in terms of foreign currency should be well approximated by the variance of currency fluctuations, ceteris paribus. In that case, incomplete variance pass–through, i.e., variance ratio less than unity, in export prices would indeed reflect the effects of pricing to market.

*Figure 3a. Variance Pass-through in Export Prices*

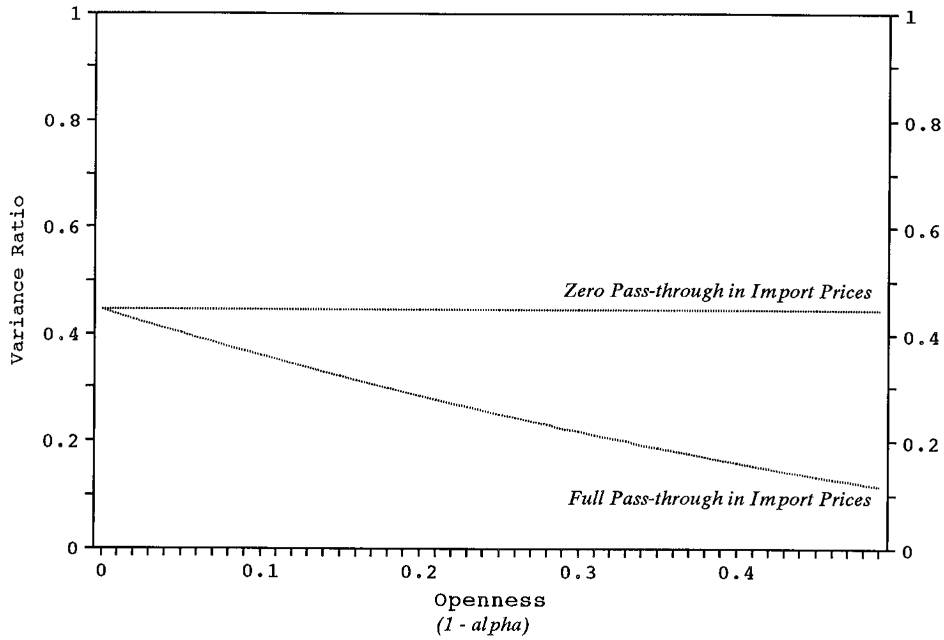
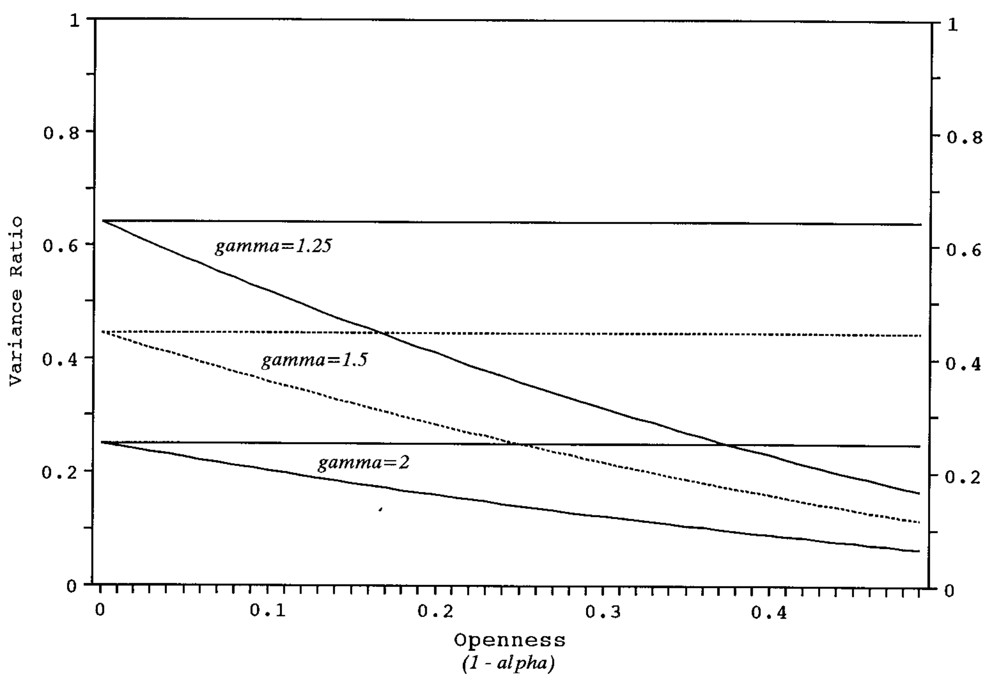



*Figure 3b. Variance Pass-through and Cost Convexity*



well insulated from the effects of exchange rate fluctuations, in which case trade volumes may also be cushioned from the impact of exchange rate volatility.

To analyze this connection between the level of prices and quantities and exchange rate uncertainty, we consider the case where producers set prices prior to the realization of the exchange rate, which is the only source of uncertainty, in the model. The optimal price rule is now determined by the maximization of the expected value of profits. Assuming that the (known) conditional distribution for the exchange rate is log–normal,[25] the modified export price rule under uncertainty is given as follows:

$$p^2 = \frac{\pi}{\pi+\theta}\,(E[e]+m^*) + \frac{\theta}{\pi+\theta}E[q] + \frac{\theta}{\pi+\theta}\,\frac{\gamma^2-\alpha^2}{2}\sigma_e^2. \qquad \textbf{(3)}$$

In equation (3), $E[.]$ denotes the mathematical expectation conditional on all available information at the time when price decisions are made. Note that equation (3) has the same form as equation (1) in expectation, except for the last term which represents a risk premium. The presence of a risk premium term in equation (3) implies that the average level of activity in the economy will be different under uncertainty.

