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ABSTRACT

A quantity adjustment cost model is developed in the context of international trade along the lines proposed by Krugman (1987). The model implies that prices adjust dynamically to exchange rate fluctuations. The price adjustment speed is determined as a function of foreign demand responsiveness, the appropriate discount rate, and an adjustment cost parameter. Pass-through is incomplete and increases over time and with the speed of price adjustment. A preliminary empirical analysis finds that the speed of price adjustment from the time series by industry and then in a cross-sectional regression tentatively relates the obtained adjustment speeds to their theoretical determinants.

1. INTRODUCTION

Theoretical and empirical work in the international trade literature dealing with the relationship between exchange rate and trade prices has been dominated and guided by the static pass-through and profit markup model(FN1) (see, e.g., Feinberg 1986; Mann 1986; Fisher 1989; Hooper and Mann 1989; Knetter 1989; Gagnon and Knetter 1995; Feenstra, Gagnon, and Knetter 1996; and Lee 1997). The shortcoming of such models is well captured by William Branson (1989, p. 333):

> Difference in adjustment response signals to me the need for a reconsideration of the theoretical framework for the analysis of the pass-through question. By now, we should be thinking about optimizing price policy for investors and exporters who know that they face an exchange rate that follows some sort of stochastic process over time. These differences call for a revision of pass-through theory along the lines of time series analysis.

Our explicit incorporation of profit-maximizing firms facing adjustment costs develops the model introduced by Krugman (1987). It transforms the traditional markup and pass-through model to explain from first principles a dynamic markup and a price adjustment speed, both depending on fundamental characteristics of the firms involved. Krugman (1989) concludes his paper on pricing to market by calling for further research on the adjustment cost model. Regarding the adjustment cost approach, he states (Krugman 1989, p. 44).

> It is still a speculative idea, not grounded in solid empirical tests; but it is a good story, and if it is correct, it has extremely important implications for economic policy.

The present paper provides the quantity adjustment cost approach that Krugman calls for. As such, it complements the work of Gagnon (1989) and Kasa (1992). While Gagnon and Kasa employ quantity adjustment cost models with many of the same features as the model developed here, they provide only approximate solutions and focus on a quite different set of issues. Gagnon examines the effect of exchange rate variability on trade volume. Kasa investigates the importance of mean reversion in exchange rates as an explanation for the pricing to market hypothesis. In contrast, our focus is on the relation between adjustment speeds and pass-through. Thus, our contribution relative to Gagnon (1989) and Kasa (1992) is that we provide the pass-through issue in a dynamic context with exact analytical solutions that relate the degree of pass-through to adjustment speeds and identify the determinants of commodity-specific adjustment speeds in response to exchange rate shocks.

The remainder of the paper is organized as follows. In section 2 we develop a partial equilibrium model, taking exchange rates as given, of the pricing policies of a profit-maximizing firm competing in foreign markets and subject to a convex quantity adjustment cost. Section 3 develops testable implications directly from the model. Section 4 discusses the data and empirical methodology for preliminary two-stage time-series and cross-sectional tests. Section 5 provides the tentative estimation, and section 6 concludes.

2. A SIMPLE PARTIAL EQUILIBRIUM MODEL

Consider a representative firm producing for export that maximizes the expected discounted value of infinite horizon real profits. The firm generates its revenue abroad in foreign currency. It has no influence on the exchange rate, may adjust its price at any point in time, but is subject to a convex cost of quantity adjustment. The firm maximizes

$\pi = E \int_0^\infty e^{-rt}[xpq - c(w_D, xw_F)q - 1/2xh(q')^2]\ dt,$ (1)

where x is the exogenously given real exchange rate at time t. We define x as the units of domestic currency per unit of foreign currency multiplied by the export destination country's price index and divided by the home country's price index. Instantaneous profits are discounted at a rate r, which is specific to the firm; this rate accounts for a standard risk premium inherent in the riskiness of the firm's activities. Price p is the real foreign currency-denominated sales price in the foreign market at time t. Quantity q represents the firm's export delivery at time t. The first term inside the integral is the revenue obtained in the foreign country converted back into home currency by the exchange rate. The second term is the firm's (indirect) cost function. For simplicity, we assume that production exhibits constant returns to scale in domestic inputs with exogenous price w_D and foreign inputs with exogenous foreign price w_F (which becomes xw_F in home currency terms). We thus consider a constant (i.e., independent of the production level) marginal production cost c (which may include a transportation cost) as a function of these input prices.

