Role of Exchange-Rate Volatility in US Import Price Pass-Through Relationships

by

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CHAPTER FIVE

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DEDICATION

To the memory of my Grandmother, Isal Kendall (10 March 1896 -- 21 June 1989)

Jon D. Kendall
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ROLE OF EXCHANGE-RATE VOLATILITY IN US IMPORT PRICE PASS-THROUGH RELATIONSHIPS

Abstract

Many authors have noted a recent breakdown in the historical long-run relationship between US non-oil import prices and the nominal exchange rate. Known as pass through, this phenomenon has been the subject of both empirical and theoretical inquiry. This literature is reviewed in Chapter One. The alternative approach presented here builds upon the theoretical body of literature. Pass through is explained within the context of profit-maximising exporting firms but with the additional feature of being tested empirically.

Chapter Two presents models highlighting the differing effects of exchange-rate variance on exporters under a system of flexible exchange rates. A risk-averse profit-maximising exporter setting price in the currency of the importing country will raise price the higher is variance. The opposite is true for an exporter setting price in its own currency where a higher variance results in a lower price. However, a firm which sets price in the importing country's currency can cover in the foreign exchange market, which lessens the positive influence of variance. The extent to which it covers hinges on the difference between the forward price of the importing country's currency and its expected value.

Chapter Three discusses estimation of this latter model by the ARCH-In-Mean technique for exchange-rates of the United Kingdom, Japan and Germany against the US dollar. A significant negative time-varying risk premium is found for Japan but not for either the United Kingdom or Germany. Results suggest that there may be an insufficient supply of forward contracts for the Yen but not for the other two currencies.

Finally in Chapter Four a common estimable form for the two exporter models of Chapter Two is recast as a Purchasing Power Parity (PPP) equation embedded in an error-correction mechanism. Quarterly aggregate data (including exchange-rate variance estimates from Chapter Three) from 1975.Q1 to 1988.Q1 for the United Kingdom, Japan and Germany are used to estimate the three recast PPP-form equations by both instrumental variables and three stage least squares. Results show PPP to hold in the long run for all three countries but only for the United Kingdom in the short run. Variance elasticities are significant and negative for the United Kingdom and Germany but not for Japan, supporting the idea that exporting firms pricing in US dollars are able to cover adequately in pounds and deutschemarks but not in yen. The remaining effect of variance on firms pricing in their own currencies explains the negative and significant results. Unfortunately results are not stable over the time period as indicated by Chow tests. However, the latter period appears to support the theory more strongly than the earlier half indicating the importance of exchange-rate variance in the 1980s.

CHAPTER 1

1. Introduction

1.1. Introduction

The sustained rise of the US dollar from 1981 to early 1985 and subsequent fall to the present has contributed to crescive interest in "pass-through" relationships between changes in exchange-rates and resulting changes in traded goods prices. Mann (1987, chart 1), shows the import-weighted nominal exchange-rate for the U.S., noting the doubling in its value from the fourth quarter of 1980 to the first quarter of 1985 and subsequent drop of about 25 per cent to the first quarter of 1987.[1] However, Mann (1986, p. 367) also points out that the historical long-run relationship between prices of non-oil imports and the nominal exchange-rate no longer holds, arguing that pronounced exchange-rate changes appear to have been absorbed into foreign supplier profit margins over this period.

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[1] The countries are Belgium, Canada, France, Federal Republic of Germany, Italy, Japan, the Netherlands, Sweden, Switzerland, and the United Kingdom and are weighted based on average 1972-76 trade shares. Mann (June, 1986, p. 366) states that this index is a "convenient summary statistic for the [US] dollar's average performance." Krugman & Baldwin (1987) and Krugman (1988) have shown similar fluctuations in the real exchange-rate as well.

1.2. A Survey of Related Literature

Recently, a body of literature has arisen in an effort to explain the shift of the US import pass-through relationship during the 1981 to 1987 time period. Mann (1986 & 1987) focusses on the behaviour of profit margins across industries and in the aggregate, noting wide differences. Woo (1984) looks at whether exchange-rate changes have had effects on the US price level (through non-oil, non-fuel import prices), noting that the appreciation of the US dollar did not have too great an impact. Krugman & Baldwin (1987) examine the causes of the persistent US trade deficit noting that lags in adjustment of import good prices and quantities to the depreciating US dollar as well as a secularly declining equilibrium real exchange-rate are the main causes. Krugman & Baldwin (1987, p. 1) speculate that the lags are due to the "tendency of firms to commit themselves to suppliers for extended periods of time."

Baldwin (1988) constructs two non-oil import-weighted real exchange-rate indices which also show the rise and subsequent fall of the US dollar. He notes a shift of the aggregate exchange-rate pass-through relationship sometime in the 1980s which is consistent with the "hysteresis hypothesis." Two specific structural models are tested. The beach-head paradigm implies that an over-valued US dollar afforded foreign producers the opportunity to enter the US market establishing "marketing beach-heads." Both supply-side and demand-side factors made it optimal for some firms not to exit in the the face of a depreciating US dollar. With the resulting increase in competition, profit margins were squeezed so as to maintain market share. The bottleneck model centres more on the "capacity constraints ('bottlenecks') in the marketing, distribution and servicing network of importers" (Baldwin [1988, p. 3]). The over-valued US dollar allowed importers to increase capacity and lower prices. When the US dollar depreciated, the resulting alleviation of marketing bottlenecks partially offset the cost increases. Baldwin finds evidence to support hysteresis in general but rather inconclusive results for either of the two specific models.

Another body of literature has examined pass-through relationships from the standpoint of profit-maximising behaviour by firms. Studies by Ethier (1973), Baron (1976), Rao & Magee (1980), Kawai (1981), Dohner (1984), Benninga, Eldor & Zilcha (1985), Kawai & Zilcha (1986), Eldor & Zilcha (1987), and Dornbusch (1987) model a typical exporting/importing firm's decisions regarding level of trade. Ethier specifies the conditions under which an importing firm's level of trade is unaffected by exchange-rate uncertainty; only the degree of forward cover is influenced in combination with the firm's risk-averseness, with the firm not necessarily fully covering. This is referred to as the Separation Theorem. However, Ethier (1973, p. 502) notes that if the firm does not know how the future exchange-rate affects future profits, exchange-rate uncertainty adversely affects trade, becoming more acute the more risk-averse the firm.

Baron (1976) also presents two models: one in which an exporting firm decides to set price in its own currency and the other in which price is set in the currency of the importing country. In the latter case, Baron finds export price to be positively affected by risk-aversion. The former case yields opposite results. Models which are derived below in Chapter Two yield similar results. Baron (1976, p. 433), using linear cost and demand functions, also finds that under a system of fluctuating exchange-rates the "expected price to be paid by importers when exports are invoiced in the currency of the exporter is strictly greater than the price paid when the price is set in the currency of the home country." Rao & Magee (1980) assert that the currency in which export price is denominated is irrelevant. Their model differs markedly from Baron's in that both the importer and exporter agree on how much to trade, fixing the price in one currency or the other. However, as Goeltz (1980) points out, the Rao-Magee model result is quite sensitive to certain key assumptions.

Articles by Kawai (1981), Benninga, Eldor & Zilcha (1985), Kawai & Zilcha (1986), and Eldor & Zilcha (1987) generalise and/or add caveats to the Separation Theorem as well as generalise previous models. These additions still assume the exporting firm to face perfect competition overseas- an assumption relaxed in this study. It is also interesting to note that these theorems do not necessarily hold when the firm has incomplete access to forward exchange, commodity, and international financial markets. In fact, Kawai (1981, p. 56) notes that a rise in exchange risk may adversely affect the firm's production. Kawai (1981, p. 57) argues that this reduction in trade is not due to exchange-rate uncertainty as such but rather to short-run departures from purchasing power parity (PPP). There are a number of articles noting violations of the law of one price, as for example, Webster (1987), Brenton & Parikh (1987), and Morandé (1983). Models derived below in Chapter Two and tested in Chapters Three and Four allow for short-run deviations from PPP as well as exchange-rate uncertainty.

Dornbusch (1987) develops models in which the degree of competitiveness and number of foreign and domestic firms affect exchange-rate pass through. Tentative empirical evidence by Dornbusch (1987, p. 104) shows that the ratios of export to import prices of selected 2 and 4 digit level industries have fallen from 1979:IV to 1985:I although not by as much as the change in relative unit labour costs, indicating only partial exchange-rate pass through.