The intuition behind the price premium above goes back to the convexity of costs. Under uncertainty, a rise in the variability of the exchange rate translates into a rise in the variability of export demand. Demand variability in turn raises expected costs due to the convexity of the cost function by Jensen's inequality; the expectation of the cost of output is greater than the cost of the expectation of output. Thus a increase in exchange rate variability generates a rise in average costs which induces a rise in average export prices and a decline in the quantity of exports. Moreover, as seen in equation (3), the risk premium is increasing in the degree of cost convexity $\gamma$.[26] Figure 4 shows the impact of an increase in exchange rate variability on the level of export prices. The magnitude of the increase in variance of currency fluctuations approximates the increase that followed the collapse of Bretton Woods.[27] As can be seen in

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[25]A variable $X$ is log–normal if $x \equiv \ln X$ is normally distributed. Assuming $x \sim N(E[x], \sigma_x^2)$, we can use the fact that $E[X] = exp(E[x] + \sigma_x^2/2)$ to solve the producer's problem under uncertainty (in log–levels). Subsequently, we assume the log exchange rate has a (conditional) normal distribution $[e \sim N(E[e], \sigma_e^2)]$ in deriving an explicit solution for the optimal (log) price rule and the risk premium.

[26]The risk premium is also increasing in the degree of openness (smaller $\alpha$), as the volatility of CPI fluctuations resulting from exchange rate variability increases. Note that if costs are linear ($\gamma$=1) and the domestic economy is closed to imports ($\alpha$=1) then exchange rate variability does not matter (risk premium=0).

[27]The change in variance used in Figure 4 is: $\Delta\sigma_e^2 = 0.01$. Based on estimated monthly

(continued...)

*Figure 4. Effects of Uncertainty on Prices with Exchange Variability*

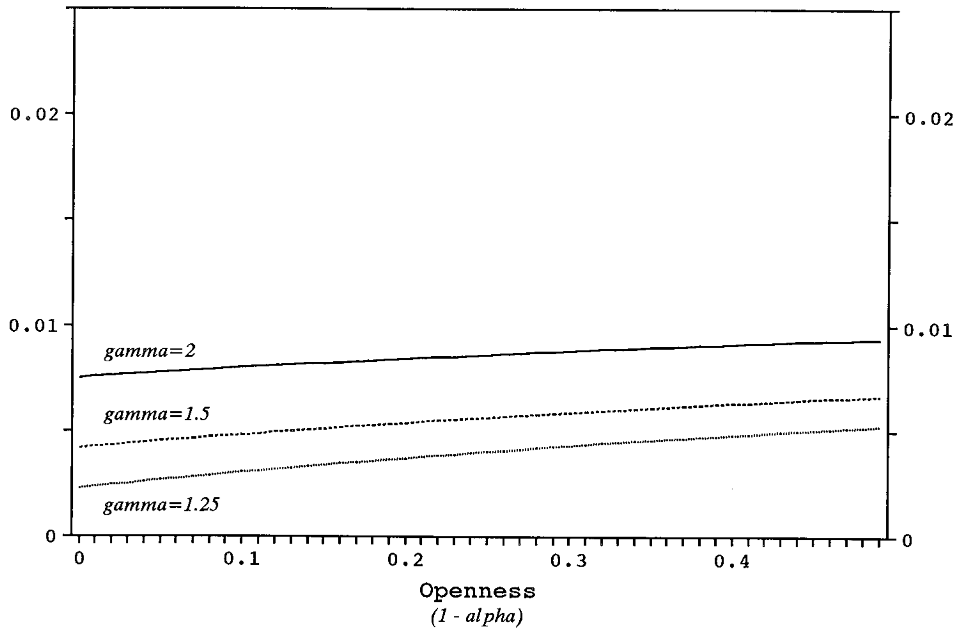

Figure 4, the model suggests that the rise in export prices associated with this increase in uncertainty is quite small, on the order of one percent or less. From the demand equations in Table 1, it can be seen that this increase in average prices translates into an equivalent percentage decline in the level of exports in equilibrium. Thus the pricing–to–market model provides a theoretical basis for the empirical evidence submerged by Goldstein (1995) that the negative impact of floating exchange rates on the level of international trade is quite small.

## IV. EMPIRICAL RESULTS

In this section we present some empirical results on the relationship between the variability of traded goods prices and nominal exchange rates. In particular, recall from the discussion of variance pass–through above that with pricing to market the ratio of the variance of destination prices, i.e., in the importer's currency, to the variance of the nominal exchange rate is less unity. In other words, the effect of pricing to market is to moderate the impact of fluctuations in nominal exchange rates on the prices paid by purchaser of traded goods. It was also noted in the previous section that there are other factors, e.g., domestic costs, that affect prices of traded goods and that variations in these factors need to be taken into account in calculating the degree of variance pass–through.

In the model described above, these other factors are combined into the constant term, $\mu$, in equation (1) for the export price. Obviously, such factors as wages, productivity changes, taxes, etc, that affect export prices are not in fact "constant" in reality and contribute to the variance of the export price at the source, Var ($p^2$), and at the destination, Var ($p^2$–$e$). To take account of the domestic cost component of $p^2$, it suffices to simplify equation (1) and represent the export price as a linear function of two components, the exchange rate, $e$, and all other factors that are represented by, $\mu$: [28]

$$p^2 = ae + b\mu \tag{4}$$

The variance $p^2$ is equal to:

$$Var(p^2) = a^2 Var\ (e) + b^2 Var\ (\mu) + 2ab Cov\ (e,\ \mu) \tag{5}$$

Substituting the right–hand side of (5) for Var($p^2$) in equation (2) gives:

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[27](...continued)
variances of (log) exchange rates, this absolute change represents on the order of a five– to ten–fold increase in volatility in percentage terms.