The last term in Equation 1 represents the convex quantity adjustment cost (with parameter h), which is here assumed quadratic for simplicity. In our continuous-time formulation, the change in quantity is indicated conventionally by q'. Note that the adjustment cost is viewed as incurred abroad so that its cost must be premultiplied by the real exchange rate to convert back to domestic currency units. A motivation for this adjustment cost formulation is provided by Krugman (1987, p. 63): Temporary bottlenecks occur because of changing trade volume. Sales cannot be expanded without an expansion of the "infrastructure" related to sales, distribution, and service. Thus, while production costs occur domestically, the quantity adjustment costs may be viewed as occurring abroad and should be adjusted for real exchange rate fluctuations.

For purposes of tractability, we consider a linear form for the foreign demand curve

$$q = a - bp,\quad (2)$$

where a and b are positive and finite-valued constants. The finiteness of b reflects the assumption of price-setting power on the part of the firms. The firm is assumed to compete monopolistically only with foreign firms producing for their own market.(FN2) Strategic interactions are ignored, not only for tractability but also because it is difficult to choose one particular strategic game to be relevant for the whole spectrum of industries we consider. As noted by Dornbusch (1987), who employs a similar linear demand curve, all nonprice determinants of demand are captured by the constant.

The decision problem for the exporting firm thus is to choose the pricing process to maximize Equation 1 subject to Equation 2. The model's functional form assumptions here are quite similar to the assumptions in the models used in the related literature by Krugman (1987), Gagnon (1989), and Kasa (1992), in particular, the partial equilibrium formulation, the constant marginal production cost, the monopolistic market form, the quadratic adjustment cost, and a specific functional form for the demand curve. A dynamic programming approach (derivation in the Appendix) produces the following solution:

$p^*_t = [p_0 = \hat{p}]e^{-\lambda_c t} + \hat{p}$. (3)

The optimal price at time t is a weighted average of the initial price at time 0 and a steady-state equilibrium price $\hat{p}$, where the weight on the initial price decreases with a negative exponential over time at a rate, depending on the speed of price adjustment λ_c:

$\lambda_c = 1/2[(r^2 + 8/bh)^{1/2} - r] > 0$. (4)

The steady-state price is given by

$\hat{p} = (ax + c(w_D, xw_F)b) / 2bx$. (5)

3. TESTABLE IMPLICATIONS OF THE ADJUSTMENT COST HYPOTHESIS

Taking the time derivative in Equation 3 produces $p'_t = -\lambda_c[p_t - \hat{p}]e^{-\lambda_c t}$. Substituting into Equation 3 then yields

$P'_t = \lambda_c[\hat{p} - p_t]$. (6)

Converting into discrete time for empirical purposes, we obtain

$p_t - p_{t-1} = \lambda(\hat{p} - p_{t-1})$. (7)

Alternatively, a similar equation can be derived by setting 5 = 1 in Equation 3, so that the discrete-time approximation in Equation 7 is exact if

$\lambda = 1 - e^{-\lambda_c}$. (8)

Equation 7 is the well-known partial price adjustment equation. However, we have an endogenous description of the speed of price adjustment λ in Equation 4 and of the steady-state equilibrium price $\hat{p}$ in Equation 5. Substituting $\hat{p}$ into 7, we obtain

$p_t = \alpha + \beta p_{t-1} + \gamma c(w_D/x, w_F)$, (9)

where

$\alpha = \lambda(a / 2b)$, $\beta = (1 - \lambda)$, $\gamma = \lambda / 2$, (10)

with $0 < \lambda < 1$ (or $0 < \lambda_c < \infty$). Equation 9 implies that the inverse of the real exchange rate (or the domestic to foreign currency real exchange rate) positively affects the export price as long as there are any domestic inputs used in the production process. This follows from the fact that the indirect cost function is increasing and homogeneous of degree one in input prices so that $c(w_D, xw_F)/x = c(w_D/x, w_F)$.

Five testable implications follow directly from the previous equations:

(i) $\beta > 0$: The speed of price adjustment is smaller than one; that is, prices adjust slowly to shocks (Eqns. 9 and 10). This requires of course that the adjustment cost parameter h in Equation 4 be strictly positive.

(ii) $\gamma\partial c(w_D/x, w_F)/\partial(1/x) > 0$: The inverse real exchange rate positively affects the export price denominated in the foreign currency (Eqns. 9 and 10). The reason here is that a depreciation in real terms of the foreign currency has a less than proportional impact on production costs, as long as any domestic inputs are used, but for a given foreign-currency export price proportionately raises the revenue from export in domestic currency terms.

(iii) β and $\gamma\partial c(w_D/x, w_F)/\partial(1/x)$ are inversely related: Both depend on λ—β inversely and γ directly (Eqns. 9 and 10). The reason is that slower adjustment in general also implies that the initial effect of an exchange rate change is less pronounced.