Giovannini (1986) relies on the assumption that firms must set their prices at the beginning of each period, along with a stochastic exchange-rate in deriving his propositions on exchange-rate uncertainty effects. This is the approach taken here in Chapter Two. Notable is the result that increasing exchange-rate risk does not affect the firm's pricing when it sets price in the currency of the importing country. This result, however, is based on the firm having a linear utility function (i.e. it is risk-neutral). In this paper, the firm is assumed to have a strictly concave utility function (i.e. it is risk-averse).

An article by Dohner (1984) explains the slowness of exchange-rate changes to affect import prices through a dynamic model incorporating lagged customer responses to price differences. In contrast to static models, Dohner (1984, p. 91) has price changes depending on "the change in customer value and the speed with which customers can be acquired" in addition to marginal cost and marginal revenue.

A final body of relevant literature concerns Purchasing Power Parity. PPP asserts that the equilibrium exchange rate between foreign and domestic currencies equals the ratio of foreign to domestic price levels (Frenkel [1981, p. 145]). The relative version states a similar relationship for rates of change instead of levels. PPP is relevant here because the models of Chapter Two are re-expressed in this form when estimated empirically in Chapter Four. Thus results are also comparable to other studies of PPP.

A review article by Officer (1976) covers the controversial topic of PPP as a theory of exchange rates. Frenkel (1981) discusses the failure of PPP during the 1970s. Recently, several articles have arisen providing evidence supporting PPP, at least in the long run. Hakkio (1984) finds the PPP hypothesis to hold during the 1970s if contemporaneous correlation across countries is taken into account but interestingly, not in the 1920s. Estimation in Chapter Four takes account of contemporaneous correlation across countries. Brenton and Parikh (1987) find the relative law of one price to hold for aggregate data in the long run but not in the short run. They also find PPP not to hold for highly disaggregated data. Their modelling of PPP is embedded within an error-correction mechanism--a similar approach is used below in Chapter Four.

These broad strands of literature briefly discussed above are forged into an explanation of exchange-rate pass through. Models developed below in Chapter Two are well-grounded in neo-classical profit-maximising theory, building upon theoretical literature (chiefly Baron) mentioned above. In addition, these models are tested empirically in Chapters Three and Four. This testing allows some comparison with the more institutional-based models presented by Baldwin, Krugman, and Mann to explain U.S. import price pass through. It also sheds some light on the empirical validity of purchasing power parity.

CHAPTER 2

2. Pass-Through Models

This chapter develops two pass-through models which explain how import prices can be affected by exchange-rate variance depending on the currency in which the exporting firm sets price. These models are then given specific functional forms which result in a common estimable pass-through equation. Discussion then focusses on optimal forward covering by firms where a model is developed to show the tradeoff between profit and risk.

Two factors determine the impact of exchange-rate variance on pass through, namely the currency in which the exporter sets price and the availability of forward foreign exchange-rate contracts. Numerous authors have examined the question of the currency in which exporting firms set price. In his studies of payments habits of Sweden, Grassman (1973 and 1976) drew attention to the fact that the US dollar was not the exclusive currency of payment between industrialised countries. He also found a tendency for US currency to be used by exporters exporting to the US. Page (1977) found a tendency for goods to be invoiced in the currency of the exporter for trade between industrialised countries. However, trade between the US and industrialised trading partners tended to mitigate this effect, with even a slight preference for the US dollar. Changes over time have not been pronounced; exceptions usually can be explained by differences in survey techniques (Page [1977, p. 78]).

Studies which have examined optimal firm behaviour under alternative invoicing strategies such as those by Ethier (1973), Baron (1976) and Giovannini (1988) discussed earlier have taken the choice of invoice currency as given. Indeed, Baron (1976, p. 426) writes:

> The objective of this paper is not so much to investigate the choice of the currency in which an exporter should invoice, since that depends largely on tradition and institutional factors such as available banking services, as it is to investigate the levels of prices and exports under the two invoicing alternatives and their response to governmental policies.

Likewise this study takes the currency of invoice as given. In light of the evidence that exports are almost evenly split in respect of invoicing currency for exports to the US, consideration must be made for the effect of exchange-rate variance on import prices both when the exports are invoiced in currency of the purchasing country as well when they are invoiced in currency of the selling country.

2.1. Derivation with Stochastic Exchange Rate: Risk-Averse Firm

2.1.1. Invoicing in the Importing Country's Currency

The firm operates within an imperfectly competitive environment (as in Feenstra[1987]), choosing p periodically in the importing country's (domestic) currency. The spot price of foreign exchange in terms of domestic currency, s, is stochastic.[2] Since the exporter cannot adjust price to every exchange-rate movement, the revenues received are uncertain.[3] The demand for imports is given

[2] As Giovannini (1986, p. 7) notes, the exchange-rate, relative to other variables which affect the import demand and cost functions (e.g. income levels and price indices) is the most difficult to forecast. In the appendix, the foreign factor price variable (w*) is also made stochastic, implying an uncertain real exchange-rate. Additional stochastic variables would render the model analytically intractable.

[3] The firm's ability to hedge is covered in section 2.4.

by x(p,q,I), where prices of imported and domestic types of a good are represented by p and q respectively; I (income) and q are exogenous.[4] Additionally, the firm sells directly to the consumer.[5] The firm is assumed to be risk-averse as in Baron (1976, section 1), maximising expected utility of profits in its own (foreign) currency. The individual firm's expected utility of profit maximisation problem is:

$$(2.1) \qquad \max_{p} E\,\{U[spx(p,q,I) - x(p,q,I)w^{*}]\},$$

where expected value is denoted by E. U is the firm's utility function; the cost function is linear with w* denoting an aggregate of foreign factor prices in foreign currency. All variables except s are deterministic.

Denoting the distribution function of s by f(s), equation 2.1 can be re-expressed as:

$$(2.2) \qquad \max_{p} \int_{0}^{\infty} u\Big[(sp - w^{*})x(p,q,I)\Big]f(s)ds$$

Let e = E(s), where e denotes the expected exchange-rate.

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[4] The demand curve, x(p,q,I), contains information regarding other firms' actions. Baron (1976, p. 428).

[5] This paper does not examine the retail/wholesale distinction; the difference is assumed not to change over the sample period. This issue is the focus of Bolton & Bonanno (1987) within a country and Morandé (1983) for the effect on purchasing power parity.

Define utility of profits in the exporting country's currency as:

(2.3) $$u(\pi^*) = U[(sp - w^*)x(p,q,I)]$$

$u[\pi^*]$ may be approximated with a second order Taylor expansion about $(ep-w^*)x$.

(2.4) $$u(\pi^*) \approx u(E\pi^*) + u'(E\pi^*)(\pi^* - E\pi^*) + \frac{1}{2}u''(E\pi^*)(\pi^* - E\pi^*)^2$$

Substituting equation (2.4) into equation (2.2) results in:

(2.5) $$\max_p \int_0^\infty \left[u(E\pi^*)+u'(E\pi^*)(\pi^*-E\pi^*)+\frac{1}{2}u''(E\pi^*)(\pi^*-E\pi^*)^2\right]f(s)ds$$

Taking expectations and noting that:

$$\int_0^\infty u'(E\pi^*)(\pi^* - E\pi^*)f(s)ds = 0$$

and $$\int_0^\infty (\pi^* - E\pi^*)^2 f(s)ds = var(\pi^*)$$

results in:

(2.6) $$E(u(\pi^*)) = u(E(\pi^*) + \frac{1}{2}u''(E\pi^*)var(\pi^*)$$

so that the exporter confronts:

$$(2.7) \qquad \max_{p}\ u(E\pi^*) + \frac{1}{2} u''(E\pi^*)\mathrm{var}(\pi^*)$$

Assuming that $u''(E\pi^*)$ is constant allows one to derive the first order conditions as:

$$(2.8) \qquad u'(E\pi^*)\left[ex + (ex - w^*)\frac{\partial x}{\partial p}\right] + \frac{1}{2} u''\frac{d}{dp}\mathrm{var}(\pi^*) = 0$$