[28] The reduced–form parameter "$a$" which measures the sensitivity of export prices to exchange rates, can be shown in the model to be between 0 and 1, depending on the degree of openness, $\alpha$, and the degree of convexity, $\gamma$: $a = 1 - \alpha/\gamma$.

Substituting the right–hand side of (5) for Var($p^2$) in equation (2) gives:

$$Var(p^2-e) = b^2 Var(\mu) + (1+a^2)\ Var(e) + 2abCov(e, \mu) - 2Cov(p^2, e) \qquad \textbf{(6)}$$

Adjusting the variance of the destination price for the domestic cost component and dividing by Var($e$), one obtains:

$$\frac{Var(p^2-e)-b^2Var(\mu)}{Var(e)} = 1+a^2 + \frac{2abCov(e, \mu)-2Cov(p^2,e)}{Var(e)} \qquad \textbf{(7)}$$

It is easy to show that Cov($p^2$,$e$) = $a$Var ($e$) + $b$Cov ($e$,$\mu$), so that (7) becomes:

$$\frac{Var(p^2-e)\ -\ b^2Var(\mu)}{Var(e)} = 1+a^2 - \frac{2aVar(e)\ +\ 2b(1-a)Cov(e, \mu)}{Var(e)} \qquad \textbf{(8)}$$

Equation (8) is useful for examining the range over which the adjusted variance ratio can vary. At one extreme, if there is full pricing to market so that there is zero pass–through of exchange rate changes to destination prices, then $a$ = 1.0 and the export price in home currency is adjusted one–for–one with exchange rate changes. In this case the *adjusted* variance ratio is zero, i.e., all of the variation in the destination price is due to domestic cost factors, $\mu$. At the other extreme, if there is no pricing to market and complete pass–through of exchange rate changes to destination prices, then $a$ = 0.0; as the export price in home currency is not changed in response to exchange rate fluctuations, the latter would be reflected in the destination price of exports. If Cov ($e$, $\mu$) = 0, then the adjusted variance ratio would equal 1.0, i.e., the variance of the destination price adjusted for domestic cost factors would be equal to the variance of the exchange rate. However, one would expect that Cov ($e$, $\mu$) > 0 because a depreciation of the home currency (rise in $e$), for example, would tend to raise domestic costs to the extent that there are imported inputs. In this case the adjusted variance ratio would have an upper bound less than 1.0.

It is useful to compare the results above for pricing to market with what one would observe if in fact the law of one price (LOP) held. Using the same notation as above, LOP implies that $p^2 = p^1$. Expressing the destination price, $p^2$, in terms of the destination currency implies (in logs) that: $p^2 - e = p^1 - e$. As the variance of the destination price, Var ($p^2 - e$), is given by equation (2) above, the unadjusted variance ratio is equal to:

$$\frac{Var\ (p^2-e)}{Var(e)} = 1 + [Var(p^1)\ -\ 2Cov(p^1,e)]/Var(e) \qquad \textbf{(9)}$$

It is clear from equation (9) that the unadjusted variance ratio will exceed 1.0 if Cov ($p^1$, $e$) $\leq$ 0. In particular, if exchange rate changes have no effect on $p^1$, then the unadjusted variance ratio will exceed 1.0 and can be quite large if the home currency price is subject to considerable fluctuations, i.e., if Var($p^1$) is large relative to Var($e$). This possibility indeed arises in some of the empirical results described below. However, if Cov ($p^1$, $e$) > 0, and in particular if Cov ($p^1$, $e$) > *Var* ($p^1$/2), then it is possible for the unadjusted variance ratio to be less than 1.0. As noted above, one would expect that $p^1$ and $e$ would have a positive covariance. Nonetheless, except for very open economies, it would appear that this covariance would be relatively small compared with the total variance of $p^1$, so that the unadjusted variance ratio in the case of a good for which LOP holds would most likely exceed unity. This conjecture is borne out by some of the empirical results reported below.

The pricing–to–market model described in the preceding section is in terms of two countries, so that there is a direct correspondence between the relevant exchange rate and the prices of exports and imports. However, price data on a bilateral basis, which can be matched with the associated bilateral exchange rate, do not exist over a long enough time span to permit the testing of the hypothesis that the variance of destination prices is less than that of exchange rates. One can, however, use data for aggregate import prices (PM) and relate fluctuations in these series to multilateral trade–weighted exchange–rate indices. We have followed this approach using two different data sets: import prices compiled by the OECD for aggregate manufactures imports for each of the G–7 countries, and data for selected SIC categories of imports for the United States.

In the case of the aggregate price index for manufactured imports, we used the IMF's nominal effective exchange rate (NEER) for each of the G–7 countries. The weights used for each bilateral exchange rate are based on disaggregated trade data for manufactured goods (SITC 5–8) averaged over the period 1989–91 and take into account direct trade with trading partners, competitive relations with third–world countries in particular markets, and differences among countries in the importance of foreign trade in the manufacturing sector.[29] Two proxies were used for the domestic cost component, $\mu$, of the foreign export price $p^2$: unit labor costs (ULC) in the manufacturing sector and the wholesale price index (WPI) of the exporting country. The weights used to compute an aggregate foreign cost variable were the same as those employed to construct the effective exchange rate for each G–7 country. The data are for the period 1980Q2–1995Q4.

In order to take account of trends in the data, all four variables—PM, NEER, ULC, and WPI—were first converted to quarterly percentage changes. The variance over the entire sample period was then computed for each variable expressed as a percentage change. The variances themselves, as well as the two adjusted variance ratios, [VAR(PM) – VAR(ULC)]/ VAR(NEER) and [VAR(PM)– VAR(WPI)]/ VAR(NEER) are given in Table 2.

[29] For a description of these weights, see Zanello and Desruelle (1997).

