

International Finance Discussion Papers

Number 302

February 1987

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## Abstract

Exchange rate pass-through is the phenomenon whereby changes in the value of foreign exchange are reflected in changes in import prices. This paper presents a model in which firms are price setters who anticipate exchange rate changes. In equilibrium, firms' strategies incorporate expectations about the exchange rate consistently and are best responses to the strategies of all others in the world market. It is shown that exchange rate changes give rise to import price changes, but the degree of exchange rate pass-through depends upon domestic and foreign market structures and the exchange rate regime. In general, exchange rate pass-through is higher if the home market is monopolistic or if the foreign market is competitive. The paper concludes with an examination of disaggregated Japanese manufacturing price indices, and it shows that the degree of exchange rate pass-through was indeed correlated with industry concentration during the most recent period of the yen's depreciation against the dollar.

# A Model of Exchange Rate Pass-Through

By

Eric O'N. Fisher\*

## 1. Introduction

During the 1980's, there have been more than 160 days when the weighted-average value of the dollar varied by more than one percent between the opening and closing of the foreign exchange market in New York. In the same period, the variance of the monthly changes of the Federal Reserve Board's dollar index has been more than six percent. The dollar prices of non-oil imports, of course, have been much less volatile. This fact is difficult to explain if goods are imported at cost in a competitive market.

In oligopolistic industries, however, it has been observed that domestic currency prices do not move immediately with exchange rate movements. Even over a relatively long period, these import prices do not reflect exchange rate movements fully. The presumption is that producers' profit margins change, at least in the short run, when foreign exchange values change. The empirical studies cited below show that, as a general rule of thumb, prices of non-oil imports into the United States have reflected only between fifty and eighty percent of a change in the value of the dollar.

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\*The author is a staff economist in the International Finance Division. This paper represents the views of the author and should not be interpreted as reflecting those of the Board of Governors of the Federal Reserve System or other members of its staff. The author would like to thank Cathy Mann for discussions which stimulated his initial interest in this subject. He would also to thank Richard Rosen, Garry Schinasi, David Gordon, Jonathan Eaton, Avinash Dixit, Sally Davies, Ralph Tryon, and seminar participants at Cornell University for comments on an earlier draft. Any remaining mistakes are of course his own.

The relationship between foreign currency price and domestic currency price is termed exchange rate pass-through. There have been quite a few empirical studies of the phenomenon, and the recent volatility of the dollar has spurred renewed interest in the subject. Several studies have showed that the mark-up of import price above marginal cost seems to have increased during the recent period of the dollar's appreciation and subsequent rapid decline. A recent study of this phenomenon is by Mann [15]; Feinberg [7] and Flood [8] have also examined exchange rate pass-through. There are several older studies as well; see Clark, Logue, and Sweeney [4] and Dunn [6], for example.

While there is a significant literature on the welfare effects of price variability which dates back to the second war (see Waugh [18], Oi [16], and Samuelson [17] for a lively debate), it is perhaps surprising that there is relatively little recent theoretical work on the microeconomics of oligopolistic price setting under exchange rate variability. Krugman [7] emphasized that the phenomenon of exchange rate pass-through was an area in which the newer models of international trade theory would find a ready application; he examined a variety of static and dynamic models illustrating aspects of the relationship between currency fluctuations and import price changes. Dornbusch [5] also studied the effect of short-term exchange rate changes in several different models of industrial organization; he emphasized that market segmentation and market organization influence the relationship between import prices and exchange rates. Both of these papers appealed to the use of several different models of industrial organization to illustrate disparate facets of exchange rate pass-through. This paper is meant to present a unified treatment of pass-through within the framework of one model, which uses price as the firm's choice variable and employs a Bayesian Nash equilibrium concept.

This model captures four stylized facts. First, it incorporates the idea that producers set prices in anticipation of exchange rate changes. Indeed, under the current exchange rate regime, it would be prohibitively expensive for most manufacturers in industrialized countries to change their offer price with every movement of the value of foreign exchange. Second, by emphasizing the strategic interdependence of producers' decisions, this model shows that market structure has an influence on exchange rate pass-through. Third, the model is built upon the premise that the effects of exchange rate changes are quite different in the short run from what they are in the long run. Fourth, it captures the notion that pass-through is different under a regime of fixed exchange rates from what it is under floating rates.

There are two effects that exchange rate movements have in any market. First, a depreciation makes domestic producers lower cost-world producers. Second, a depreciation shifts world demand towards the home country. It is not immediately obvious what the best response of a foreign oligopolist would be in such a situation. If he had been pricing above marginal cost, should he cut his offer price to maintain world market share? Will domestic producers raise price more than proportionately because of increased world demand for their goods? What are the interactions between the best responses of home and foreign producers? In perfectly competitive markets, will price move exactly to match exchange rate changes? What effects will differential degrees of domestic and foreign competitiveness have on exchange rate pass-through? The model presented here will address these questions.

The paper is structured as follows. In the second section, we present the model, and in the third section, we show that an equilibrium exists for any description of home and foreign market structures. In the fourth section,

we describe the effects of exchange rate pass-through in a regime of fixed exchange rates, and in the fifth section, we show its effects in a regime of floating rates. The sixth section presents an empirical analysis of these ideas using sales and price data from nine Japanese manufacturing industries; it shows that pass-through was significantly correlated with industry concentration during the period of the dollars appreciation, but this correlation is less significant during the dollar's depreciation. The seventh section presents our conclusion.

## 2. The Model

We assume that there are  $n$  domestic firms and  $n^*$  foreign firms, where  $n$  and  $n^*$  are positive integers. The firms produce a homogeneous good and act as Bertrand competitors. The firms in any one country are identical; they have constant marginal cost and no capacity constraints. We normalize prices in the domestic currency so that the marginal cost of a domestic firm is unity. We assume further that foreign marginal costs are unity in terms of foreign currency. Hence, when the exchange rate is one, domestic and foreign costs are equal. This is meant to capture the notion of long-term factor price equalization, which is of course a real, not a monetary phenomenon.

There is a domestic and a foreign market for the good. Demand in the domestic market is given by  $D(p)$ , and demand in the foreign market is given by  $D^*(p)$ . These demand functions place the analysis unabashedly within the framework of partial equilibrium because there are no income effects. We make the following further assumptions about demand.

Assumption 1:  $D(p)$  and  $D^*(p)$  are continuous, non-increasing, and concave. There exists  $\bar{p} > 1$  such that, for all  $p \geq \bar{p}$ ,  $D(p) = 0$ . Also,  $D(0)$  is

finite. Further, there exists  $\bar{p}^* > 1$  such that, for all  $p \geq \bar{p}^*$ ,  $D^*(p) = 0$ . Also,  $D^*(0)$  is finite. We do not assume that  $\bar{p} = \bar{p}^*$

Assumption 1 states that there are prices above which there is no demand in the domestic and the foreign market. It also implies that demand does not become unbounded as price decreases. The concavity of the demand in each country will allow for natural comparative statics; in particular, an expected depreciation will cause a domestic monopolist to raise his offer.