Let $u' = u'(E\pi^*)$ and $u'' = u''(E\pi^*)$; divide through by $e\frac{\partial x}{\partial p}$ and u':

$$(2.9) \qquad \frac{x}{\frac{\partial x}{\partial p}} + (pe - w^*)\frac{1}{e} + \frac{u'}{u''}\left[\frac{\frac{d}{dp}\ \mathrm{var}(\pi^*)}{e\frac{\partial x}{\partial p}}\right] = 0$$

Let $-\eta = \left[\frac{dx}{dp}\right]\frac{p}{x}$ and $R_u = -\left[\frac{u''}{u'}\right]$, where η is the responsiveness of import demand (x) to home currency price (p) and R_u is an Arrow-Pratt absolute measure of local risk-aversion (Varian 1984 p. 161); as in Baron (1976, p. 430) a strictly concave utility function is assumed. Equation (2.9) may then be rearranged as:

$$(2.10) \qquad \underbrace{p\left(1 - \frac{1}{\eta}\right)}_{MR} - \underbrace{\left[\frac{w^*}{e}\right]}_{MC} = \frac{1}{2} R_u\left[\frac{\frac{d}{dp}\ \mathrm{var}(\pi^*)}{e\frac{\partial x}{\partial p}}\right]$$

Notice that the signs of R_u (positive) and $\frac{\partial x}{\partial p}$ (negative) are known, leaving the sign of $\frac{d}{dp}\mathrm{var}(\pi^*)$ to decide if marginal revenue is less than or greater than marginal cost.

After working out the calculus one finds that:[6]

(2.11) $$\frac{d}{dp}\,\mathrm{var}(\pi^*) = 2\sigma_s^2 p\left[1 - \frac{1}{\eta}\right]\frac{\partial x}{\partial p}(px) < 0$$

since the exporting firm sets price in the elastic portion of the demand curve (i.e $\eta > 1$). Thus, var(π^*) is reduced by raising price p; the firm will set price where marginal revenue is greater than marginal cost. Equation (2.10) may be rewritten as:

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[6] Recall that:

$$\mathrm{var}(\pi^*) = E(\pi - \pi^*)^2$$

$$= \sigma_s^2 (px)^2$$

where σ_s^2 is the variance of the nominal exchange rate.

Thus,

$$\frac{d}{dp}\,\mathrm{var}(\pi^*) = 2\sigma_s^2\left[x + p\frac{\partial x}{\partial p}\right](px)$$

or

$$\frac{d}{dp}\,\mathrm{var}(\pi^*) = 2\sigma_s^2 p\left[1 - \frac{1}{\eta}\right]\frac{\partial x}{\partial p}(px) < 0$$

since the firm sets price in the elastic portion of the demand curve (i.e $\eta > 1$).

(2.12) $$p(1 - \frac{1}{\eta}) - \left[\frac{w^*}{e}\right] = R_u\left[\frac{\sigma_s^2}{e}\right]p(1 - \frac{1}{\eta})px > 0$$

With $\sigma_s^2 > 0$ and $R_u > 0$, an exporting firm setting price in the currency of the importing country will set marginal revenue above marginal cost. This means that price is also raised with higher variance or risk aversion. The reason is that higher price reduces revenue and therefore the variance of profits in equation (2.11).

Additional intuition about how changes in risk and changes in the nominal exchange-rate variance affect import prices can be gained by rearranging equation (2.12) as follows

(2.13) $$\left[\frac{p\left[1 - \frac{1}{\eta}\right] - w^*\frac{1}{e}}{p\left[1 - \frac{1}{\eta}\right]}\right] = R_u\left[\frac{\sigma_s^2}{e}\right]px$$

The greater is the Arrow-Pratt local measure of absolute risk-aversion (R_u), the greater the percentage gap between marginal revenue and marginal cost and, consequently, the higher the price charged by the firm. Also, the higher the variance of the spot exchange-rate, the greater the gap. Note that if R_u or $\sigma_s^2 = 0$, then marginal revenue equals marginal cost.[7] The graph below emphasises this relationship. The p_0, x_0 price and quantity represent usual price-setting equilibrium whilst the p_1, x_1 equilibrium shows the effect of exchange-rate variance.

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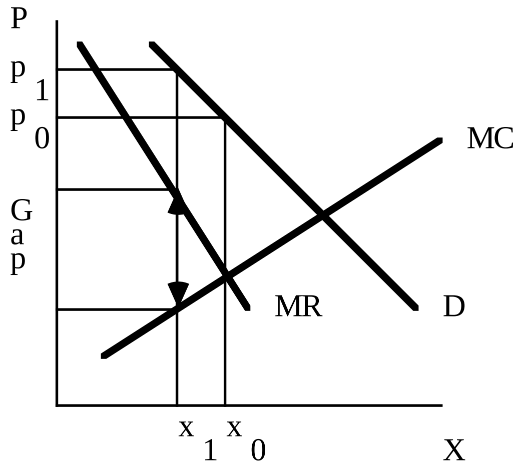
[7] These results are the same as in Baron (1976, p. 430), although he does not assume constant marginal costs. He also examines the case where the firm's utility function is linear, which would cause R_u to become zero which in the above case would remove any exchange-rate uncertainty effect on import prices.



If firms (pricing in the importing country's currency) are risk-averse one would expect to find the import price to be higher with greater variance of the exchange-rate. Why would firms do this?

> An exporter invoicing in a foreign currency has its total revenue exposed to exchange risk and a risk-averse exporter prefers to reduce its exposure. Since the exporter prices so that demand is elastic and the risk-averse exporter increases price thus reducing total foreign exchange exposure. While the higher price reduces profit, it increases expected utility. (Baron (1976, p. 430).

Formalising Baron's argument involves rewriting equation (2.6) as:

(2.14) $$E(u(\pi^*)) = u(E(\pi^*) + \frac{1}{2} u''(E\pi^*)(px)^2\sigma_s^2$$

The above states that the expected utility of profit is a function of both the utility of expected profit and a variance term. The more risk-averse the firm (i.e. u'' < 0 , becomes smaller) the higher must be price. Although the utility of expected profit ($u[E\pi^*]$) falls, the higher price *increases* the second term by more than enough to compensate since the firm sets price in the elastic portion of the demand curve. A similar argument can be made for increasing the variance of the nominal exchange-rate (σ_s^2). The higher the variance, the greater will be the price of imports.

2.1.2. Invoicing in the Exporting Country's Currency

The maximisation problem confronting an exporting firm which sets price in its own currency is similar to profit maximising above except that now profit is maximised based on p*.

$$\max_{p^*} \; u(E\pi^*) + \frac{1}{2}u''(E\pi^*)\mathrm{var}(\pi^*) \tag{2.15}$$

where,

$$\pi^* = (p^* - w^*)x\left(\frac{p^*}{s}, q, I\right)$$

where $\frac{p^*}{s}$ is random. Again the firm sets price before the exchange rate is known but, unlike the case where the exporter sets price in the domestic currency, revenues here are uncertain due to random fluctuations in import demand.

The first-order condition for equation (2.15) (noting that $\frac{\partial x}{\partial p^*} \equiv \frac{\partial x}{\partial p}\frac{1}{s}$) is:

$$u'\left(Ex + (p^* - w^*)E\left[\frac{\partial x}{\partial p}\frac{1}{s}\right]\right) + \frac{1}{2}u''\frac{d}{dp}\mathrm{var}(\pi^*) = 0 \tag{2.16}$$

Divide equation (2.16) through by $E\left[\frac{\partial x}{\partial p}\frac{1}{s}\right]$ and u'; simplify:

$$p^*\left[1 + \left[\frac{Ex}{E\left[\frac{\partial x}{\partial p}\frac{1}{s}\right]}\frac{1}{p^*}\right]\right] - w^* = -\frac{1}{2}\left[\frac{u''}{u'}\right]\left[\frac{\frac{d}{dp^*}\mathrm{var}(\pi^*)}{E\left[\frac{\partial x}{\partial p}\frac{1}{s}\right]}\right] \tag{2.17}$$

Let $R_u \equiv -\frac{u''}{u'}$ and $\eta^* \equiv -E\left[\frac{\partial x}{\partial p}\frac{1}{s}\right]\left[\frac{p^*}{Ex}\right]$. Then equation (2.17) may be expressed as:

(2.18)
$$\underbrace{p^*(1 - \frac{1}{\eta^*})}_{MR} - \underbrace{w^*}_{MC} = \frac{1}{2} R_u\left[\frac{\frac{d}{dp^*}\ \mathrm{var}(\pi^*)}{E\left[\frac{\partial x}{\partial p}\ \frac{1}{s}\right]}\right]$$

Notice the similarity with equation (2.10) for the exporter invoicing in the domestic currency. Again the wedge between marginal revenue and marginal cost hinges on the sign of the derivative of profit variance with respect to price set in foreign currency.