Table 2. Variances and Adjusted Variance Ratios

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Country | Var(NEER) | Var(PM) | Var(ULC) | Var(WPI) | (2–3)/1 | (2–4)/1 |
| United States | 13.16 | 1.69 | 1.45 | 0.45 | 0.02 | 0.09 |
| United Kingdom | 12.23 | 4.26 | 1.16 | 0.62 | 0.25 | 0.30 |
| France | 2.46 | 2.47 | 1.17 | 0.68 | 0.53 | 0.73 |
| Unified Germany | 2.32 | 1.66 | 1.10 | 0.71 | 0.24 | 0.41 |
| Italy | 5.45 | 6.39 | 1.27 | 0.53 | 0.94 | 1.08 |
| Canada | 2.67 | 2.04 | 1.07 | 0.85 | 0.36 | 0.45 |
| Japan | 20.50 | 13.95 | 0.93 | 0.68 | 0.64 | 0.65 |

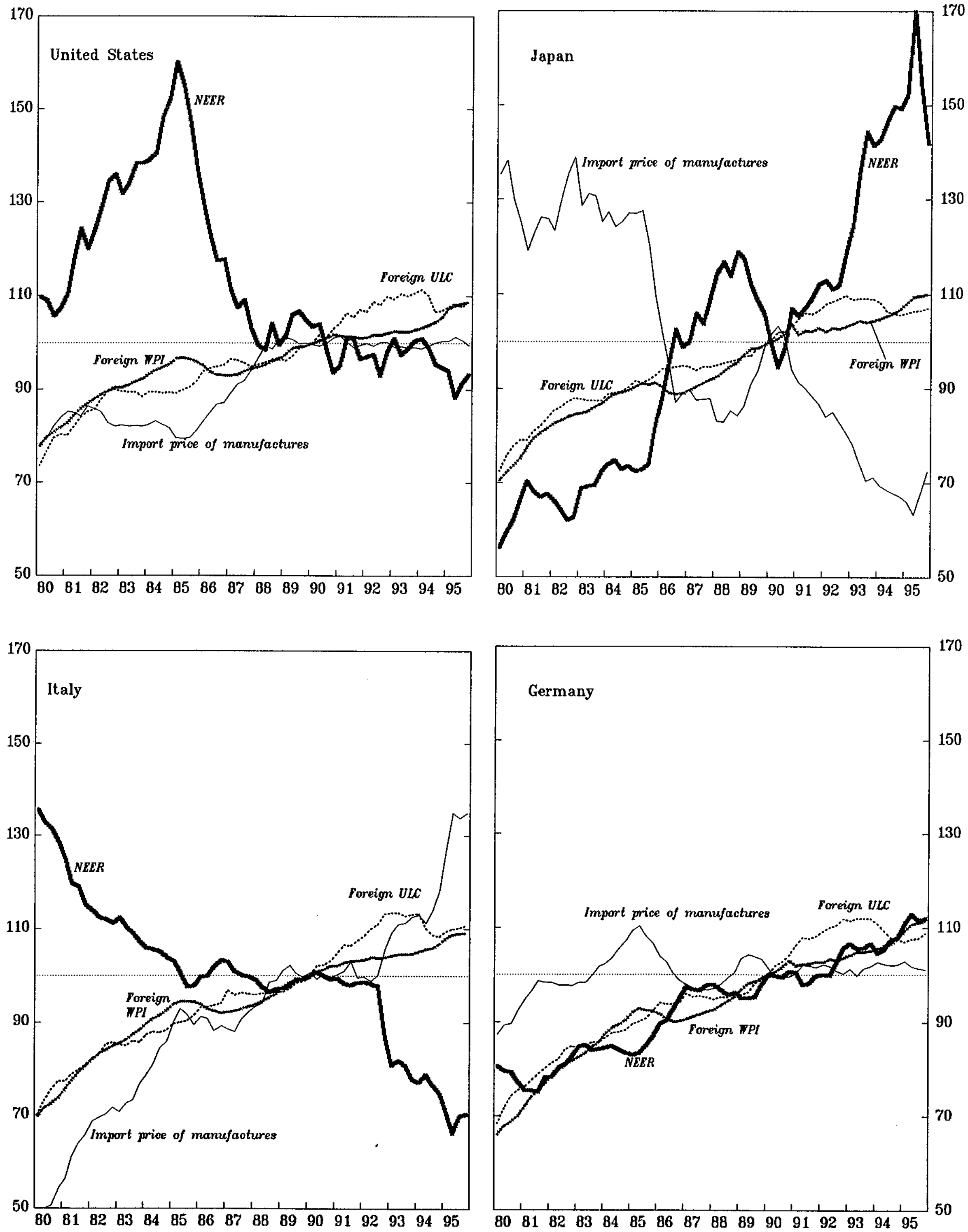
In Table 2, note that except for France and Italy, the variance of import prices of manufactures is less than the variance of the exchange rate. What is perhaps remarkable is that the U.S. import prices had the lowest variance of all G–7 countries except Germany, and yet the U.S. nominal effective exchange rate had the highest variability except for Japan. Thus, for the United States there is strong evidence of pricing to market, perhaps reflecting its relative country size. This result that has also been found in a number of other studies, e.g., Knetter (1993). With the exception of Italy, there is also evidence of significant pricing to market in the other G–7 countries, as the adjusted variance ratios—the last two columns of Table 2—are all considerably below unity.

Figure 5 provides a visual representation of the data underlying these variances. In the case of the United States, the massive changes in the NEER are only partly reflected in import prices over the period 1981–1989, and there is little correspondence between these two variables thereafter. This relative lack of association corresponds to the adjusted variance ratio of close to zero in Table 2. For Italy, there is almost a complete match between the two series, which is reflected in a variance ratio around 1.0. There is also a huge variation in the Japanese NEER, which is generally associated with similar movements in import prices of manufactures and a fairly high variance ratio.