Further testable implications can be obtained for estimated λ: Once speeds of price adjustment have been obtained, they can be compared cross sectionally. Equation 4 together with Equation 8 implies the following:

(iv) $\partial\lambda/\partial r < 0$: A higher rate of discounting the future implies that the firm values the benefits of quick price adjustment less, as the future opportunity cost of deviations in price from the myopic optimum are weighted less heavily.

(v) $\partial\lambda/\partial b < 0$: A more horizontal demand curve causes the firm to adjust price more slowly. The reason is that, for any given difference between the current and the steady-state quantity, the difference between the current price and the steady-state price is less. Thus, the cost of slow adjustment in terms of revenue forgone is lower compared to the quantity adjustment cost.

Additionally, higher adjustment costs h decrease the optimal speed of quantity adjustment, which in turn requires a lower speed of price adjustment. This implication cannot be tested, however, since no proxies for h are available.

The testable implications from our dynamic model should extend as well as complement those that are explicit or implicit in the predominantly static pass-through literature.(FN3) In this view, changes in the nominal exchange rate (highly correlated with real exchange rate changes) will be partially absorbed in the markup of an imperfectly competitive firm. Hooper and Mann (1989) allow for the possibility that over time markups gradually return toward their desired levels so that pass-through slowly builds up over time. They confirm this empirically in finding a short-run pass-through of 20% increasing to 60% in the long run.

Our model yields similar results. Defining the markup as $M = xp/c$, with $c = c(w_D, x_t w_F)$, we find from Equations 9 and 10 and the homogeneity of the indirect cost function that

$$\partial M / \partial x = (a/2b) + ([p_0 - (a/2b)]e^{-\lambda_c t}) / c(w_D/x,\ w_F)^2 (w_D/x^2) c_1(w_D/x,\ w_F) > 0 \quad (11)$$

since both numerator and denominator are positive. Note that partial derivatives are denoted by a numerical subscript indicating the function argument. It is easy to derive from Equation 11 that

$$\text{sgn}\ \partial(\partial M/\partial x) / \partial t = \text{sgn}\ \partial(\partial M/\partial x) / \partial\lambda = \text{sgn}[(a / 2b) - p_0] < 0. \quad (12)$$

For a feasible initial price, $p_0 > a/2b$, the absorption of the exchange rate change in the profit margin diminishes over time, implying increasing pass-through as time progresses. In addition, the initial absorption of the exchange rate change in the profit margin is less when the speed of price adjustment is lower.

4. DATA AND EMPIRICAL METHODOLOGY

Data on U.S. export prices by commodity are obtained from the Bureau of Labor Statistics (BLS). These data start in the third quarter of 1978 at the earliest and in the last quarter of 1994 at the latest. Data for most commodities end in December 1995. Eliminating the series with less than 10 years of data together with several other selection criteria produces time series of prices for a set of 31 commodities.(FN4) We use quarterly data, although part of the series is monthly. All the price data in the estimation are expressed in U.S. dollar terms. We divide the price data by the U.S. consumer price index (CPI) to obtain the real price. The BLS does not indicate the destination or source countries for the traded commodities. Accordingly, we cannot use bilateral exchange rates but instead use the real trade-weighted exchange rate index available from Citibase.

In order to illustrate how to test implications (iv) and (v), which relate the speed of price adjustment to the commodity-specific discount rate and the commodity-specific demand curve, we obtained the following data for a preliminary analysis. To capture the discount rate appropriate for the commodity under consideration, we consider the average stock return by commodity. The average stock returns include a risk premium that is thus estimated using a theory-free approach. That is, we are not required to specify a specific risk model (such as the Capital Asset Pricing Model [CAPM]). Data on the rates of return on equity for the industries examined here are obtained from Compustat. From the international trade price code numbers provided by the BLS, we obtain the best-matching standard industrial classification code numbers.(FN5)

As a debatable proxy for the slope of the demand curve, we use the Herfindahl index: Less competitive firms may have lesser demand slope b and also may be in more concentrated industries with a higher "Herfindahl index" number.(FN6) Feinberg (1986) previously employed the Herfindahl index to represent concentration in the context of explaining differences in degree of pass-through across industries. For each industry, the Herfindahl index for this study is obtained from the Census of Manufactures of the U.S Department of Commerce. Since no data are available on the quantity adjustment cost parameter, we assume that this parameter is held constant across industries.