We can now write the profit function of a domestic producer under the assumption that his offer is the lowest offer in terms of the domestic currency. We have

$$\pi(s;e) = \begin{cases} (s-1)(D(s) + D^*(s/e)) & \text{if } s/s^* \leq e \\ 0 & \text{if } e < s/s^* \end{cases} \quad (1)$$

where  $\pi$  is profits in domestic currency,  $s$  is the firm's domestic offer price,  $e$  is the realized value of the exchange rate, and we recall that the marginal cost of production is normalized to be unity. Note that an increase in  $e$  is a depreciation of the domestic currency. Domestic currency profits are random and depend upon the exchange rate because foreign consumers pay a price denominated in the foreign currency. Equation (1) uses the implicit assumption that the home producer cannot discriminate between geographically distinct markets; this is equivalent to assuming that no dumping is allowed. We write the profit function for an analogous foreign producer for completeness' sake

$$\pi(s^*; e) = \begin{cases} 0 & \text{if } s/s^* \leq e. \\ (s^*-1)(D(es^*) + D^*(s^*)) & \text{if } e < s/s^* \end{cases} \quad (2)$$

where foreign profits are denominated in foreign currency and again we have used the assumption that foreign marginal costs are unity in terms of foreign currency.

We assume that the exchange rate  $\tilde{e}$  follows a process summarized by the density  $f(e)$ . Following the usual convention, we interpret  $F(t)$  as the probability that the event  $e \leq t$  occurs, where  $F(e)$  is of course the cumulative distribution function corresponding to  $f(e)$ . In this case, we interpret the event  $F(t)$  as the event that the level of the exchange rate has appreciated at least to  $t$ . To avoid mathematical complexities, we shall assume

Assumption 2: The support of  $\tilde{e}$  is either: (i) a point greater than 0; or (ii) a subset of the positive real numbers which is a bounded closed interval not containing 0. Further, if (ii) is the case, then  $f(e)$  is continuous, differentiable on its support, and  $\Phi(e) = f(e)/[1-F(e)]$  is increasing in  $e$ .

The first part of Assumption 2 imposes the constraint that the exchange rate cannot depreciate or appreciate infinitely. The second part of this assumption ensures that the first order conditions for a firm's expected profit maximization are well behaved. The term  $\Phi(e)$  is the hazard rate corresponding to the density  $f(e)$ ; it is increasing for a normal or a uniform density. This assumption will enable us to analyze the comparative statics of an expected exchange rate change.

As is typical in analyses of Bertrand competition, we assume that all demand in any market is allocated to the seller declaring the lowest offer. The sequence of events influencing the oligopolists' decisions is as follows. First, firms simultaneously announce offers in their respective currencies; these announcements are interpreted as binding commitments to sell to all demanders, regardless of provenance, at the announced offer price. Second, the exchange rate is realized, and demand is allocated to the lowest offer in a common currency. In the case of ties, demand is allocated (equally) to the producer(s) having the lowest cost(s), using the realized value of the exchange rate to compare. This rationing rule is an artifice used to make proofs of the existence of an equilibrium easier. We use it to simplify the analysis, and it will enable us to use the standard result that the equilibrium price in a Bertrand game is (just under) the cost of the second lowest cost producer. In a discrete price space, we would not have to worry about this technicality, and here it does not alter the nature of our results.

The timing of decisions in the model is quite similar to that in Mankiw [14]. He assumes that firms set prices in anticipation of shocks to industry demand. When there is a small shock to industry demand, firms may be unwilling ex post to change their prices because they must pay a cost to do so. The nature of contracts in international trade and the current volatility of exchange rates make this assumption about the timing of firms' decisions a natural one for our model.

We conclude this section with a formal statement of the expected profits of a home and a foreign producer. Any producer who does not declare a minimal offer among the set of producers of his own nationality makes no profit; hence, we need consider only the most competitive domestic and foreign

offers. Then, ignoring the possibility of ties for a moment, we can write a domestic firm's expected profits as

$$V = \int_{(s/s^*)}^{\bar{e}} \pi(s;e) f(e) de \quad (3)$$

where the upper limit of integration is the highest possible devaluation that can occur and the lower limit of integration corresponds to the event whose probability is  $F(s/s^*)$ , which occurs when the exchange rate appreciates sufficiently so that the offer  $s$  is no longer competitive against  $s^*$ , the best foreign offer. In particular,  $1-F(s/s^*)$  is equivalent to the probability that  $s < es^*$ , which is the event that the best offer by a domestic firm is the best offer in the world market. Likewise, again temporarily ignoring ties, we have the foreign firm's expected profits given by

$$V^* = \int_{e_-}^{(s/s^*)} \pi^*(s^*;e) f(e) de \quad (4)$$

where the lower limit of integration is the greatest possible appreciation of the currency and the upper limit again represents the event that the exchange rate depreciates sufficiently so that the foreign firm's offer is no longer competitive. We say that  $s$  and  $s^*$  are equilibrium strategies if, given common expectations about the exchange rate process as summarized by  $f(e)$ ,  $s$  maximizes (3) and  $s^*$  correspondingly maximizes (4).

### 3. Equilibrium

The central result of this section is that an equilibrium exists for all possible combinations of domestic and foreign market structures. The assumption of Bertrand competition provides a convenient description of the domestic and foreign market structures. If there is one domestic producer, we shall say that the domestic market is monopolistic; if there are two or more domestic producers, we shall say that the domestic market is perfectly competitive. We use the analogous definitions for the foreign market. This corresponds to the intuition we derive from the fact that two identical Bertrand competitors price at marginal cost in equilibrium if there is no capacity constraint facing either one.

We begin with a simple lemma.

Lemma 1: If there are two or more domestic (foreign) producers, then in equilibrium either (i) no domestic (foreign) firm has positive expected sales or (ii) the best offer by a domestic (foreign) firm is an offer at marginal cost.

Proof: Assume that the best offer by a domestic firm is an offer above marginal cost and that it has positive expected sales. Let  $s^o$  be that offer. By assumption  $s^o > 1$ . Then, the expected return of that strategy is

$$V(s^\circ) = \int_{(s^\circ/s^*)}^{\bar{e}} \pi(s; e) f(e) de \quad (5)$$

where again  $s^*$  is the best foreign offer. Since the firm has positive expected sales,  $s^\circ/s^* < \bar{e}$ , and for any  $s$  satisfying  $1 < s < s^\circ$ , it is true that  $V(s) > 0$ . Hence the best response of a firm calling an offer above  $s^\circ$  is to offer some  $s < s^\circ$ , which contradicts the assumption of equilibrium.