One problem with the highly aggregated series used in Table 2 is that the import price and exchange rate variables for each country are constructed separately. Therefore the exchange rates in the weighted average—NEER—may not correspond precisely to those exchange rates implicit in the aggregate import price index. This deficiency is largely remedied in an alternative set of data for U.S. imports disaggregated by SIC category that is part of the U.S. Bureau of Labor Statistics International Price Program.[30] For each SIC import price

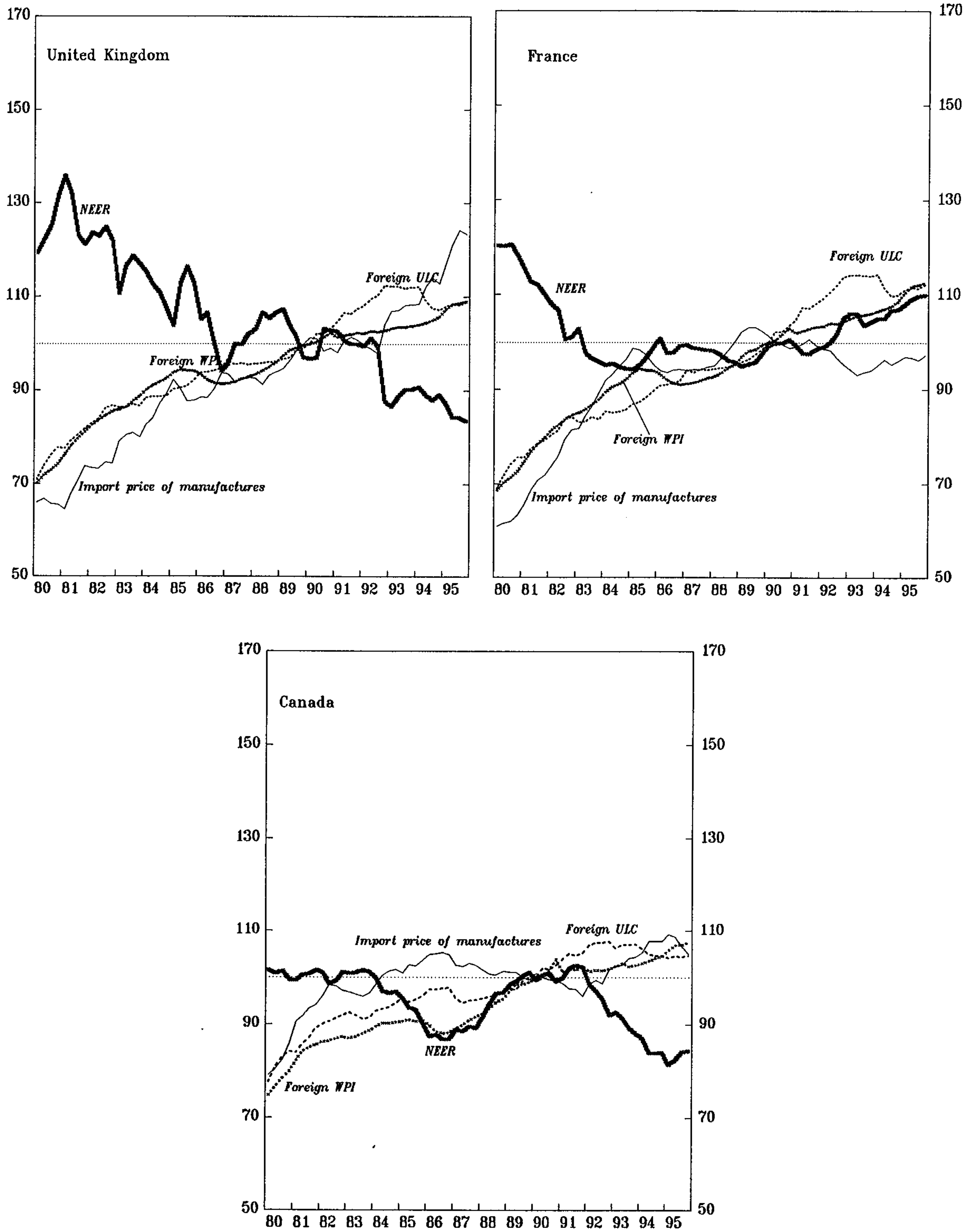
[30] For a description of the methodology used to construct these series, see Chapter 15,
(continued...)

Figure 5.
Import Price of Manufactures, Nominal Exchange Rates, and Foreign Costs: 1980 - 1995.
(1990 = 100)




Source: International Monetary Fund and OECD.

Figure 5 (continued).
Import Price of Manufactures, Nominal Exchange Rates, and Foreign Costs: 1980 - 1995.
(1990 = 100)




Source: International Monetary Fund and OECD.

category an appropriate exchange rate index was calculated using the relevant trade flows, i.e., imports, from each country in 1985 to weight the exchange rate of that country. In most cases, trade coverage was over 90 percent in each import category. Exchange rate data were used for 41 countries that had significant exports to the United States, whose exchange rates were not distorted by multiple exchange rate practices or other distortions, and whose annual rate of CPI inflation did not deviate by more than 10 percentage points from U.S. inflation in 1985–1987. For most SIC import categories the price and corresponding exchange rate indices were available from 1980 through 1992 for the months of March, June, September, and December.

The advantage of this disaggregated data set is that the calculated exchange rate series matches closely to the corresponding import price series. The only major source of error is that the import weights are for one year, 1985, which may not correspond precisely to the composition of imports reflected in the price index for all years in the sample. There is, however, a drawback to this disaggregation in that relevant domestic cost series for each 2– and 3–digit SIC category are not readily available. Nonetheless, one can proceed to test the hypothesis that the unadjusted variance ratio is less than unity, because failure to adjust for variability in the domestic cost component of the import price will bias the variance ratio upward. If the variance ratio is less than unity without the adjustment, then *a fortiori* it will be below unity if the adjustments for cost variability were made.