After working out the calculus one finds that:[8]

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8 $\frac{d}{dp^*}\ \mathrm{var}(\pi^*) = \frac{d}{dp^*}\ E[(p^* - w^*)x - (p^* - w^*)Ex]^2$

$= \frac{d}{dp^*}\ E[(p^* - w^*)(x - Ex)]^2$

$= \frac{d}{dp^*}\ (p^* - w^*)^2\ \mathrm{var}(x)$

Noting that $\frac{d}{dp^*}\ \mathrm{var}(x) = E[(x - Ex)^2]$, one obtains:

$= 2(p^* - w^*)\mathrm{var}(x) + (p^* - w^*)^2 E\left\{ 2(x - Ex)(\frac{\partial x}{\partial p}\ \frac{1}{s} - E\left[\frac{\partial x}{\partial p}\ \frac{1}{s}\right])\right\}$

$= 2(p^* - w^*)\mathrm{var}(x) + (p^* - w^*)^2 2\mathrm{cov}\left[x, \frac{\partial x}{\partial p}\ \frac{1}{s}\right]$

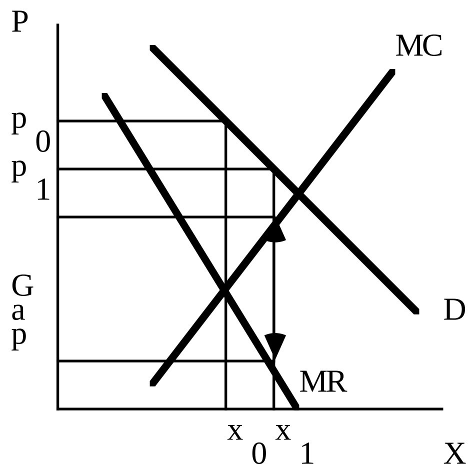
(2.19) $$\frac{d}{dp^*}\,\mathrm{var}(\pi^*) = \underbrace{2(p^* - w^*)\mathrm{var}(x)}_{>\ 0} + \underbrace{2(p^* - w^*)^2\mathrm{cov}(x, \frac{\partial x}{\partial p}\frac{1}{s})}_{?\ 0}$$

The sign of the second term depends on the nature of the import demand function. Its form is discussed in Chapter Four. Assume that there is no covariance between import demand and marginal revenue. Then substituting equation (2.19) into equation (2.18) reveals:

(2.20) $$\underbrace{p^*(1 - \frac{1}{\eta^*}) - w^*}_{<\ 0} = \frac{1}{2}\,R_u\left[\frac{2(p^* - w^*)\mathrm{var}(x)}{E\left[\frac{\partial x}{\partial p}\ \frac{1}{s}\right]}\right]$$

Thus, the firm will set marginal revenue at *less* than marginal cost therefore *reducing* p* due to variance in exchange rates and demand. The reason is that the variance of profits now depends on the price-cost margin, $\mathrm{var}(\pi^*) = (p^* - w^*)^2\mathrm{var}(x)$, which is reduced by lowering price.

Equation (2.20) shows that the greater is the Arrow-Pratt local measure of absolute risk-aversion (R_u), the greater the gap between marginal revenue and marginal cost and, consequently, the lower the price charged by the firm. Also, the higher the variance of import demand, the greater the gap. So if R_u or var(x) = 0, then marginal revenue equals marginal cost. The graph below emphasises this relationship. The p_0, x_0 equilibrium depicts usual price-setting behaviour, whilst p_1, x_1 shows the dampening effect of variance on price.



2.2. Derivation of Functional Form for Estimation

The sections above derive a relationship between marginal revenue (or price), marginal cost, and the variance of the exchange rate. The exchange rate variance has differing effects, depending on the currency in which the exporting firm sets prices. The task now is to adopt a specific functional form for demand which will allow the first-order condition for the exporter to be written in a form suitable for estimation.

Let the demand curve be given as:

(2.21a) $$x(p, q, I) = \left[\frac{\alpha}{p} - \frac{\beta}{q}\right] I$$

for an exporter pricing in the importing country's currency and

(2.21b) $$x\left(\frac{p^*}{s}, q, I\right) = \left[\frac{\alpha s}{p^*} - \frac{\beta}{q}\right] I$$

for an exporter pricing in its own currency.

This functional form, while not familiar, has very conventional properties:

($x_p < 0$): Decreasing function in own price.

($x_q > 0$): Increasing function in price of import-competing goods.

$x \geq 0$ only for $p \leq q\left[\frac{\alpha}{\beta}\right]$: If the price of imported goods is sufficiently higher than domestic import-competing goods, then demand for imported goods will be zero. Note that alpha and beta can be thought of as reflecting the qualities of imported and domestic goods.

$\left[\frac{\partial x}{\partial I}\ \frac{I}{x}\right] = 1$: a unitary elasticity of income.

The two forms of equation (2.21) will be used to derive the specific relationship between price, marginal cost, and exchange rate variance depending on the currency in which the exporter sets price.

2.2.1. Estimable Form for Exporter Pricing in Importing Country's Currency

Substitution for x and $\frac{\partial x}{\partial p}$ in equation (2.12) results in:[9]

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[9] Recall that $p(1 - \frac{1}{\eta}) = p + \frac{x}{\frac{\partial x}{\partial p}}$.

Given the functional form defined in equation (2.21) and the fact that $\frac{\partial x}{\partial p} = -\frac{\alpha}{p^2}$, it follows that

$$p(1 - \frac{1}{\eta}) = p + \frac{-\frac{\alpha}{p} + \frac{\beta}{q}}{\alpha} p^2$$

$$= \frac{\beta}{q}\frac{p^2}{\alpha}.$$

$$(2.22) \qquad \left[\frac{\beta}{\alpha}\ \frac{p^2}{q}\right] - \frac{w^*}{e} = R_u\left[\frac{\sigma_s^2}{e}\right]\left[\frac{\beta}{\alpha}\ \frac{p^2}{q}\right]px$$

Rearranging equation (2.22) reveals:

$$(2.23) \qquad \left[\frac{\beta}{\alpha}\ \frac{p^2}{q}\right]\left[1 - R_u\left[\frac{\sigma_s^2}{e}\right]px\right] = \frac{w^*}{e}$$

Taking logs of both sides gives:

$$(2.24) \qquad \ln\frac{\beta}{\alpha} + 2\ln p + -\ln q + \ln\left[1 - R_u\left[\frac{\sigma_s^2}{e}\right]px\right] = \ln\frac{w^*}{e}$$

Equation (2.24) is further distilled into an estimable form by noting that

$$\ln\left[1 - R_u\left[\frac{\sigma_s^2}{e}\right]px\right] \approx -R_u\left[\frac{\sigma_s^2}{e}\right]px.$$

Substituting the above derivations into equation (2.24) and rearranging provides a preliminary estimable form:

$$(2.25) \qquad \ln p = -\frac{1}{2}\ln\frac{\beta}{\alpha} + \frac{1}{2}\ln q + \frac{1}{2}\ln\left[\frac{w^*}{e}\right] + \frac{1}{2}R_u\left[\frac{\sigma_s^2}{e^2}\right]px$$

Notice how exchange-rate variance positively affects import prices given that firms are risk-averse. Signs of the other coefficients are as expected. Higher prices of competing domestically-produced goods (q) cause higher import prices in the domestic currency. Higher expected foreign factor costs ($\frac{w^*}{e}$) also lead to increased import prices.

2.2.2. Estimable Form for Exporter Pricing in Own Currency

Making appropriate substitutions based on the functional form of equation (2.21b) into the first order conditions of equation (2.16) reveals:[10]

---

[10] Recall that $p^*(1 - \frac{1}{\eta^*}) = p^*\left[1 + \frac{Ex}{E\left[\frac{\partial x}{\partial p}\frac{1}{s}p^*\right]}\right]$.