An exactly analogous line of reasoning follows for the case where there are two or more foreign competitors. Q.E.D.

The intuition behind Lemma 1 is simple enough. If the best offer by a domestic competitor is above marginal cost and is still good enough to have some chance of beating the best foreign offer, then the best response of a second domestic competitor will be to undercut it. This allows only for offers at marginal cost in equilibrium.

We can now state an existence theorem.

Theorem 1: Under Assumptions 1 and 2, an equilibrium exists for all possible market structures.

Proof: Whenever  $n \geq 2$  and  $n^* \geq 2$ , we can use Lemma 1 to construct an equilibrium in which all competitors price at their respective marginal costs. In the rest of the proof, we will explore the cases where  $n=1$  or  $n^*=1$ .

Again, let the infimum of the support of  $\bar{e}$  be given by  $e_-$  and its supremum by  $\bar{e}$ . By Assumption 2,  $0 < e_- \leq \bar{e} < \infty$ . Let  $S = \{s: 1 \leq s \leq$

$\max\{\bar{p}, \bar{p}^*/e_{-}\}$ ), and  $S^* = \{s: 1 \leq s \leq \max[\bar{e}, \bar{p}, \bar{p}^*]\}$ . Notice that for a domestic firm any  $s \notin S$  is dominated by an  $s \in S$ ; likewise, for a foreign firm any  $s \notin S^*$  is dominated by an  $s \in S^*$ . Without loss of generality, then, we can restrict our attention to strategies on  $S$  and  $S^*$ . Note that  $S$  and  $S^*$  are non-empty and compact.

There are two cases to consider: either (i)  $\bar{e}$  is a degenerate random variable; or (ii)  $f(e)$  is continuous and differentiable on a closed interval. If  $f(e)$  is continuous, for any fixed  $s$  and  $s^*$  played in equilibrium, the probability that  $s=e=s^*$  is zero; hence, we can ignore the possibility of ties. Consider the expression for a domestic firm's expected profits as given in (3). It is easy to see that  $\pi(p)$  is continuous because  $D$  and  $D^*$  are. Further, because  $f(e)$  is continuous and bounded at the lower limit of integration,  $V(s)$  is continuous on  $S$ . Analogous arguments are true for the continuity of a foreign producer's expected profits. Then, by Glicksberg [9], an equilibrium exists.

If  $\bar{e}$  is a degenerate random variable and hence  $e_{-} = \bar{e}$ , the theorem is equivalent to stating that an equilibrium exists in a Bertrand game where demand is continuous and the competitors have different costs. Because of the rationing rule stated in the second section, such an equilibrium exists, with the lowest cost world producer pricing at the cost of the second lowest cost firm, using the exchange rate to compare costs of firms of different nationalities.

Q.E.D.

Before concluding this section, it will be instructive to write out the first order condition for a monopolist's profit maximization. Differentiating (3) and taking full advantage of the smoothness of world

demand and the exchange rate distribution, we see that a domestic monopolist's equilibrium strategy satisfies

$$\frac{\partial V}{\partial s} = \int_{(s/s^*)}^{\bar{e}} (\partial \pi(s; e) / \partial s) f(e) de - (1/s^*) \pi(s; s/s^*) f(s/s^*) = 0. \quad (6)$$

Recall that  $s/s^*$  is the level of the exchange rate that just makes the home firm competitive. This makes the interpretation of (6) straight-forward; it says that the equilibrium price charged by the domestic firm is such that its expected marginal profit in states of the world where the exchange rate has depreciated sufficiently to make it competitive is just equal to the gain from undercutting the best price of a foreign competitor. Likewise, the first order condition for a foreign monopolist is

$$\frac{\partial V^*}{\partial s^*} = \int_{e_-}^{(s/s^*)} (\partial \pi^*(s^*; e) / \partial s^*) f(e) de - (s/s^{*2}) \pi^*(s^*; s/s^*) f(s/s^*) = 0. \quad (7)$$

Again, equation (7) has the interpretation that the foreign firm charges a price high enough so that the expected marginal increase in profits in states of the world where the currency appreciates is equal to the loss from not matching the best price of a home firm at the critical value of the exchange rate. These first order conditions will be useful in the subsequent analysis.

4. Pass-Through Effects in a Regime of Fixed Exchange Rates

In the preceding section, we concentrated on analyses of the equilibrium offers by domestic and foreign firms; we did not discuss the expected equilibrium market price that such offers and the density of the exchange rate entail. As will become apparent in this section, the equilibrium price prevailing in the market does not always reflect fully realized changes in the exchange rate.

We begin with the observation that the equilibrium (home currency) price in the market is given by

$$p(e; s, s^*) = \min[s, es^*] \quad (8)$$

where again  $s$  and  $s^*$  are respectively the best home and foreign firms' offers. An immediate consequence of the timing of offers in the model is that prices ex post may not reflect fully the effects of large depreciations. To see this more clearly, let us turn our attention to Figure 1, which appears on page 33. Figure 1 graphs the equilibrium market price in terms of the realized exchange rate under the arbitrary assumption that  $(s/s^*) > 1$ . Notice that, for large depreciations the home currency, the equilibrium price can be no larger than  $s$  because the best domestic offer is fixed in the short term. On the other hand, realizations of the exchange rate  $e < (s/s^*)$  will result in market prices which are lower than  $s$ , but even if  $e < 1$ , it may still be the case that  $p(e) > 1$ . As we shall see below, a shift in the distribution of the exchange rate has two effects: first, it causes firms' offers to change in a Bayesian Nash equilibrium; second, given those equilibrium offers, it changes the expected equilibrium market price. This is an important positive

distinction because equilibrium offers may not be observable, whereas market prices are.

We are now in a position to define exchange rate pass-through formally. Recall that we have structured the model so that the implicit status quo is that the current realization of the exchange rate is unity; moreover, the past expectation of the exchange rate process was also unity, albeit the distribution of the exchange rate may have had some variance. The current market price, however, may not be 1; in particular, it depends upon the best foreign and domestic offers, which were based upon expectations held before the current period. Exchange rate pass-through will be defined with respect to this benchmark. Let  $s$  and  $s^*$  be the best offers in an initial equilibrium where  $E\tilde{e}=1$ , and let  $s'$  and  $s^{*}$  be best offers under an alternative distribution of the exchange rate where  $E\tilde{e}\neq 1$ . Further, let  $\rho(e)$  be the pass-through coefficient, where we have denoted explicitly that pass-through depends upon the realization of the exchange rate. We have then

Definition:  $\rho(e) = [p(e; s', s^{*}) - p(1; s, s^{*})] / [e - 1]$  (9)

where  $p(e)$  is given in (8) and depends implicitly on  $s$  and  $s^*$  as well as  $e$ . This equation defines observed exchange rate pass-through is the percentage change in market price divided by the percentage change in the exchange rate. Notice that  $\rho(e)$  is well defined only when  $e \neq 1$ ; that is, there must be an exchange rate change in order for there to be exchange rate pass-through. Although we have defined pass-through in terms of changes in domestic currency prices, it could have been defined equally well in terms of foreign currency price changes.