Given the presence of a lagged endogenous variable, we must transform the data to correct for serial correlation, if present, as ordinary-least-squares (OLS) estimates would otherwise be inconsistent.(FN7) The legitimate application of OLS on the transformed data requires that all series be stationary and, more restrictively, that the errors be free of serial correlation. We find that we can reject nonstationarity on the transformed data for all commodity price series and the trade-weighted real exchange rate index using Dickey-Fuller tests. After we obtain the estimates of the speed of price adjustment λ for each commodity from the transformed data, we may regress the λ's on the foreign demand slope and discount rate proxies by OLS.(FN8)

5. PRELIMINARY ESTIMATION RESULTS AND INTERPRETATION

The following equation is estimated with time series data on 31 commodities exported from the United States:

$p_{ti} = \alpha_i + \beta_i p_{t-1i} + \gamma_i\ 1 / x_t + e_i$. (13)

Note that $c(w_D/x_t,\ w_F)$ is approximated by $1/x_t$ (and the constant), which represents a first-order approximation that is reasonable if the input prices are not too strongly correlated with the other right-hand-side variables in the regression.

Table 1 shows that the coefficients β_i, γ_i both are significantly positive for the majority of the commodities, supporting implications (i) and (ii) of the model. More precisely, since $\lambda_i = 1 - \beta_i$, the price adjustment coefficient is significantly below one for 18 of the 31 commodities (and not significantly different from one in all other cases). Further, γ_i is significantly positive in 25 out of 31 cases, implying that a real appreciation of the dollar typically raises the foreign currency price of U.S. exports as expected. The average values for all commodities are $\lambda = 0.76$ and $\gamma = 0.62$.

The point exchange rate elasticities of the product price differ by quarter because of variation in the x/p ratio. To obtain a general picture, we calculate the point elasticities for all time periods available in the data set. We then delete the five lowest and highest point elasticities to avoid outliers and calculate the averages for each commodity. Table 2 reports the means and standard deviations of the point elasticities of the trade prices with respect to the exchange rate. Notice that the short-run point elasticity equals $\eta(s) = [dp/d(1/x)][(1/x)/p] = \gamma/px$ in Equation 13, while the long-run point-elasticity is found as $\eta(1) = \eta(s)/\lambda$. Most industries respond in less than full proportion in the short run, with a mean elasticity of 0.81. The mean long-run elasticity equals 1.07 (but falls slightly below one if 5% of the outliers are removed on both sides).(FN9)

The Durbin h-statistics in Table 1 show that significant correlation remains after transformation in 11 out of 31 cases (critical Durbin h of $\pm$ 1.96 at the 5% level). These cases are generally those commodities for which we find immediate price adjustment. To confirm implication (iii), we obtain the correlation between the λ_i and γ_i, which is significantly positive as predicted, $\rho(\lambda, \gamma) = 0.66$. If we consider only those commodities with an acceptable Durbin h-statistic, we find that $\rho(\lambda, \gamma) = 0.89$.

In the second stage of the empirical analysis, we regress the speeds of price adjustment for the exported commodities on the proxies for the discount rate and the price responsiveness. Based on Equation 4, assuming a constant adjustment cost cross sectionally, the speed of price adjustment theoretically depends negatively on the discount rate (implication [iv]), and positively on the slope of the foreign demand curve (implication [v]). Results are presented here for the sake of illustration since the use of questionable proxies (to some extent, the average stock returns by commodity representing discount rates but in particular the Herfindahl index as a proxy for the slope of foreign demand) makes these results tentative at best:

$\lambda_i = c_0 + c_1 Herf_i + c_2 Rate_i + Error_i$. (14)

Table 3 reports the illustrative regression result based on Equation 14. The sign of the rate variable is negative as predicted with significant t-statistic of 2.79, thus illustrating implication (iv). The estimated coefficient for the Herfindahl index equals 0.00, not statistically significant (t-statistic = 0.09), so that implication (v) is not confirmed in this illustration.

6. CONCLUSION

The motivation for our paper is twofold. First, it adds a dynamic element to the traditional pass-through analysis, which is mainly static in nature, except for Dixit (1989). Second, more generally, we take a small step toward taking advantage of the exchange rate variability in the post-Bretton Woods era, which makes international trade a perfect arena from which to study price rigidity. By assuming a quantity adjustment cost, we are able to derive a theoretical link between price adjustment speed, the dynamics of the markup, and pass-through.

We find that pass-through increases over time, if price adjustment is noninstantaneous, and increases in the speed of price adjustment; thus, the theoretical covariance between pass-through and price adjustment speed is positive. Further, the speed of price adjustment and, accordingly, the degree of pass-through in the short run, depend on the slope of the demand curve, the discount rate, and the quantity adjustment cost parameter.