Table 3 shows the unadjusted variance ratio for selected 2–digit SIC categories for which the data were available for both series over the sample period. The results in Table 3 show clear evidence consistent with the pricing–to–market hypothesis in most of the industrial categories covered. Moreover, the variation across industries is also in accord with the theory, namely, the more differentiated the product, the greater the degree of market power and the greater the extent to which exchange rate fluctuations do not get reflected in movements in import prices.

Specifically, nearly all industrial categories 30–39 are characterized by considerable stability in import prices relative to the movement in the corresponding exchange rates. The obvious exception is SIC 33 (primary metal products) which has a variance ratio closer to unity, which one would expect from the fact that the goods in this industrial category are more homogenous. The four categories with variance ratios exceeding 1.0 appear to be industries with products that are relatively homogenous and that are subject to large cyclical

[30](...continued)
"International Price Indexes," Bureau of Labor Statistics Handbook of Methods, U.S. Department of Labor, Bulletin 24 - 90, April 1997, U.S. Government Printing Office. The authors are indebted to William Alterman, Supervisory Economist, Division of International Prices, Office of Prices and Living Conditions, Bureau of Labor Statistics, for making these data available to them.

Table 3. Variance Ratios for 2-Digit SIC Categories

| SIC | Description | Variance Ratio |
|---|---|---|
| 08 | Forestry products, not elsewhere specified | 4.56 |
| 09 | Fish and other marine products | 1.06 |
| 20 | Food and kindred products | 0.43 |
| 22 | Textile mill products | 0.31 |
| 23 | Apparel and related products | 0.47 |
| 24 | Lumber and wood products, except furniture | 4.17 |
| 25 | Furniture and fixtures | 0.48 |
| 26 | Paper and allied products | 1.01 |
| 28 | Chemicals and allied products | 0.21 |
| 30 | Rubber and miscellanous plastic products | 0.15 |
| 31 | Leather and leather products | 0.38 |
| 32 | Stone, clay, glass, and concrete products | 0.28 |
| 33 | Primary metal products | 0.86 |
| 34 | Fabricated metal products, machinery, and transport | 0.21 |
| 35 | Machinery, except electrical | 0.23 |
| 36 | Electrical machinery, equipment, and supplies | 0.13 |
| 37 | Transportation equipment | 0.20 |
| 38 | Measuring, photographic, and optical instruments | 0.37 |
| 39 | Miscellaneous manufactured commodities | 0.34 |

fluctuations. As noted above, in the case of homogeneous goods where LOP is more likely to hold, one would expect the unadjusted variance ratios to exceed unity. In particular, the two SIC categories of wood products (8 and 24) are in an industry subject to sharp cyclical movements reflecting large shifts in demand and supply, resulting in variation in import prices that are over four times that of the relevant exchange rate. By contrast, category 25 (furniture and fixtures) is subject to the same housing cycle, but as the products are much more differentiated, firms have greater ability to price to market and therefore can damp movements in the import price relative to those in the exchange rate.

Table 4 shows variance ratios for selected 3–digit industrial categories for which data were available for the same period for both the import prices and the exchange rate series. While the picture that emerges is similar to that revealed in Table 3, there is much greater dispersion in the variance ratios. Thus, while the ratios are, with one exception, below 1.0 in the manufacturing categories 301–394, the results for the 3–digit components of a 2–digit category display considerable variation. For example, the variance ratio for category 36 (electrical machinery, equipment, and supplies) is 0.13, but the results for the 3–digit component for which data are available range from 0.12 for SIC 365 (radio and TV receiving equipment) to 0.94 for SIC 364 (electric lighting and wiring equipment). An examination of the underlying series reveals that while the exchange rates for the two categories move in a broadly similar fashion, the price series are quite different: dollar prices of imported radio and TV equipment declined moderately from 1980 to 1992, whereas prices of imported electric lighting and wiring equipment rose sharply over this same period.

More generally, the results in Table 4 show a fairly large number of categories with variance ratios above 1.0. These would appear to reflect the greater homogeneity of the product in the category, as well as the specific characteristics of the sub–category. For example, the import price of SIC 261 (pulp mill products) is extremely volatile compared with the SIC 262 (paper mill products), which explains the much higher variance ratio of the former category: 7.95 vs. 1.02.

In summary, the variance ratio test for pricing–to–market behavior and smoothing out the effects of exchange rate fluctuations on import prices is a very weak test. In particular, the unadjusted ratio takes no account of variations in cost factors that contribute to variability in import prices, to say nothing of changes in demand and non–cost supply conditions that generate movements in import prices. Nonetheless, the evidence presented above showing in many cases unadjusted variance ratios considerably below 1.0 is at least consistent with the hypothesis of pricing to market. Moreover, the particular industries with low variance ratios would appear to be those where firms would have the necessary market power on account of product differentiation. Further work would of course be needed to explore more precisely the extent to which the variance ratios are related to measures of product homogeneity as well as the degree of import competition in the SIC categories considered here.