Assume that past expectations are summarized by a degenerate random variable  $\tilde{e}$  which is equal to 1 with probability 1; assume, not inconsistently, that the current realization of the exchange rate is also 1. Assume further that there is a new density for the exchange rate such that  $E\tilde{e} = 1+k$ , for  $k$  in a neighborhood of 0; that is, firms perfectly anticipate a devaluation (revaluation) of  $100k$  percent if  $k > 0$  (if  $k < 0$ ). We now state a series of lemmata which lead to the main result of this section.

Lemma 2: Under fixed exchange rates, if  $n > 1$  and  $n^* > 1$ , then (i) if  $k < 0$ ,  $\rho(1+k)=1$ , and (ii) if  $k > 0$ ,  $\rho(1+k)=0$ .

Proof: Using Lemma 1, we know that  $s=s^*=1$ . The conclusion follows from the uniqueness of the equilibrium and an evaluation of (9).

Q.E.D.

Lemma 2 shows immediately that exchange rate changes can have asymmetric effects. This follows, of course from the assumption that demand is allocated according to the lowest price in domestic currency.

We continue with Lemma 3.

Lemma 3: Under fixed exchange rates if  $n > 1$  and  $n^*=1$ , then (i) if  $k < 0$ ,  $\rho(1+k)=0$ , and (ii) if  $k > 0$ ,  $\rho(1+k)=0$ .

Proof: Again, using Lemma 1, we know that  $s=1$ . It is easy to check that  $s^*=1/(1+k)$  is a best response to  $s$ . Again, the conclusion follows from the uniqueness of the equilibrium and an evaluation of (9). Q.E.D.

We now state Lemma 4.

Lemma 4: Under fixed exchange rates if  $n=1$  and  $n^* > 1$ , then (i) if  $k < 0$ ,  $\rho(1+k)=1$ , and (ii) if  $k > 0$ ,  $\rho(1+k)=1$ .

Proof: The reasoning is exactly analogous to that of Lemma 3. Q.E.D.

We state Lemma 5.

Lemma 5: Under fixed exchange rates if  $n=1$  and  $n^*=1$ , then (i) if  $k < 0$ ,  $\rho(1+k)=0$ , and (ii) if  $k > 0$ ,  $\rho(1+k)=1$ .

Proof: If  $k < 0$ , then, again using the rationing rule described in section 2, the unique equilibrium strategies are  $s^*=1/(1+k)$  and  $s=1$ . If  $k > 0$ , then the unique equilibrium is given by  $s^*=1$  and  $s=1+k$ . Again, the conclusion follows from an evaluation of (9). Q.E.D.

We now state the main result of this section

Theorem 2: Under fixed exchange rates, an appreciation is deflationary if and only if the foreign market is competitive, and a depreciation is inflationary if and only if the domestic market is monopolistic.

Proof: The conclusion follows from Lemmata 2 through 5. Q.E.D.

Theorem 2 makes explicit our intuition. We see that there is a strong pass-through effect to the extent that the domestic or foreign market structure enables a producer to use his market power to set price when the exchange rate moves in his favor. One policy implication of Theorem 2 is that fixed exchange rates, with periodic readjustments, display an inflationary bias for monopolized industries. Of course, when we speak of inflation here, we mean a once and for all change in the price level of an industry, not a persistent change in the rate of increase of a macro-economic price index. Moreover, we are not describing a steady state in the international industry. Implicit in our modeling framework is the notion that industry costs are equalized at the prevailing steady-state exchange rate; if there is a depreciation which makes the domestic industry a world monopoly, then, in the long run, there will be entry into the industry by a domestic firm or a change of production techniques by foreign producers to restore the initial status quo in which both foreign and domestic firms had the same expected costs.

##### 5. Pass-Through Effects in a Regime of Floating Exchange Rates

In this section, we analyze the effects of pass-through when the distribution of the exchange rate is not degenerate. In particular, we will examine the case where the support of  $\tilde{e}$  is an interval and  $f(e)$  is smooth, as described by Assumption 2(ii). This assumption allows in essence for some short-term price noise, which affects the equilibrium offers of the oligopolists. Before proceeding to the heart of the analysis, it is worth mentioning that the assumption of a regime of floating exchange rates gives rise to an inherent difference between the expected market price and the realized market price; likewise, there is a difference between the expected

pass-through effect and the realized pass-through effect. Under a regime of fixed rates, these distinctions are moot, but it will be important to have that distinction clearly in mind during the rest of the discussion.

It is well known that the convexity of the profit function implies that expected profits increase with a mean-preserving spread of the price of output. In our model, this implies that price noise gives rise to positive expected profits for a monopolist in of either nationality. We state Lemma 6.

Lemma 6: Under flexible exchange rates, if  $n=1$  ( $n^*=1$ ), then either (i)  $s > 1$  ( $s^* > 1$ ) or (ii) the domestic (foreign) monopolist has no expected sales. Further, a system of flexible exchange rates guarantees positive expected profits even if there is no expected exchange rate change.

Proof: Let  $s^*$  be a best foreign offer in equilibrium. If  $\bar{e}s^* \leq 1$ , then a home firm has no expected sales. If  $1 < \bar{e}s^*$ , then for any  $s$  such that  $1 < s < \bar{e}s^*$ , we have

$$V(s) = \int_{(s/s^*)}^{\bar{e}} \pi(s;e) f(e) de > 0 \quad (10)$$

where in (12)  $V$ , again, is the value of the game for the home firm. An exactly analogous argument is true for a foreign monopolist. The last part of the lemma follows from the fact that if  $E\bar{e} = 1$ , Assumption 2(ii) implies  $e_- < 1 < \bar{e}$ .

Q.E.D.

The intuition behind Lemma 6 is that the assumption of flexible exchange rates introduces enough price noise so that, if there is some chance that the exchange rate will depreciate, a domestic monopolist can still have positive expected sales by pricing above marginal cost.

The best response of a monopolist will in general depend upon all the moments of the distribution of the exchange rate. The easiest way to see this is to rewrite equation (6) as

$$\int_{(s/s^*)}^{\bar{e}} \partial \pi(s; e) / \partial s f(e) de = [(s-1)/s^*] [D(s) + D^*(s^*)] f(s/s^*). \quad (11)$$

Equation (11) is a restatement of the first order necessary condition for a home monopolist. The left hand side of (11) depends not only on the mean of the exchange rate but also on the weight that the density  $f(e)$  places on different levels of marginal profits in the world market.