Empirically, we find that in response to, say, a 10% change in the exchange rate, pass-through in U.S. export prices for 31 commodities equals 8.1% on average in the short run, increasing eventually to about 10%. Although the degree of rigidity in the aggregate does not appear to be as important economically as was found in some previous studies, a significant degree of rigidity is found in the majority of the sectors we investigate. We also find that the correlation coefficient across the industries between the degree of pass-through and price adjustment speed is significantly positive in the range of 0.6 to 0.9.

The substantial variation in pass-through elasticities as presented in Table 2 indicates that the effects of exchange rate changes are not uniform across industries. A currency depreciation will thus have different effects on different industries. Industries appear to cope with exchange rate changes in different ways, and there may be serious distribution effects of currency adjustments.

The results presented here for the adjustment cost view must be interpreted cautiously. Our partial equilibrium approach takes the exchange rate as exogenous and, for example, does not allow for mean reversion in exchange rates that, if present, must surely affect price setting in our adjustment-cost environment. We further assume a linear demand curve and ignore potential strategic interactions within industries. We do not distinguish empirically between export destinations and so cannot address the issues of price discrimination raised by Knetter (1989). Inability to distinguish export destinations also decreases the reliability of our price adjustment tests since trade weights of specific commodities change significantly over time.

Our model, however, has provided some insights into the dynamics of pass-through. We expect that key results—related, for example, to the correlation between price adjustment speed and exchange-rate sensitivity—and the effect of discount rates on price adjustment speed and short-run pass-through will survive in a more complex framework.

ADDED MATERIAL

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Table 1. Time-Series Regression Estimates of the Speed of Some U.S. Export Prices (Variables Measured in Levels)

$p_t = \alpha + \beta\, p_{t-1} + \gamma\, (l/x_t) + u_t, \quad \lambda \equiv 1 - \beta$

Export Price	Time Range	β	$t(\beta)$	γ	$t(\gamma)$	Durbin's h
Wheat	80:4-95:4	0.70	7.85	0.17	1.47	-0.80
Rice	84:4-95:4	0.31	2.19	0.58	2.05	2.99(FN*)
Soybeans	80:4-95:4	0.64	6.56	0.18	1.76	-1.67
Other oilseeds	83:3-95:4	0.35	2.64	0.28	2.41	-0.31
Corn	84:4-95:4	0.62	4.67	0.18	1.58	-0.88
Feedgrains	84:4-95:4	0.66	5.07	0.25	2.27	-0.59
Other feedgrains	83:1-95:4	0.04	0.36	0.99	5.82	0.52
Meat and poultry	83:1-95:4	0.21	3.01	0.68	11.14	0.13
Fruits	84:4-95:4	0.33	2.37	0.30	2.19	0.19
Vegetables	84:4-95:4	0.58	4.44	0.13	1.38	0.20
Fish	83:1-95:4	0.29	2.79	0.77	5.82	1.55
Tobacco	83:3-95:4	0.01	0.27	0.68	19.85	3.27(FN*)
Iron and steel	82:1-95:4	-0.04	-1.18	0.70	28.37	2.81(FN*)
Aluminum	81:3-95:4	0.39	3.83	0.64	4.96	-0.41
Paper and pulp	83:3-95:4	0.52	5.67	0.99	6.70	3.96(FN*)
Newsprint	80:4-95:4	0.28	5.35	0.81	15.98	4.01(FN*)
Plastic materials	83:3-95:4	0.31	4.28	1.07	11.03	2.86(FN*)
Fertilizers	84:4-95:4	0.18	2.19	0.81	9.95	1.11
Generators	80:4-95:4	0.04	1.34	0.74	32.38	1.13
Electric apparatus	80:4-95:4	-0.01	-0.25	0.74	30.87	3.33(FN*)
Drilling equipment	80:4-95:4	-0.04	-0.64	0.62	12.59	4.63(FN*)
Excavating machinery	80:4-95:4	0.04	1.43	0.74	32.90	-0.65
Machine tools	80:4-95:4	-0.00	-0.17	0.75	41.29	1.45
Textiles	80:4-95:4	0.03	0.91	0.75	25.50	0.83
Woodworkings	84:4-95:4	-0.03	-0.83	0.74	26.58	-0.51
Paper machinery	84:4-95:4	0.01	0.17	0.71	30.46	0.76
Computers	80:3-95:4	0.42	2.74	0.40	2.74	1.72
Computer equipment	84:4-95:4	0.13	2.29	0.78	15.62	2.76(FN*)
Laboratory instruments	80:4-95:4	0.04	0.96	0.67	20.18	3.29(FN*)
Aircraft parts	80:4-95:4	0.31	5.22	0.66	11.98	3.51(FN*)
Appliances	84:4-95:4	-0.02	-0.74	0.73	28.18	1.36

FOOTNOTE

* Indicates serial correlation at the 5% level of significance.