The following definitions and derivations are based on equation (2.21b):

$$\frac{\partial x}{\partial p}\frac{1}{s} \equiv \frac{\partial x}{\partial p^*} = -\frac{\alpha s}{p^{*2}} I \ .$$

$$E(x) = \left[\frac{\alpha e}{p^*} - \frac{\beta}{q}\right] I \ .$$

$$E\left[\frac{\partial x}{\partial p}\frac{1}{s}\right] = -\frac{\alpha e}{p^{*2}} I \ .$$

$$\mathrm{var}(\pi^*) = (p^* - w^*)^2 \mathrm{var}(x)$$

$$= (p^* - w^*)^2 \left[\left[\frac{\alpha s}{p^*} - \frac{\beta}{q}\right] I - E\left[\frac{\alpha s}{p^*} - \frac{\beta}{q}\right] I\right]^2$$

$$= \left[1 - \frac{w^*}{p^*}\right]^2 (\alpha I)^2 \sigma_s^2$$

It follows that

$$(2.26)\; u'\left[\left[\frac{\alpha e}{p^*} - \frac{\beta}{q}\right] I + (p^* - w^*)\left[\frac{-\alpha e}{p^{*2}}\right] I\right] + \frac{1}{2} u''\left[2\frac{(p^* - w^*)w^*}{p^{*3}}(\alpha I)^2 \sigma_s^2\right] = 0$$

Rearranging, taking logs, and letting $R_u = -\frac{u''}{u'}$ yields:

$$(2.27) \qquad \ln\frac{\beta}{\alpha} + 2\ln p^* - \ln(eq) = \ln w^* + \ln\left[1 - R_u\left[\frac{(p^* - w^*)w^*}{p^*}\right](\alpha I)\ \frac{\sigma_s^2}{e}\right]$$

Equation (2.27) is further distilled into an estimable form by noting that

$$-R_u\left[\frac{(p^* - w^*)w^*}{p^*}\right](\alpha I)\ \frac{\sigma_s^2}{e} \approx \ln\left[1 - R_u\left[\frac{(p^* - w^*)w^*}{p^*}\right](\alpha I)\ \frac{\sigma_s^2}{e}\right]$$

and also defining

$$\bar{p} = Ep \approx \frac{p^*}{e}$$

$$(2.28) \qquad \ln\bar{p} = k + \frac{1}{2}\ln\frac{w^*}{e} + \frac{1}{2}\ln q - \frac{1}{2} R_u \frac{\sigma_s^2}{e}\, \alpha I\left[\frac{p^* - w^*}{p^*}\right]$$

$$\frac{d}{dp^*}\mathrm{var}(\pi^*) = 2\left[1 - \frac{w^*}{p^*}\right]\left[-\frac{-w^*}{p^*}\right](\alpha I)^2\sigma_s^2$$

$$= 2\left[\frac{(p^* - w^*)w^*}{p^{*3}}\right](\alpha I)^2\sigma_s^2$$

which is greater than zero.

where $k = \frac{1}{2} \ln \frac{\beta}{\alpha}$

Notice the similarity of the estimable form above with equation (2.25). The coefficients on the first three variables have the same expected signs as for an exporter pricing in the domestic currency whilst the exchange-rate variance exerts a negative influence on import price. The terms multiplying the variance differ between equations. Previously variance was multiplied by value of imports. Here it is multiplied by quality of imported goods (α), nominal income (I), and cost mark-up $\left[\frac{p^* - w^*}{p^*}\right]$. These terms, while important for individual firms, become irrelevant later in Chapter Four when aggregate data is used to estimate these equations.

2.3. A Common Pass-Through Equation

Further refinements are needed to obtain a pass-through equation capable of nesting the exporter's choice of pricing in either its own currency or that of the importing country. Firstly, estimation will be carried out with coefficients not necessarily equal to $\frac{1}{2}$ as implied by the functional form. Secondly, the risk-aversion coefficient R_u will be multiplied by σ_s^2. The other terms multiplying the variance apply to individual firms as mentioned previously above. These terms cannot be measured from the available aggregate data used for estimation and hence are omitted. The profit function is homogeneous of degree one meaning that a given proportionate increase in optimal import price results from increasing its arguments in the same proportion. Thus coefficients for foreign marginal costs (w*) and goods produced domestically (q) sum to one. Foreign marginal costs expressed in expected currency of the importing country ($\frac{w^*}{e}$) may be rewritten as:

$$\ln w^* - \ln e$$

The problem of determining the expected exchange rate lne (or more precisely $E_{t-1}lns_t$) is handled in Chapter Four.

Finally the following derivation allows one to estimate $\frac{\sigma_s^2}{e^2}$. An AR representation of the natural log of the actual spot exchange-rate, s, is given as:

$$lns_t = \sum_{i=1}^{k} ø_i lns_{t-i} + u_t$$

Taking expectations yields

$$lne_t = \sum_{i=1}^{k} ø_i lns_{t-i}$$

$$\therefore \; lns_t = lne_t + u_t$$

with $u_t \sim N(0, \sigma^2)$.

Noting that $u_t \approx \ln(1 + u_t)$ implies,

$$lns_t = lne_t + \ln(1 + u_t)$$

Taking exponentials yields,

$$s_t = e_t(1 + u_t)$$

which is a reasonable approximation provided u_t is not too large.

The variance of the error term (u_t) can then be used for the following[11]

---

11 Derivation is as follows. Taking the expected value of s_t

$$E(s_t) = E[e_t(1 + u_t)]$$

$$= E(e_t)[E(1) + E(u_t)]$$

$$= e_t[1 + 0]$$

$$\sigma^2_{s,t} = e^2_t \sigma^2_{u,t} \qquad \therefore \; \sigma^2_{u,t} = \left[\frac{\sigma^2_{s,t}}{e^2_t}\right]$$

The common form incorporating the above changes as well time subscripts appears as:

(2.29) $$p_t = \alpha_0 + \alpha_1(w^*_t - E_{t-1}s_t) + (1 - \alpha_1)q + \alpha_2\sigma^2_{u,t}$$

where:

w^*_t = Log of foreign marginal costs.

p_t = Log of import price in U.S. currency.

q_t = Log of U.S. domestic price.

s_t = Log of spot exchange-rate: foreign currency per U.S. dollar.

$$= e_t$$

Then,

$$\sigma^2_{s,t} = E(e^2_t) - (e_t)^2$$

Substituting from above

$$= E\left([e_t(1+u_t)]^2\right) - e^2_t$$

$$= e^2_t E\left([(1+u_t)]^2\right)$$

$$= e^2_t E\left(1 + 0 + E\left[\quad (u^2_t)\right]\right) - e^2_t$$

$$= e^2_t \left[\sigma^2_{u,t} + 1\right] - e^2_t$$

$$= e^2_t \sigma^2_{u,t}$$

$\sigma^2_{u,t}$ = variance of the forecast error in s_t. i.e.

$$\sigma^2_{u,t} \equiv E_{t-1}(s_t - E_{t-1}s_t)^2$$

with expected signs:

$0 \leq \alpha_1 \leq 1$ and α_2 > or < 0 depending on which currency the exporter sets price.

The results derived above showed α_2 to be positive (negative) when the exporter prices in the currency of the importing (exporting) country. However, this result does not account for the possibility of reducing risk by covering in the forward foreign exchange market..The next section investigates how the sign and magnitude of α_2 is affected by optimal forward covering.

2.4. Forward Covering

Exporting firms which set price in their own currency cannot cover on the foreign exchange market. Revenues are uncertain due to uncertain quantity demanded. Price denominated in the importing country's currency fluctuates with changes in the exchange rate which in turn causes ups and downs in quantity demanded. Theory still predicts $\alpha_2 < 0$ for these exporters even in the presence of forward markets.[12]

The story differs for firms setting price in the domestic (i.e. importing country's) currency because they can cover. Let f denote the price of forward foreign exchange (i.e. exporting country's currency per unit of importing country's currency) at time t - 1 for a contract settled in

[12] Evidence presented by Grassman (1973 and 1976) and Page (1977) seems to indicate that the choice of currency invoicing appears to depend on institutional arrangements rather than on ability to hedge exchange-rate movements.

time t. Then the extent to which firms can cover their foreign revenues depends on how f compares with the expected exchange rate e.