This leads us to examine a class of shifts of the distribution of the exchange rate which change the first moment but not any other central moments. In particular, we will examine distributions which belong to the same location family. Let  $f(e)$  be an arbitrary distribution satisfying Assumption 2(ii) and  $\int e f(e) de = 1$ . For  $k$  in a neighborhood of 0, we define

Definition: The density  $g$  is a  $k$ -shift of  $f$  if and only if  $g(e+k) = f(e)$ .

This definition is convenient because the expectation of the exchange rate with respect to  $f$  is 1, while its expectation with respect to  $g$  is  $1+k$ .

The definition of a  $k$ -shift captures the idea that the exchange rate is expected to depreciate by  $k$  with no change in its variance or other moments. Because the status quo level of the exchange rate is assumed to be unity, implicit in the assumption that the expectation of the exchange rate is 1 is the idea that the exchange rate follows a random walk. We are interested, however, in more general exchange rate processes.

We proceed with an analysis of the effect of an expected change in the level of the exchange rate. The assumption that the exchange rate distribution is given exogenously is equivalent to the assumption that the oligopolists are Bayesians who share a common prior on how the exchange rate will move. If their expectation of the exchange rate is given by  $\int e f(e) de = 1$ , then they assume implicitly that the exchange rate follows a random walk, whereas if their expectation is given by  $\int e g(e) de = 1+k$ , then they expect the exchange rate to move by  $100k$  percent. We now state a simple result having to do with the comparative statics of equilibrium.

Lemma 7: Under a regime of floating exchange rates, an expected depreciation (appreciation) causes a domestic monopolist to raise (lower) his offer. Further, a domestic monopolist's equilibrium offer is unique.

Proof: We examine a  $k$ -shift of the exchange rate. Recall that  $s$  solves equation (11), which is equivalent to

$$[1/f(s/s^*)] \int_{(s/s^*)}^{\bar{e}} \partial\pi(s;e)/\partial s f(e) de = \pi(s;s/s^*). \quad (12)$$

The right side of (12) is increasing for any  $s$  less than the monopoly price in the world market. Because  $D^*(p)$  is concave, we know that, for all  $e \geq s/s^*$ ,  $\partial\pi(s;e)/\partial s \geq \partial\pi(s;s/s^*)/\partial s$ . Hence,

$$[1/f(s/s^*)] \int_{(s/s^*)}^{\bar{e}} \partial\pi(s;e)/\partial s f(e) de \leq \partial\pi(s;s/s^*)/\partial s [1-F(s/s^*)]/[f(s/s^*)],$$

which is equivalent to

$$[1/f(s/s^*)] \int_{(s/s^*)}^{\bar{e}} \partial\pi(s;e)/\partial s f(e) de \leq \partial\pi(s;s/s^*)/\partial s [1/\Phi(s/s^*)] \quad (13)$$

where again  $\Phi(\cdot)$  is the hazard rate of the density  $f(\cdot)$ . By Assumption 2, we know that  $[1/\Phi(s)]$  is decreasing in  $s$ ; since  $D(p)$  and  $D^*(p)$  are concave,  $\partial\pi(s;s/s^*)/\partial s$  is also decreasing in  $s$ . Hence, the the left side of (12) is decreasing in  $s$ . This establishes the uniqueness of the equilibrium offer.

Further, note that for all  $k > 0$

$$\int_{(s/s^*)}^{\bar{e}} \partial \pi(s; e) / \partial s f(e) de \leq \int_{(s/s^*)}^{\bar{e}} \partial \pi(s; e+k) / \partial s f(e) de.$$

Hence, a k-shift of the exchange is equivalent to an outward shift of the curve defined implicitly by the left side of (12). This implies that an expected depreciation causes a domestic monopolist's equilibrium offer to rise.

The reasoning for an appreciation is exactly analogous. Q.E.D.

For completeness, we state Lemma 8.

Lemma 8: Under a regime of floating exchange rates, an expected depreciation (appreciation) of the home currency causes a foreign monopolist to lower (raise) his offer. Further a foreign monopolist's equilibrium offer is unique.

Proof: This follows as a corollary of Lemma 7. Q.E.D.

We are now in a position to examine systematically the effects of exchange rate pass-through with respect to market structure. Assume for the next four lemmata that the past expectations of the exchange rate were such that  $E\bar{e} = 1$ , the current value of the exchange rate is also 1, and there has been a shift of expectations so that now  $E\bar{e} = 1+k$  for some  $k$  in a neighborhood of 0.

Lemma 9: Under floating exchange rates, if  $n > 1$  and  $n^* > 1$ , then the pass-through function is given by

$$\rho(e) = \begin{cases} 1 & \text{if } e < 1 \\ 0 & \text{if } e > 1 \end{cases}$$

Proof: The proof is identical to that of Lemma 2.

Q.E.D.

Note that the expected pass-through for this industry is given by  $1-F(1+k)$ , which states that higher expected pass-through is associated with larger expected appreciations. Likewise, the higher the probability of a depreciation, the less likely that any pass-through will be observed.

We continue with Lemma 10.

Lemma 10: Under floating exchange rates if  $n > 1$  and  $n^*=1$ , then the pass-through function is given by

$$\rho(e) = \begin{cases} (es^{*'} - 1)/(e-1) & \text{if } e \leq 1/s^{*'} \\ 0 & \text{if } e > 1/s^{*'} \end{cases}$$

where  $s^{*'}$  is the foreign monopolist's equilibrium offer under the assumption that  $E\tilde{e}=1+k$ .

Proof: Under the initial exchange rate expectations, using Lemmata 1 and 6, we know that  $s=1$  and  $s^* > 1$ . Hence,  $p(1;s,s^*)=1$ . If the new expectations of the exchange rate are such that  $E\tilde{e}=1+k$ , it is still true that  $s'=1$ , but  $s^{*'}$   $\neq$   $s^*$ . Nonetheless, using Lemma 6,  $s^{*'}$   $> 1$ . The conclusion then follows

from the uniqueness of the equilibrium and an evaluation of (9).

Q.E.D.

There are three important observations to make about Lemma 10. First, by the assumption that the current level of the exchange rate is 1 and the fact that the foreign monopolist took advantage of ex ante flexible rates to shade up his offer above marginal cost, only the home firms had sales in the initial equilibrium. Hence, the initial market price was 1. Second, there are small realized appreciations ( $1/s^{*'} < e < 1$ ) for which there is no pass-through; this occurs because foreign monopolists have higher (expected) profit margins than the domestic competitors. Third, even if there is a large enough realized appreciation so that we observe pass-through, we have  $\rho(e) < 1$  because  $s^{*'} > 1$ . Hence, we will never see full exchange rate pass-through.

We now state Lemma 11.