Table 2. Elasticities of Some U.S. Export Prices with Respect to the Exchange Rate

Export Price	Time Range	Mean of the Short-Run Elasticity	Standard Deviation of the Short-Run Elasticity	Mean of the Long-Run Elasticity	Standard Deviation of the Long-Run Elasticity
Wheat	80:4-95:4	0.19	0.04	0.61	0.13
Rice	84:4-95:4	0.74	0.10	1.09	0.14
Soybeans	80:4-95:4	0.21	0.04	0.59	0.10
Other oilseeds	83:3-95:4	0.38	0.04	0.58	0.07
Corn	84:4-95:4	0.24	0.03	0.64	0.07
Feedgrains	84:4-95:4	0.34	0.03	1.01	0.10
Other feedgrains	83:1-95:4	1.22	0.17	1.27	0.17
Meat and poultry	83:1-95:4	0.89	0.03	1.14	0.04
Fruits	84:4-95:4	0.40	0.02	0.59	0.04
Vegetables	84:4-95:4	0.18	0.01	0.42	0.03
Fish	83:1-95:4	1.03	0.09	1.43	0.12
Tobacco	83:3-95:4	0.85	0.07	0.87	0.08
Iron and steel	82:1-95:4	0.89	0.05	0.86	0.05
Aluminum	81:3-95:4	0.90	0.12	1.47	0.20
Paper and pulp	83:3-95:4	1.45	0.23	3.03	0.47
Newsprint	80:4-95:4	1.08	0.07	1.50	0.10
Plastic materials	83:3-95:4	1.40	0.13	2.02	0.19
Fertilizers	84:4-95:4	1.05	0.08	1.29	0.10
Generators	80:4-95:4	0.98	0.03	1.03	0.03
Electric apparatus	80:4-95:4	0.94	0.05	0.93	0.05
Drilling equipment	80:4-95:4	0.75	0.08	0.72	0.08
Excavating machinery	80:4-95:4	1.01	0.01	1.05	0.01
Machine tools	80:4-95:4	0.97	0.01	0.96	0.01
Textiles	80:4-95:4	0.99	0.03	1.03	0.03
Woodworkings	84:4-95:4	0.97	0.02	0.94	0.01
Paper machinery	84:4-95:4	0.93	0.01	0.94	0.01
Computers	80:3-95:4	0.48	0.14	0.83	0.24
Computer equipment	84:4-95:4	1.04	0.18	1.20	0.21
Laboratory instruments	80:4-95:4	0.86	0.03	0.90	0.03
Aircraft parts	80:4-95:4	0.85	0.04	1.23	0.05
Appliances	84:4-95:4	0.97	0.04	0.94	0.03

Table 3. Cross-Sectional Regression of the Speed of U.S. Export Price Adjustment on Commodity-Specific Factors (Employing the Estimates of λ from Table 1)

Variable	Estimated Coefficient	Standard Error	t-statistic
Constant	0.83	0.07	11.75
Herfindahl	0.69E-05	0.75E-04	0.09
Discoun rate	-0.03	0.01	-2.79

The equation used is $\lambda_i = c_0 + c_1 Herf_i + c_2 Rate_i + Error_i$. Correlation coefficient between lambda and the Herfindahl index is -0.17. Correlation coefficient between lambda and the discount rate is -0.49.

FOOTNOTES

1 The relationship between local currency import prices (or the foreign export prices denominated in the currency of the importing country) and exchange rates has been referred to as the “pass-through” relationship in the literature. If a less than proportional relationship between import prices and exchange rates holds, pass-through is said to be incomplete.

2 To the extent that the foreign competitors’ costs are also affected by the exchange rate (if they use the other country’s inputs), they may adjust their prices as the

exchange rate changes, which would affect the demand curve in Equation 2. However, the natural presumption is that their costs will be affected less than the domestic firm producing for export so that qualitative results will continue to hold.