2.4.1. Optimisation when the Price of Forward Foreign Exchange Equals the Expected Exchange Rate

If f = e (that is ${}_{t-1}f_t = {}_{t-1}e_t$) then exporting firms pricing in the importing country's currency would fully cover revenues, since the *expected* exchange rate in time t is equal to the current price of a forward foreign exchange contract. The profit function would appear as:

(2.30) $$\pi^* = (fp - w^*)x(p,q,I)$$

where the variables are previously defined:

$$= E\pi^*$$

with var(π^*) = 0 unlike the case in equation (2.10). Here, in contrast, one finds that:

(2.31) $$\underbrace{p\left(1 - \frac{1}{\eta}\right)}_{MR} = \underbrace{\frac{w^*}{f}}_{MC}$$

Exchange-rate variance would not affect the firm's profit-maximising decision. Therefore, the variance of the exchange rate would not enter the pricing equation (2.29); $\alpha_2 = 0$.

2.4.2. Optimisation when the Price of Forward Foreign Exchange is less than the Expected Exchange Rate

If f < e, the firm can move along a tradeoff locus between expected profit E(π^*) and variance of profit var(π^*). There will be some optimal level of forward covering given the firm's aversion to variance of profits. Firms reduce expected profit ($E\pi^*$) by covering but also reduce the variance of profit since they are risk averse. Suppose that the firm covers a fraction λ of revenues. Then:

(2.32) $$\pi^* = \{[\lambda f + (1 - \lambda)s]p - w^*\}x(p,q,I)$$

with $$E\pi^* = \{[\lambda f + (1 - \lambda)e]p - w^*\}x(p,q,I)$$

and $$\mathrm{var}(\pi^*) = (1 - \lambda)^2\sigma_s^2(px)^2$$

The firm solves:

(2.33) $$\max_{p,\lambda} u(E\pi^*) + \frac{1}{2}u''\mathrm{var}(\pi^*),$$

choosing both p and λ.

2.4.2.1. Choice of λ

Taking first-order conditions with respect to λ results in:

(2.34) $$u'(f - e)px + \frac{-1}{2}u''2(1 - \lambda)\sigma_s^2(px)^2 = 0$$

Rearranging:

(2.35) $$\left[\frac{f - e}{e}\right] = -R_u\left[\frac{\sigma_s^2}{e}\right](1 - \lambda)px$$

Thus firms will optimally choose $\lambda < 1$ if $f < e$. That is, they will choose to cover only a portion of revenues so long as forward foreign exchange contracts yield less of their currency per unit of the other currency than is their expectation of the future spot rate. The reason is that an insufficient supply of forward contracts bids up the forward price of the exporters' currency, hence lowering f. In this situation, the firm prefers to face some risk in its revenues rather than fully covering.

2.4.2.2. Choice of p

Taking first-order conditions with respect to p results in:

$$\text{(2.36)} \qquad u'\left\{[\lambda f + (1-\lambda)e]x + (p[\lambda f + (1-\lambda)e] - w^*)\frac{\partial x}{\partial p}\right\}$$

$$+ \frac{1}{2}u''\frac{d}{dp}\operatorname{var}(\pi^*) = 0.$$

but

$$\frac{d}{dp}\operatorname{var}(\pi^*) = 2(1-\lambda)^2\sigma_s^2 p(1 - \frac{1}{\eta})\frac{\partial x}{\partial p}(px) > \text{iff } \lambda \neq 1$$

So one may rewrite equation (2.36) as:

$$\text{(2.37)} \qquad \underbrace{p(1 - \frac{1}{\eta})}_{MR} - \underbrace{\frac{w^*}{\left[\lambda f + (1-\lambda)e\right]}}_{MC} =$$

$$\frac{1}{2}R_u\left\{\frac{\frac{d}{dp}\operatorname{var}(\pi^*)}{[\lambda f + (1-\lambda)e]\frac{\partial x}{\partial p}}\right\}$$

Equation (2.37) is easily compared with equation (2.10) for the firm invoicing in domestic currency. So long as there is an insufficient supply of forward contracts, causing f < e (causing λ < 1) the firm will price such that MR > MC. A rising variance σ_s^2 will lead to a higher gap between MR and MC, and, consequently, higher p. On the other hand, the gap between MR and MC shrinks as λ approaches unity. Thus, if firms can cover much of their dollar revenues (increasing as f approaches e), then the variance of the exchange rate does not affect their pricing decision.

When exporters price in their own currency, they cannot cover, so variance enters with a negative sign in equation (2.29). But when exporters price in the currency of the importing country, α_2 is positive, although its magnitude depends on the extent of forward covering. The magnitude of α_2 decreases to zero as the proportion of covered uncertain sales revenue approaches 100 per cent.

Estimation will be at an aggregate level by country. Thus, it will combine the response of firms invoicing in both currencies. But the choice of invoicing currency affects the sign and significance of the variance term. Consider first the case when f approximately equals e. Variance will have no effect on exporters setting price in the importing country's currency since they will cover revenues. In such a case α_2 is predicted to be negative, reflecting the remaining effect of variance on exporters pricing in their own currency as discussed above. Now consider the case where there is a limited supply of contracts causing f to be less than e. The sign on exchange-rate variance will appear negative for exporters pricing in their own currency as before. But now exporters pricing in the importing country's currency will not be fully covering, causing α_2 to also have a positive sign. In this latter case one cannot predict a sign for α_2 when estimated at the aggregate level. In fact it is likely to be statistically insignificant when tested empirically.

The next two chapters address the problem of developing estimable forms for these models. The task of estimating exchange-rate variances as well as detecting the presence of a time-varying risk premium in the forward foreign exchange market are handled first in Chapter Three. The job of estimating a common pass-through equation for exporters pricing in either currency is taken up in Chapter Four.

APPENDIX TO CHAPTER TWO

Derivation with both Exchange-Rate and Foreign Factor Prices as Stochastic Variables; Risk-Averse Firm

The firm may also be unsure about foreign factor prices. Thus it is useful to derive results in which both the exchange-rate variable (s) and aggregate foreign factor prices variable (w*), are random.

The individual firm's expected utility of profit maximisation problem is:

(A2.1) $$\max_{p} E\,\{U[spx(p,q,I) - \phi(x)w^*]\},$$

where s and w* are stochastic; remaining variables are deterministic and are defined in Chapter Two. Assuming continuity, the first order conditions for equation (A2.1) can be written as:

(A2.2) $$\int_0^\infty\int_0^\infty u'(\bullet)\left[s\left(x + p\frac{dx}{dp}\right) - \phi'\frac{dx}{dp}w^*\right]f(s,w^*)\,ds\,dw^* = 0$$

Assume $\phi(x) = x$. Then $\phi'(x) = 1$ and $\phi''(x) = 0$ i.e. constant marginal costs. Equation (A.2.2) is then rewritten as:

$$\text{(A2.3)} \qquad \int_0^\infty\!\!\int_0^\infty u'(\bullet)\left[sx + sp\frac{dx}{dp} - 1\frac{dx}{dp}w^*\right]f(s,w^*)\,ds\,dw^* = 0$$

Let the expected values of s and w* be denoted by e and v* respectively. Also let expected profit, $E\pi$ = epx - xv*. Approximate $u'(\bullet)$ by first order Taylor expansion about $[epx - xv^*]$:

$$\text{(A2.4)} \qquad u'(\bullet) \approx u'(E\pi) + u''(E\pi)[px(s - e) - x(w^* - v^*)]$$

Substitute equation (A2.4) into equation (A2.1) and expand.

$$\text{(A2.5)} \int_0^\infty\!\!\int_0^\infty u'(E\pi)\left[s\left(x + p\frac{dx}{dp}\right) - \frac{dx}{dp}w^*\right] + u''(E\pi)[px(s - e) - x(w^* - v^*)]$$

$$\left[s\left(x + p\frac{dx}{dp}\right) - \frac{dx}{dp}w^*\right]\}f(s,w^*)\,ds\,dw^* = 0$$

Integrate equation (A2.5); simplify.