Lemma 11: Under floating exchange rates if  $n=1$  and  $n^* > 1$ , then the pass-through function is given by

$$\rho(e) = \begin{cases} 1 & \text{if } e < s' \\ (s' - 1)/(e - 1) & \text{if } e \geq s' \end{cases}$$

Proof: In the initial equilibrium, the best response of the foreign firms was  $s^{*}=1$ , while that of the domestic monopolist was  $s > 1$ . Under the new exchange rate expectations, we still have  $s^{*}=1$  and  $s' > 1$ . The conclusion follows from an evaluation of (9).

Q.E.D.

Because the foreign firms make offers at cost and the domestic monopolist makes an offer above cost, there are small depreciations for which the foreign competitors still supply the world market. This corresponds to the common notion that foreign firms are keeping their offers down so as to maintain market share; what is really happening is the domestic producer prices above cost even if there is an expected appreciation.

Finally, we state Lemma 12.

Lemma 12: Under fixed exchange rates if  $n=1$  and  $n^*=1$ , then the pass-through function is given by

$$\rho(e) = \begin{cases} [es^* - \min[s, s^*]]/[e-1] & \text{if } e < s/s^*, \\ [s' - \min[s, s^*]]/[e-1] & \text{if } e \geq s/s^*, \end{cases}$$

Proof: In the initial equilibrium, the best offers were given by  $s$  and  $s^*$ . By Lemma 6, we know that  $s > 1$  and  $s^* > 1$ . Therefore, the initial equilibrium price  $p(1; s, s^*) = \min[s, s^*]$ . The conclusion follows from an evaluation of equation (9).

Q.E.D.

We have illustrated way each monopolist's offer changes under the assumption of an anticipated depreciation in Figure 2, which appears on page 34. Figure 2 illustrates the two ways that an expected depreciation affects the equilibrium market price. First, the best offer of the domestic firm rises and that of the foreign firm falls. Second, the entire exchange rate distribution shifts rightward, increasing the likelihood that a depreciation will actually be realized.

There are two points worth emphasizing about Lemma 12. First, the market price is above cost even when the realization of the exchange rate is 1; we know, of course, that this follows from the fact that price noise allows both international duopolists to make offers above cost. Since we have not made any assumptions about the symmetry of the exchange rate distribution or about that of world demand, we cannot determine a priori whether  $s > s^*$  or  $s < s^*$ . We do know, however, for  $e=1$ , that  $\min[s, es^*] > 1$ ; this implies that  $p(1; s, s^*) > 1$ . Second, when there is an expected large depreciation (appreciation), there are small realized depreciations (appreciations) such that the equilibrium home currency market price actually falls (rises); that is, observed pass-through can actually be negative. Lemmata 7 and 8 imply that the home monopolist raises (lowers) his offer in expectation of the depreciation (appreciation), while the foreign monopolist lowers (raises) his offer. We have graphed the pass-through function, under the assumption of an expected depreciation and using some arbitrary best response parameters, in Figure 3, which appears on page 35.

We now state the main result of this section

Theorem 3: If there is an expected depreciation (appreciation), then expected pass-through will be higher (lower) if the domestic (foreign) market is monopolistic relative to its foreign (domestic) counterpart.

Proof: This follows directly from Lemmata 9 through 12. Q.E.D.

This theorem is of course the analog, for a regime of floating exchange rates, of Theorem 2. In particular, it makes the positive prediction that, under the

current market expectations of a depreciation of the dollar, observed exchange rate pass-through will be higher in domestic industries which are monopolistic than in those which are competitive. Further, during the period of the dollar's expected appreciation, one should have observed lower pass-through in industries which were foreign monopolies. This occurs, of course, because monopolists of either nationality will increase their profit margins when the exchange rate is expected to move in their favor.

#### 6. Observed Pass-Through in Japanese Manufactures

In this section, we present evidence on the relationship between industry concentration and exchange rate pass-through during 1984 and 1986. These are of course both periods during which the major currencies were floating, and the first was a period of strong yen depreciation (against the dollar), while the second was one of strong yen appreciation. We assume that oligopolists expected the yen to weaken against the dollar in 1984 and to strengthen in 1986. We did not use data from 1985 because it was a year of changing expectations about the yen's strength. Our theoretical analysis makes the positive prediction that pass-through will be higher in Japanese industries which were relatively concentrated.

It is unfortunately extremely difficult to get a current measure of concentration in a cross-spectrum of Japanese industries. There is some work on industrial organization in Japan by Caves and Uekusa [3], but they rely on concentration ratios collected by the Fair Trade Commission of Japan given in [10]. Those ratios are dated, and they give only the historical evolution of concentration within selected industries, not concentration across a sample of industries. In order to construct measures of concentration across

industries, we used the Japan Statistical Yearbook [11]. The chapter entitled Business Operations gives summary aggregate financial data for principal enterprises in a cross-spectrum of industries; a principal enterprise is either a company with a capitalization of at least one billion yen or a company which is considered a "leading enterprise" in its industry. In 1981, there were a total of 342 such companies in the nine manufacturing industries in our sample. These data are not given on a firm by firm basis but are presented as a total for all the principal enterprises in an industry. This chapter also gives total sales figures for these different manufacturing industries. These sales figures were used to calculate a rough measure of industry concentration in 1981, and they are reported in the first column of the table below.

It is of course almost impossible to get data on oligopolists' offers, but the Research and Statistics Department of the Bank of Japan does provide disaggregated wholesale price indices in [2]. These indices are disaggregated into ten different manufacturing subsectors, and they are further disaggregated in each subsector into average prices for exports, imports, and goods produced for domestic demand. The manufacturing subsectors correspond serendipitously to those defined in the Japan Statistical Yearbook, and nine of the universe of ten were chosen for the table below. The petroleum industry was excluded because there is only one petroleum product exported from Japan, and its pricing did not move at all with exchange rate adjustments.

Exchange Rate Pass-Through and Industrial Concentration in Japanese  
Manufacturing Industries in 1984 and 1986

Manufacturing Industry	Concentration (A)	1984 (B)	1986 (C)
Processed Foodstuffs	22.7	1.6	-9.6
Machinery	23.2	1.1	-4.5
Ceramic, Stone, and Clay Products	24.8	4.9	-14.7
Textile Products	36.0	-1.4	-5.7
Chemicals and Allied Products	37.3	1.6	-14.9
Electrical Machinery, Equipment, and Supplies	43.6	0.1	-3.7
Non-Ferrous Metal Products	46.1	9.1	6.7
Iron and Steel	59.6	5.2	-14.6
Transport Equipment	76.6	4.5	-1.1

Notes:

All numbers are percents. Column (A) measures the ratio of sales by principal enterprises to total industry sales in 1981. Column (B) measures the difference between the change in export prices and domestic prices for each industry during the twelve months ending in December 1984. Column (C) is the analogous measure for the twelve months ending in November 1986. The sources are described in the text.