3 The implications of other adjustment cost formulations are quite similar to those of the quantity adjustment formulation considered here. If adjustment of (real) prices is costly, implications (i) to (iv) will continue to hold, but the sign of (v) is reversed. Motivations for such costs relate to future profit losses resulting from large real price changes that antagonize customers and hurt the reputation of the firm (Okun 1981; Rotemberg 1982), increase risk (Greenwald and Stiglitz 1989), or lower the precision of demand forecasts (Balvers and Cosimano 1990). Note that each of these explanations rests on price changes as measured in the currency of the importing country. If quantity adjustment costs stem from, say, the costs of hiring and firing labor instead of stemming from bottlenecks as trade levels change in a particular market, then the adjustment costs occur in the domestic currency instead of the relevant foreign currency. Implications from this formulation are equivalent to those obtained previously, with the addition that the speed of price adjustment now depends (positively) on the real exchange rate. These results are available from the authors on request.

4 The exact criteria for selecting the set of commodities examined are as follows. First, we use all data sets available from the BLS Web site that have a time series of at least 10 years. Second, we choose the data at the most disaggregate five-digit international price code level. Third, we exclude all industries under the SIC code numbers for which the Herfindahl index is not available. Finally, we exclude all industries under a particular SIC code number for which the data on rates of return are not available from Compustat. Applying these selection criteria, we end up with 31 sets of commodities with export price data from an original total of 141 sets of commodities on the BLS Internet site.

5 “Census of Manufactures” issued February 1992 by the U.S. Department of Commerce provides the corresponding SIC code number for given BLS code numbers. If the match is not perfect, we use a range of SIC codes.

6 Our use of the Herfindahl index as a proxy for the slope of the demand curve is questionable for several reasons. First, since market demand slopes vary by industry, two industries that are equally concentrated will likely have different demand slopes. Second, there may not be a close correlation between an industry’s concentration in the United States (as measured) and that abroad (as needed theoretically). Third, the SIC categorization defining the industries need not represent a good characterization of the true market in which the firm operates.

7 Using the Durbin h-test, we find significant serial correlation in all cases. To correct for serial correlation, Harvey (1990), Maddala (1992), Greene (1993), and others suggest choosing the lagged value of one of the exogenous right-hand variables, in our case x_{t-1}, to instrument for the lagged endogenous variable, in our case p_{t-1}. Since x is exogenous to any industry, x_{t-1} is, by definition, uncorrelated with the error so that the conditions necessary for consistency are satisfied. The structure of the model ensures that x_{t-1} will show a reasonably high degree of correlation with p_{t-1}. Thus, we perform instrumental variable estimation to obtain the parameter values ρ for the degree of first-order serial correlation to be used in transforming the data.

8 This two-step procedure is preferred over estimating Equation 9, with the equation for λ related to Equation 4 substituted in, directly in one step: The estimate of λ is consistent directly from time-series Equation 9, even though additional cross-sectional information exists that theoretically could improve the estimate. However, using the cross-sectional information directly would require one of two compromises: either the

more exact multiplicative formulation would be maintained so that the variables explaining λ would enter multiplicatively with the lagged price and the real exchange rate (this would likely cause serious multicollinearity problems) or the expression would be linearized without interaction variables, in which case the estimate of the lagged price coefficient or any inferred estimate of λ would become inconsistent.

9 The linear demand assumption implies that the price elasticity is decreasing in price and implies incomplete pass-through in the long run. If we assume constant elasticity of demand, we cannot solve the model analytically for the price dynamics. However, the steady-state price moves proportionately with the exchange rate so that pass-through is complete in the long run. We speculate that pass-through would be incomplete in the short run for constant elasticity of demand: If an exchange rate depreciation implies a proportionate price increase in the long run and an associated decrease in production, then, because of the quantity adjustment costs, production decreases slowly over time toward the decreased steady state. During the adjustment, however, quantity is above and, accordingly, price below its steady state, so the pass-through is incomplete in the short run. Our empirical results of a 0.81 short-run elasticity becoming 1.0 in the long run thus appears to be most consistent with a constant-elasticity formulation. Several of the long-run elasticities in Table 2 are significantly above one. Such outcomes would be expected when demand curves are more convex than under constant elasticity.

REFERENCES

Balvers, Ronald J., and Thomas F. Cosimano. 1990. Actively learning about demand and the dynamics of price adjustment. The Economic Journal 100:882-98.

Branson, William. 1989. Discussant comment on Hooper, Peter and Catherine Mann. Exchange rate pass-through in the 1980s: The case of U.S. import manufactures. Brookings Papers on Economic Activity 1:297-37.

Dixit, Avinash. 1989. Hysteresis, import penetration, and exchange rate pass-through. Quarterly Journal of Economics 104:205-28.

Dornbusch, Rudiger. 1987. Exchange rates and prices. American Economic Review 77:93-106.

Feenstra, Robert C., Joseph E. Gagnon, and M. Michael Knetter. 1996. Market share and exchange rate pass-through in world automobile trade. Journal of International Economics 40:187-207.