Table 4. Variance Ratios for 3-Digit SIC Categories

| SIC | Description | Variance Ratio |
|---|---|---|
| 147 | Chemical and fertilizer minerals | 9.98 |
| 201 | Meat and meat-packing products | 1.71 |
| 202 | Dairy products | 0.43 |
| 208 | Beverages and flavoring extracts | 0.06 |
| 209 | Miscellanous food preparations and products | 0.93 |
| 229 | Textile goods, not elsewhere specified | 0.50 |
| 231 | Men's or boy's suits and coats, except raincoats | 0.64 |
| 238 | Apparel and accessories, not elsewhere specified | 0.72 |
| 232 | Men's or boy's shirts, trousers, night- and underwear | 1.38 |
| 242 | Lumber, flooring, shingles, and cooperage | 6.99 |
| 243 | Millwork, plywood, and veneer | 1.15 |
| 261 | Pulp mill products | 7.95 |
| 262 | Paper mill products | 1.02 |
| 281 | Industrial inorganic chemicals | 1.56 |
| 301 | Tires and inner tubes | 0.10 |
| 314 | Footwear, except rubber | 0.51 |
| 236 | Ceramic sanitary and industrial ware, and chinaware | 0.80 |
| 331 | Blast furnace, steel works, rolling and finishing mill | 0.27 |
| 333 | Smelter and refined nonferrous metals | 5.41 |
| 335 | Rolled, drawn, and extruded nonferrous metals | 0.47 |
| 345 | Bolts, nuts, screws, rivets, and washers of base metals | 0.44 |
| 353 | Construction, mining, and oil-field machinery and | 0.34 |
| 354 | Metal working machinery, equipment, and parts | 0.36 |
| 356 | General industrial machinery and equipment and parts | 0.56 |
| 357 | Office, computing, and accounting machines and parts | 0.17 |
| 364 | Electric lighting and wiring equipment | 0.94 |
| 365 | Radio and TV receiving equipment | 0.12 |
| 367 | Electronic components and accessories | 0.65 |
| 369 | Electric machinery, equipment, and supplies | 0.37 |
| 382 | Mechanical measuring and controlling instruments | 0.75 |
| 386 | Photographic equipment and supplies | 0.18 |
| 387 | Watches, clocks, clockwork-operated devices, and parts | 0.77 |
| 394 | Toys and amusement, sporting, and athletic goods. | 0.56 |

## V. Concluding Remarks

Since the abandonment of the Bretton Woods system of fixed exchange rates in 1973 there has been marked rise in both nominal and real exchange rate variability. Perhaps surprisingly, this development has not been accompanied by the substantial transmission of exchange-rate- induced price changes from one country to another, as the prices and quantities of traded goods appear to have been relatively insulated from short-run exchange rate volatility. The absence of a tight connection between exchange rate changes and prices of imports and exports has also been consistently documented in numerous empirical studies that have found systematic departures from the law of one price.

The paper has developed a model of pricing to market that can account for the observed lack of convergence of prices of the same goods across different markets. With pricing to market, forces that would assure spatial arbitrage are absent, allowing the corresponding prices to diverge across markets. With export prices somewhat detached from domestic prices for the same good on account of segmented markets, prices are in effect set in terms of local currency and pricing-to-market behavior thus ensures greater stability in terms of the currency of the export market. In the two-country model, monopolistic competitors set prices for their differentiated products depending on the demand facing each competitor, with price discrimination arising between the domestic and export markets because costs are assumed to be separable and convex in the production of domestic and export goods. Optimal, i.e., profit maximizing prices are obtained by maximising revenues from domestic and export sales minus the separable production costs, with the result that producers prefer destination price stability in the currencies of both markets.

Using this model based on segmented markets, the analysis focuses on the consequences of pricing to market for the extent to which there is pass-through of exchange rate changes on the levels and variances of export prices and quantities. The degree of pass-through, which depends in an important way on the convexity of costs and the openness of the exporting economy, is shown to be incomplete, i.e., the effects of exchange rate changes are considerably damped. The analysis is also extended to explore the effects of exchange rate uncertainty. It is found that unpredictable movements in exchange rates have a comparatively small effect in raising the level of export prices and in reducing the volume of international trade.

The paper also presents some estimates of the variance pass-through, i.e., the extent to which the variance of the exchange rate is reflected, or passed-through, to the variance of import prices. It is found that there is incomplete pass-through using aggregate price data for the G-7 countries. The same result is also found for many industries using industry-specific data for the United States. However, there are a number of cases where the variance of import prices exceeds that of the exchange rate by a considerable margin. Nonetheless, these appear to be industries producing homogenous products, so that the segmented markets required for pricing–to-market behavior are not likely to obtain.

In summary, the pricing-to-market model used in this paper can account for the fact that the prices of traded goods are in general rather insulated from exchange rate fluctuations. This result reflects the profit-maximizing behavior of producers who wish to stabilize their production levels and therefore dampen the effect of exchange rate changes on the destination prices of their output. Thus the analysis suggests that the considerable short-run volatility of nominal exchange rates over the last 25 years is unlikely to have adversely affected economic performance in a significant manner.

## I. THE CONSUMER'S PROBLEM

For the home country, producer-consumer I's utility function is given as follows:

$$U_i=\left(\frac{C_i}{\mu}\right)^{\mu}\left(\frac{M_i/Q}{1-\mu}\right)^{1-\mu}-\frac{1}{\gamma}\left(Y_i^1\right)^{\gamma}-\frac{1}{\gamma}\left(Y_i^2\right)^{\gamma}-F_i;\quad 0<\mu<1,\gamma>1, \tag{A1}$$

where $C_i$ is a consumption basket of home and foreign goods, $M_i$ represents money holdings of home currency (no currency substitution), Q is the domestic consumer price index, and $Y_i^1$, $Y_i^2$ are agent I's the level of output for the domestic and export markets. $F_i$ denotes fixed costs in the production of a particular variety. Lastly, $\mu$ and $1-\mu$ represent the constant expenditure shares of goods and money, while $\gamma-1$ measures the elasticity of marginal disutility with respect to output (for each market).