The industries are presented in order of increasing concentration.

The second column gives the percentage difference between the change in industries' average export prices and average domestic prices during 1984, and the third column gives the analogous number for 1986. We use the difference between export prices and domestic prices in order to control for the effect that exchange rate movements had on costs, which was explicitly not a part of our model. First, it is reassuring that export prices rose more rapidly than domestic prices when the yen was depreciating and fell more rapidly when the yen was appreciating; this is of course one of the positive implications of our theory. Second, the Spearman statistic for the rank correlation between pass-through and industry concentration is significant at the ninety percent confidence level for 1984, but it is not significant for

1986. The small decrease in the export prices of transport equipment contributes to the rejection of a rank correlation in 1986. Perhaps the "voluntary" export restraints on automobile exports to the United States have sufficiently cartelized the international industry so that Japanese firms have not had to cut export prices significantly as the yen has appreciated.

7. Conclusion

The central conclusion of this paper is that observed exchange rate pass-through depends upon market structure. This conclusion was corroborated by evidence from a sample of Japanese manufacturing industries during the period of the yen's depreciation. In particular, the model shows that oligopolists use their market power to set prices in anticipation of exchange rate movements; we should expect, then, to see higher rates of inflation in relatively concentrated domestic industries during the course of the current depreciation of the dollar.

Two limitations of this model are that it is a model of a homogeneous good produced by identical firms facing no capacity constraints and that it does not consider the longer run evolution of market structure. First, much of the growth of international trade in the last decades has occurred in goods where product differentiation is important, and the current international environment for commercial policy makes the assumption of no capacity constraints quite suspect. It is unfortunate that product differentiation and barriers to trade are a very real part of any oligopolistic international industry; indeed, they probably serve to create such oligopolies. Second, the model did not investigate the effects of continued exchange rate shocks on the evolution of the number of firms in an industry. We did not model the entry

or exit decisions of firms in industries where there were positive or zero expected profits. See Baldwin [1] for some recent work on the effect of sunk costs in an environment with exchange rate variability.

The model does serve to underscore several important considerations. First, the strategic inter-dependence of firms' decisions are an important part of the pass-through effect. Second, one ought not to expect that exchange rate pass-through is uniform across industries that have different competitive structures; moreover, home monopoly tends to increase pass-through while foreign monopoly tends to decrease it. Third, both exchange rate expectations and realizations matter for equilibrium prices in oligopolies. In particular, the large depreciation of the dollar during the last eighteen months may matter less than oligopolists' expectations about how the dollar will move during the course of their firms' current planning horizons. Fourth, although exchange rate volatility increases the profit margins of monopolistic firms, it does so at the expense of consumer surplus. It is in this sense that volatile exchange rates, like barriers to trade, may serve to decrease world welfare while raising the expected profits of producers in oligopolistic industries.