Feinberg, Robert M. 1986. The interaction of foreign exchange and market power effects on German domestic prices. Journal of Industrial Economics 35:61-70.

Fisher, Eric. 1989. A model of exchange rate pass-through. Journal of International Economics 26:119-37.

Gagnon, Joseph E. 1989. Adjustment costs and international trade dynamics. Journal of International Economics 26:327-44.

Gagnon, Joseph E., and M. Michael Knetter. 1995. Markup adjustment and exchange rate fluctuations: Evidence from panel data on automobile exports. Journal of International Money and Finance 14:289-310.

Greene, William H. 1993. Econometric analysis. 2nd edition. New York: Macmillan.

Greenwald, Bruce, and Joseph E. Stiglitz. 1989. Toward a theory of rigidities. American Economic Review 79:364-9.

Harvey, Andrew C. 1990. The econometric analysis of time series. 2nd edition. New York: Philip Allan.

Hooper, Peter, and Catherine Mann. 1989. Exchange rate pass- through in the 1980s: The case of U.S. imports of manufactures. Brookings Papers on Economic Activity 1:297-337.

Kasa, Kenneth. 1992. Adjustment costs and pricing-to-market: Theory and evidence. Journal of International Economics 32:1-30.

Knetter, Michael. 1989. Price discrimination by U.S. and German exporters. American Economic Review 79:198-210.

Krugman, Paul. 1987. Pricing to market when the exchange rate changes. In Real Financial Linkages among Open Economies, edited by Sven W. Arndt and J. David Richardson. Cambridge, MA: MIT Press, pp. 48-70.

Krugman, Paul. 1989. Exchange-rate instability. Cambridge, MA: MIT Press.

Lee, Jaewoo. 1997. The response of exchange rate pass-through to market concentration in a small economy: The evidence from Korea. Review of Economics and Statistics 79:142-5.

Maddala, G. S. 1992. Introduction to econometrics. 2nd edition. New York: Macmillan.

Mann, Catherine. 1986. Prices, profit margins, and exchange rates. Federal Reserve Bulletin 72:366-79.

Okun, Arthur. 1981. Prices and quantities: A macroeconomic analysis. Washington, DC: The Brookings Institution.

Rotemberg, Julio. 1982. Monopolistic price adjustment and aggregate output. Review of Economic Studies 49:517-31.

APPENDIX

DERIVATION OF THE MODEL SOLUTION

The model of Equations 1 and 2 in the text implies the following value function:

$J(q, x, t) = \max / [u]^{\infty}_{t}\ E \int^{\infty}_{t} e^{-rs} [xpq - cq - 1 / 2xhu^2]\ ds,$ (A1)

defining $q' = u$ and setting for simplicity $c(w_D, xw_F) = c$. The Bellman equation becomes

$-J_3(q, x, t) =$ [Graphic Character Omitted] $[e^{-rt}(xpq - cq - 1 / 2xhu^2) + J_1(q, x, t)u],$ (A2)

subject to Equation 2, where numerical subscripts indicate partial derivatives. The optimal choice of u implies that

$u = e^{rt}J_1/hx.$ (A3)

Next, guess a functional form for the value function

$J = e^{-rt}[Aq^2x + Bqx + Cq + D/x + Fx + G],$ (A4)

where A, B, C, D, F, and G are constants to be determined. Obtaining J_1 and J_3 from Equation A4 and u from Equation A3 and substituting into Equation A2 implies the following restrictions on the constants:

$rA = -(1/b) + 2A^2/h$ (A5)

$rB = (a/b) + 2AB/h$ (A6)

$rC = -c + 2AC/h$ (A7)

$rD = C^2/2h$ (A8)

$rF = B^2/2h$ (A9)

$rG = BC/h.$ (A10)

Clearly, our guess for the form of the value function can be verified. For the control variable from Equations A3 and A4 we have

$u = q' = [2Aq + B + (C/x)]/h.$ (A11)

Solving the first-order differential equation in Equation A11 for q produces

$q_t = [q_0 + (B + (C/x)) / 2A]e^{(2A/h)t} - (B + (C/x) / 2A).$ (A12)

Thus, to obtain the explicit solution, we need only solve for A, B, and C. From Equation A5, we find that

$A = [rh - (r^2h^2 + 8h/b)^{1/2}]/4,$ (A13)

where we have taken the negative root, which ensures convergence. Using the solution for A, it is easy from Equation A6 and A7 to solve for B and C as well.

Substituting the solutions for A, B, and C into Equation A12 and employing Equation 2 to convert quantity into price produces Equations 3, 4, and 5 in the text as desired.