$$\text{(A2.6) } u'(E\pi)\left[e\left(x + p\frac{dx}{dp}\right) - \frac{dx}{dp}v^*\right] + u''(E\pi)\{px\sigma_s^2\left(x + p\frac{dx}{dp}\right) - px\sigma_{s;w^*}\frac{dx}{dp}$$

$$-x\sigma_{w^*;s}x - xp\sigma_{w^*;s}\frac{dx}{dp} + x\sigma_{w^*}^2\frac{dx}{dp}\} = 0$$

where the variances and covariances of s and w* are,

$$\sigma_s^2 = \int_0^\infty\int_0^\infty s(s - e)f(s,w*)dsdw*, \quad \sigma_{w*}^2 = \int_0^\infty\int_0^\infty w*(w* - v*)f(s,w*)dsdw*,$$

$$\sigma_{s;w*} = \int_0^\infty\int_0^\infty s(w* - v*)f(s,w*)dsdw*,$$

$$\sigma_{w*;s} = \int_0^\infty\int_0^\infty w*(s - e)f(s,w*)dsdw*,$$

and $\sigma_{s;w*} = \sigma_{w*;s}$

Multiply by $\frac{1}{e}\left[\frac{dp}{dx}\right]\frac{1}{p}$; rearrange and simplify.

$$\text{(A2.7)}\ u'(E\pi)\left\{\left[\left(\frac{dp}{dx}\right)\frac{x}{p} + 1\right] - \frac{1}{p}\left[\frac{v*}{e}\right]\right\} + u''(E\pi)\{px\frac{\sigma_s^2}{e}\left[\left(\frac{dp}{dx}\right)\frac{x}{p} + 1\right] + -x\left[\frac{\sigma_{s;w*}}{e}\right]$$

$$+ -x\left[\frac{\sigma_{w*;s}}{e}\right] + -x\left[\frac{\sigma_{w*;s}}{e}\left(\frac{dp}{dx}\right)\frac{x}{p}\right] + \left[\frac{x}{p}\right]\frac{\sigma_s^2}{e}\} = 0$$

Let $-\eta = \left[\frac{dx}{dp}\right]\frac{p}{x}$; rearrange so as to make use of the definition of elasticity and multiply by p.

$$\text{(A2.8)}\quad u'(E\pi)\left\{\left[p\left(1 - \frac{1}{\eta}\right) - \frac{v*}{e}\right] + u''(E\pi)\sigma_s^2 pxp\left[\frac{1-\frac{1}{\eta}}{e}\right] + x\left[\frac{\sigma_{w*}^2}{e}\right] + \right.$$

$$- \sigma_{s;w*}\left[\frac{px}{e} + px\frac{\left(1-\frac{1}{\eta}\right)}{e}\right]\Bigg\} = 0$$

Rearrange letting $R_u = -\left[\frac{u''(E\pi)}{u'(E\pi)}\right]$.Multiply specific terms by $\frac{e}{e}$,

$\frac{v*}{v*}$, and $\frac{v*^2}{v*^2}$; factor out $p\left[1 - \frac{1}{\eta}\right]$ on LHS and $\frac{v*}{e}$ on the RHS and then simplify.

(A2.9)
$$p\left[1 - \frac{1}{\eta}\right]\left\{1 - R_u\left[\frac{\sigma_s^2}{e^2} pxe - \frac{\sigma_{s;w*}}{ev*} xv*\right]\right\} =$$

$$\frac{v*}{e}\left[1 - R_u\left(\frac{\sigma_{s;w*}}{ev*} pxe - \frac{\sigma_{w*}^2}{v*^2} v*x\right)\right]$$

The following assumptions and manipulations are necessary in order to get equation (A2.9) into an estimable form.

Let marginal revenue $p\left[1 - \frac{1}{\eta}\right] = r(p,q,i)$ and make the following substitutions:

$$R_u\left(\frac{\sigma_s^2}{e^2} pxe - \frac{\sigma_{s;w*}}{ev*} xv*\right) = \delta_1 \text{ and } R_u\left(\frac{\sigma_{s;w*}}{ev*} pxe - \frac{\sigma_{w*}^2}{v*^2} v*x\right) = \delta_2.$$

Equation (A2.9) may be rewritten as:

(A2.10) $$r(p,q,I) = \left[\frac{v^*}{e}\right]^{\frac{[1-\delta_2]}{[1-\delta_1]}}$$

Given $-\frac{\partial r(\bullet)}{\partial p} \neq 0$ (Recall that $\frac{\partial MC}{\partial p} = 0$), the implicit function rule allows inversion of equation 10 yielding the following import price relationship:

(A2.11) $$p = \pi\left[\left[\frac{v^*}{e}\right]^{\frac{[1 - \delta_2]}{[1 - \delta_1]}};q;I\right]$$

Estimation necessitates a log-linear form of equation (A2.11).

(A2.12) $$\ln p = \ln\left[\left[\frac{v^*}{e}\right]^{\frac{[1 - \delta_2]}{[1 - \delta_1]}}\right] + \ln q + \ln I$$

Expanding and noting that $\ln[1 - \delta_2] \approx -\delta_2$ and $-\ln[1 - \delta_1] \approx \delta_1$, one obtains:

(A2.13) $$\ln p = \ln\left[\frac{v^*}{e}\right] - \delta_2 + \delta_1 + \ln q + \ln I$$

Substituting in for δ_2 and δ_1 yields:

(A2.14) $$\ln p = \ln\left[\frac{v^*}{e}\right] - R_u\left(\frac{\sigma_{s;w^*}}{ev^*}\,pxe - \frac{\sigma^2_{w^*}}{v^{*2}}\,v^*x\right) +$$

$$R_u\left[\frac{\sigma^2_s}{e^2}\,pxe - \frac{\sigma_{s;w^*}}{ev^*}\,xv^*\right] + \ln q + \ln I$$

If one assumes that the expected aggregate of foreign factor prices is approximately equal to the price of the imported goods, expressed in the expected value of foreign currency (i.e. $v^* \approx pe$), then equation (2.14) may be rewritten as:

$$(2.15) \qquad \ln p \approx \ln\frac{v^*}{e} + R_u\left[\frac{\sigma_s^2}{e^2} + \frac{\sigma_{w^*}^2}{v^{*2}} - 2\frac{\sigma_{s;w^*}}{ev^*}\right]pxe + \ln q + \ln I$$

One can derive,

$$\left[\frac{\sigma_s^2}{e^2} + \frac{\sigma_{W^*}^2}{v^{*2}} - 2\frac{\sigma_{s;w^*}}{ev^*}\right]$$

$$\approx \mathrm{var}\left[\ln\left[\frac{s}{w^*}\right]\right]$$

$$= \mathrm{var}[\ln s - \ln w^*]$$

$$= \mathrm{var}(\ln s) + \mathrm{var}(\ln w^*) - 2\mathrm{cov}(\ln s, \ln w^*)$$

where all variances and covariances depend on time.

The final result becomes:

$$(A2.16) \qquad \ln p_t \approx \beta_0 + \beta_1 \ln\left[\frac{v_t^*}{e_t}\right] + \beta_2[D_t]p_t x_t e_t + \beta_3 \ln q_t + \beta_4 \ln I_t + \varepsilon_t$$

where $\varepsilon_t \sim(o,1)$.

with

$$D_t = \det \begin{bmatrix} \sigma_s^2 & \sigma_{s;w*} \\ \sigma_{w*;s} & \sigma_{w*}^2 \end{bmatrix}$$

where all variances and covariances depend on time.

The problem with equation (A2.16) is in finding estimates for the covariance between the exchange rate and foreign factor prices. Multivariate Simultaneous ARCH (See appendix to Chapter Three) would be especially useful in this regard. However, there are no weekly data for foreign factor prices for estimation.

CHAPTER THREE

3. ARCH-IN-MEAN

The theoretical section above demonstrates how exchange-rate variance enters as a risk premium measure. That is:

$$(3.1) \qquad \left[\frac{f - e}{e}\right] = -R_u\left[\sigma_s^2\right](1 - \lambda)px + e_t$$

where $Var(e_t) = \sigma_s^2$

The task now is to estimate equation (3.1). An explanation of ARCH models is necessary in order to understand how a measure of risk and an estimate for exchange-rate variance can be obtained simultaneously.

3.1. Introduction to ARCH Models

A body of literature has developed recently which applies particularly well to estimation of equation (3.1). Engle (1982) first proposed a class of time series models which took account of systematic changes in the disturbance term.[13] More efficient estimation could result if past magnitudes of the disturbance term provided information about the variance of the current disturbance. Engle obtained a prediction of variance at time t by formulating a maximum likelihood function which took account of information from lagged squared residuals. Whilst the

[13] Technical details of ARCH are found in the appendix to this chapter.

unconditional variance of the model remained constant, satisfying classical linear regression assumptions for estimation by OLS, a time-varying conditional variance could be incorporated to make more accurate predictions about the confidence interval surrounding the predicted mean value at time t.