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Figure 1

Equilibrium Market Price as a Function of the Realized  
Exchange Rate

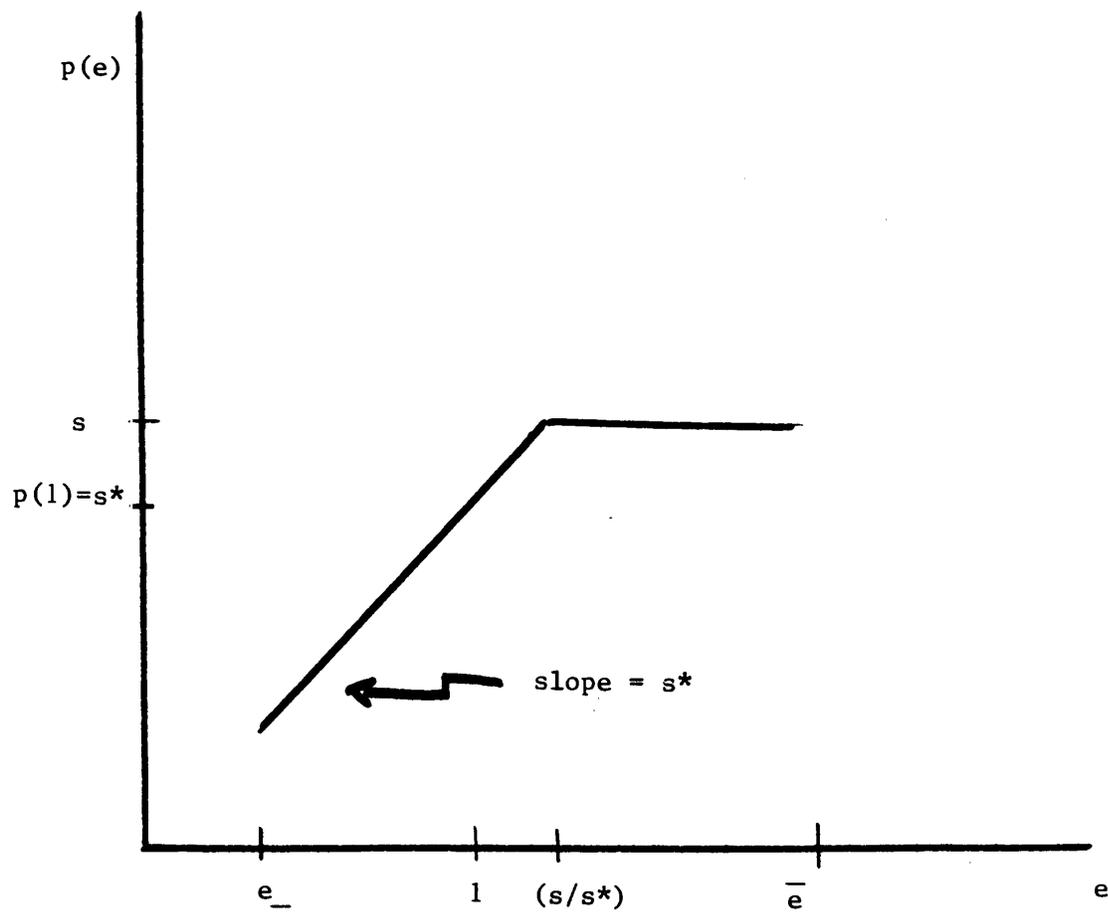


Figure 2

The Effect of an Expected Depreciation on Equilibrium Market Price

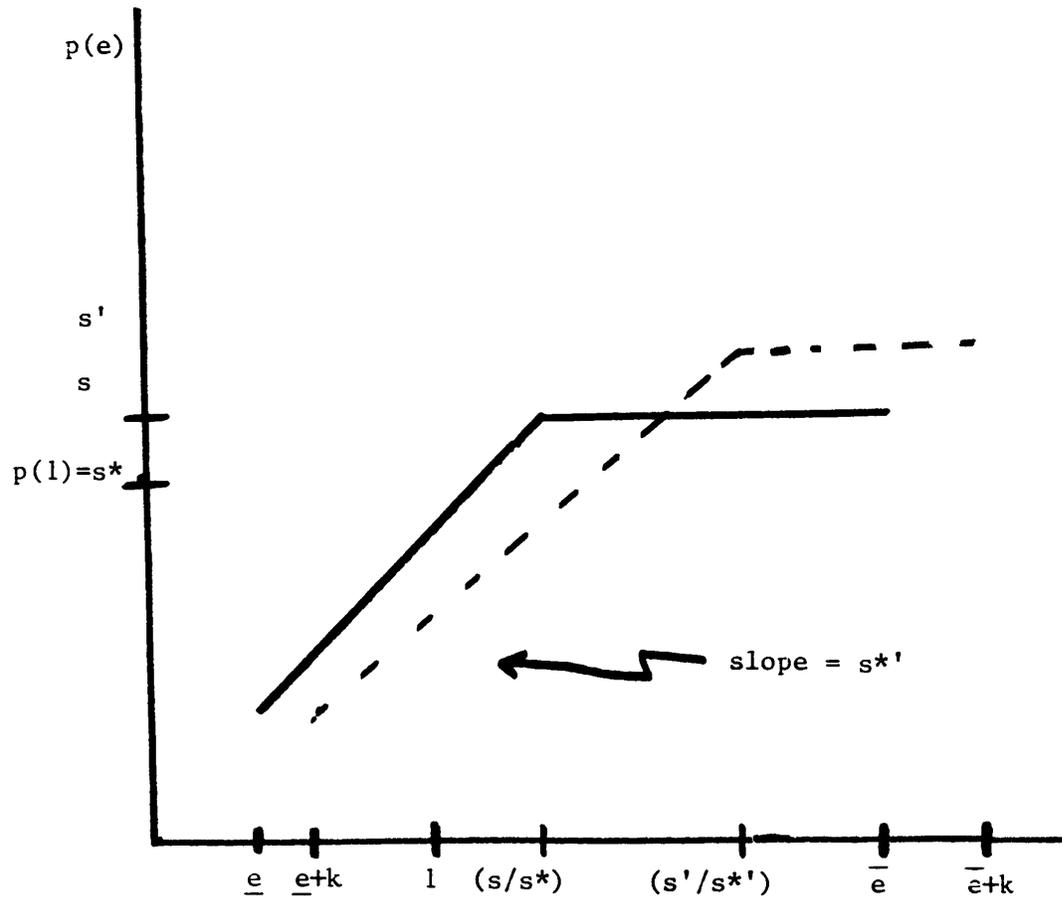
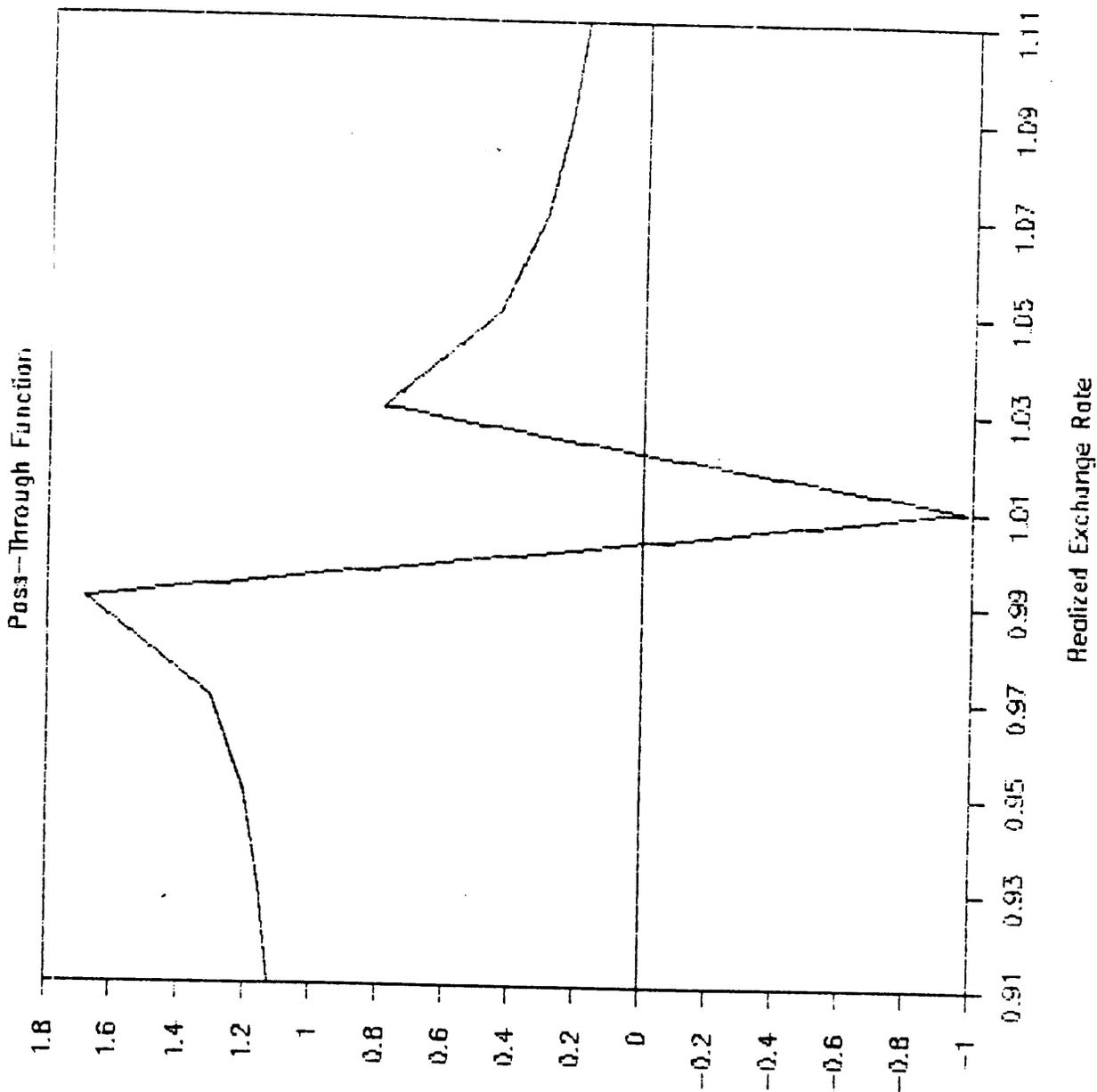


Figure 3



$(s, s^*) = (1.04, 1.03)$   
 $(s', s'^*) = (1.05, 1.02)$   
 Expected Depreciation

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