In the case of intersectoral trade, agents have CES subutilities over home and foreign varieties of goods, respectively. Explicitly, $C_i$ is given as:

$$C_i=\left(\frac{C_i^h}{\alpha}\right)^{\alpha}\left(\frac{C_i^f}{1-\alpha}\right)^{1-\alpha};\quad \frac{1}{2}<\alpha<1, \tag{A2}$$

where $C_i^h$ represents I's consumption basket of all home goods:

$$C_i^h=(n)^{1/1-\epsilon}\left[\sum_{j=1}^{n}\left(C_{ij}^h\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}};\quad \epsilon>1, \tag{A3}$$

and where $C_i^f$ represents I's consumption basket of all foreign goods:

$$C_i^f=(n)^{1/1-\epsilon}\left[\sum_{j=1}^{n}\left(C_{ij}^f\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}};\quad \epsilon>1. \tag{A4}$$

In these last two subutility expressions, $C_{ij}^h$ and $C_{ij}^f$ represent agent *I's* consumption levels of home good *j* and foreign good *j*, while $\epsilon$ measures the constant elasticity of substitution between any two home or any two foreign varieties, respectively.

The budget constraint completes the formulation of the consumer's problem facing the home agent:

$$\sum_{j=1}^{n}P_j^1C_{ij}^h+\sum_{j=1}^{n}EP_j^{1*}C_{ij}^f+M_i=I_i\ , \tag{A5}$$

where $P_j^1$ is the price of home good $j$ (in home currency) and $P_j^{1*}$ is the price of foreign good $j$ (in foreign currency) prevailing in the home market, $E$ is the nominal exchange rate (home currency price of foreign currency), and $I_i$ is agent I's level of nominal wealth.

Solving the consumer's problem by maximizing (A1), given equations (A2) through (A4), with respect to $C_{ij}^h$, $C_{ij}^f$, and $M_i$ subject to (A5) yields the following individual demand functions for domestic goods, imports and money:

$$C_{ij}^h = \left(\frac{P_j^1}{P^1}\right)^{-\epsilon}\left(\frac{\alpha\mu I_i}{nP^1}\right) \textit{ for } j=i...n; \textit{ where } P^1 = \left[\frac{1}{n}\sum_{j=1}^{n} P_j^{1\,1-\epsilon}\right]^{1/1-\epsilon}, \tag{A6}$$

and

$$C_{ij}^f = \left(\frac{P_j^{1*}}{P^{1*}}\right)^{-\epsilon}\left(\frac{(1-\alpha)\mu I_i}{nEP^{1*}}\right) \textit{ for } j=1...n; \textit{ where } P^{1*} = \left[\frac{1}{n}\sum_{j=1}^{n} P_j^{1*^{1-\epsilon}}\right]^{1/1-\epsilon}, \tag{A7}$$

and

$$M_i = (1-\mu)I_i \tag{A8}$$

## II. The Producer's Problem

Producer I's revenues plus his or her initial money holdings make up the individual's nominal wealth: $I_i = P_i^1 Y_i^1 + P_i^2 Y_1^2 + \bar{M}_i$. Using this definition of wealth, the indirect utility function (ignoring menu costs) is:

$$U_i = \frac{P_i^1 Y_i^1 + P_i^2 Y_i^2}{Q} - \frac{1}{\gamma}\left(Y_i^1\right)^{\gamma} - \frac{1}{\gamma}\left(Y_i^2\right)^{\gamma} - F_i + \frac{\bar{M}_i}{Q}. \tag{A9}$$

For stability, "marginal cost"—in terms of the marginal disutility of output—must be nondecreasing, requiring $\gamma-1\geq 0$. Hence, scale economies in production in the model refer to decreasing average rather than marginal costs. The producer's problem can be stated as maximizing the modified profit function (A9) with respect to each price given demand for output in each market shown in Table 1. The explicit solutions to the producer's problem are also shown (in logs) in Table 1.

## III. General Equilibrium

### A. Money Market Equilibrium

Using the money demand function in (A8) and the definition of wealth, domestic money market equilibrium is given by:

$$\bar{M} \equiv \sum \bar{M}_i = \sum M_i = (1-\mu)\left(\sum I_i\right) = \frac{1-\mu}{\mu}\sum (P_i^1 Y_i^1 + P_i^2 Y_i^2) \;, \tag{A10}$$

where the total money stock held by home agents equals domestic aggregate money demand and is proportional to nominal GNP. Based on this quantity equation relationship at home and similarly abroad, one can derive the demand facing each producer in both the local and export market shown in Table 1, where $M \equiv \frac{\mu}{1-\mu}\frac{1}{n}\bar{M}$ is equal to GNP per capita.

### B. Goods Market Equilibrium

In symmetric equilibrium at the industry level, identical producers set identical prices. Consequently, the following relative prices are unity in general equilibrium: $P_i^1/P^1 = P_i^2/P^2 = 1$ and correspondingly for foreign producer prices. Adding up product demands in Table 1—given relative producer prices in equilibrium—yields an income-expenditure equality condition for the home country:

$$P^1Y^1 + P^2Y^2 = QC, \tag{A11}$$

where quantity variables without I subscripts indicate measures summed over all home agents (e.g., $C = \sum C_i$). Note that goods market equilibrium in (A14) equates GNP at market prices with aggregate consumption, requiring balanced trade (NX = 0) in the absence of capital mobility.

### C. Exchange Rate Equilibrium

Given goods and money market clearing and balanced trade ($EP^{1*} = P^2Y^2$), the nominal exchange rate in equilibrium is given by:

$$E = \frac{M}{M^*} \tag{A12}$$

The rate of exchange adjusts to ensure balance of payments equilibrium. In symmetric equilibrium at the country level, national money supplies are assumed to be equal. Hence, local and export prices respectively are also equal at home and abroad. The initial symmetric steady-state equilibrium has both the nominal and real exchange rate equal to unity: $E = R = 1$.

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