By-products of the ARCH model are the estimated conditional variances of the dependent variable of the mean equation. Engle (1983, p. 287) asserted that for a well-specified mean equation these variance estimates were superior to, say, moving average constructions. "The model for the mean is surely misspecified and therefore deviations from it will give biased estimates of the variance (p. 287)." Exchange-rate variances estimated from models in this chapter are used as measures of risk in pass-through estimation of Chapter Four.

Further refinements to ARCH became necessary due to problems with estimation. In many instances the signs of the lagged squared residual parameters were negative--clearly a result which violated the requirement of positive variance estimates. *Ad hoc* procedures were developed to overcome this problem. Engle (1982 and 1983) regressed squared residuals on a linearly declining weighted average of past squared error terms, reducing the parameters to be estimated to two. Other authors such as Diebold and Nerlove (October 1985) and Domowitz and Hakkio (1985) squared the ARCH parameters, imposing the non-negativity constraint directly.

In contrast to the above techniques for dealing with non-negativity, Bollerslev (1986) proposed a Generalised ARCH model which allowed for past conditional variances in the variance model. Rigid lag structures and inflexible nonegativity constraints were no longer necessary. This extension was analogous to adding moving average terms to an auto-regressive model. Bollerslev showed that this extension yielded a more intuitively pleasing economic interpretation, particularly if the GARCH(1,1) model was used. Bollerslev (1986, p. 308) argued that Garch(1,1) afforded "both a longer memory and a more flexible lag structure" in contrast to the above ARCH models.

GARCH is, in fact, "an infinite order ARCH model with exponentially decaying weights for larger lags (Engle and Bollerslev [1986, p. 19])." Baillie and Bollerslev (July 1987 and September 1987), and Engle and Bollerslev (1986) have found that GARCH(1,1) more accurately represents conditional heteroskedasticity exhibited by exchange rates.

Engle & Bollerslev (1986) pushed the ARCH research still further when they noticed considerable persistence of ARCH effects in a number of exchange rates they were modelling. Lagged squared residuals from the distant past still influenced conditional variance. This prompted them to run an Integrated GARCH(1,1) model in which the parameters summed to one, the implication being that past innovations forever impart information to forecasts of future conditional variances.

Even as the ARCH model itself was undergoing modification, new frontiers were being forged. Engle, Lilien, and Robins (March 1987) proposed an ARCH-in-Mean (ARCH-M) model in which conditional variance became an explanatory variable of the mean equation. They were interested in how "changing conditional variances directly affect the expected return on a portfolio (p. 392)." ARCH-M is more complex to estimate as both the mean and variance equations must be estimated simultaneously. However the ability to model the risk premium of a financial asset simultaneously with its price, with risk as one of the determinants of price, is the benefit. Indeed, Domowitz and Hakkio (1985) used ARCH-in-Mean to test their empirical model of exchange-rate risk premium, where the risk premium was "a function of the conditional variance of market forecast errors (p. 47)."

Bollerslev's generalisation of ARCH (chiefly GARCH(1,1)), combined with ARCH-M has been standard practice in recent literature as exemplified by Engle & Bollerslev (1986). GARCH-M (now just referred to as ARCH-In-Mean) is thus a logical technique by which to estimate equation

(3.1) above since exchange-rate variance is an explanatory variable in determining the forward exchange rate forecast error.

3.2. Preparation of Data for Estimation by ARCH-In-Mean

Estimation of equation (3.1) is carried out using spot and one-month forward exchange-rate data for days 7, 14, 21, and 28 of each month. Countries chosen include United Kingdom (UK), Japan, and Federal Republic of Germany (FRG). Data covers the period June 1974 to September 1988--a total of 688 observations. The data appendix at the end of this chapter covers more thoroughly the sources and types of data used in estimation. Variance estimates are also presented.

Any modelling of the risk premium, which utilises conditional variance techniques, requires the series in question to be stationary. There is ample evidence in the literature that the forward forecast error (dependent variable of equation (3.1)) is a stationary stochastic process as shown in Meese & Singleton (1982), Baillie & Bollerslev (1987b and c), and Modjtahedi & Kendall (1988). Figures 3.1 through 3.3 (at the end of this chapter) present plots of forward forecast errors for the UK, Japan, and FRG over time. Visual inspection detects no deviations from stationarity.

By using weekly data the number of observations are increased. But this also adds moving average terms to the error; four of the day observations will be influenced by the same shocks since the observation interval is finer than the relevant forward-contract interval as pointed out in Hakkio (1981) and also Baillie & Bollerslev (Sept. 1987, pp. 7-8). Four moving average terms are necessary for estimations involving weekly data to overcome this problem.[14,15]

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[14] Empirically the raw forward forecast error series rejected the null hypothesis of being white noise overwhelmingly.

The estimable form of equation (3.1), taking into consideration moving average terms as well as the time-varying variance term, becomes:

(3.2) $$f_t - s_{t+4} = \beta_0 + \gamma h_t + \beta_1\varepsilon_{t-1} + \beta_2\varepsilon_{t-2} + \beta_3\varepsilon_{t-3} + \beta_4\varepsilon_{t-4} + \varepsilon_t$$

$$\varepsilon_t \mid I_{t-1} \sim N(0,h_t)$$

$$h_t = \alpha_0 + \alpha_1\varepsilon^2_{t-1} + \alpha_2 h_{t-1}$$

where,

h_t is the conditional variance represented by a GARCH(1,1)-in-Mean process.

β_0 ? 0 Negative risk premium if $\beta_0 + \gamma h_t < 0$.

$\gamma < 0$ Also significant if exporters do not fully cover in the forward foreign exchange market.

γ ? 0 Also insignificant if exporters fully cover.

β_1 through $\beta_4 > 0$ Moving average terms.

α_0 ? 0 Unimportant.

$\alpha_1 > 0$ Significant and large if last period's variance is a good predictor of today's variance.

$\alpha_2 > 0$ Significant and large if past variances have a lingering influence on today's variance.

---

[15] Authors such as Hakkio (1981), Baillie & Bollerslev (Sept 1987), and many others use weekly Thursdays as the spot rate whilst using weekly Tuesdays as the forward rate. This gives rise to a slight alignment problem in which the forward rate is really forecasting the $s_{t+4\ 2/5}$ spot rate. In the case at hand the forward contract maturity date and the s_{t+4} spot rate fall on precisely the same date so in theory, the fourth moving average term should be unnecessary. Preliminary regressions, however, detected its presence, particularly for Japan and FRG.

Because h_t also appears in the mean equation, maximum likelihood estimation for the β and α parameters is considerably more complex as noted in Engle, Lilien, and Robins (1987, p.397) since consistent estimation requires these parameters to be estimated simultaneously.[16]

The risk premium models for the three countries are first estimated with only the constant and the four moving average terms. Results are shown in Table 3.1. All parameters are significant as expected with the exceptions being the constant and 4th moving average term for the pound. These variables are left in for consistency of estimation with the other two currencies. Box-Pierce statistics and accompanying autocorrelations and partial autocorrelations for 8th order serial correlation are shown for the residuals of these models in Table 3.2. The Box-Pierce numbers are dramatically smaller; most of the autocorrelations are within $\pm 2/\sqrt{684} = \pm.038$ bounds.[17] Nevertheless, the results indicate a lingering serial correlation in all three countries which is certainly plausible since the variance terms are omitted from the mean equations.

3.3. Testing for ARCH

Figures 3.4 through 3.6 show plots of the residuals from the above estimations. Immediately noticeable is that large residual changes tend to be followed by large but unpredictable residual

[16] The elements in the off-diagonal block of the information matrix are not zero as is the case for ARCH or even GARCH. See Engle, Lilien, and Robins (1987, p. 397). Also estimates of the betas are consistent if $\beta_1 = 0$.

[17] Similar results are noted for estimated autocorrelations and partial autocorrelations for 36th order serial correlation.

changes whilst small changes tend to be followed by small but unpredictable changes. This pattern is characteristic of data exhibiting autoregressive conditional heteroskedastic processes. Other studies have noted this phenomenon for exchange rates.[18]

Formal tests of ARCH are suggested by Engle (1982, p. 1000). First, the squared residuals are regressed on p past lags. A LaGrange multiplier test is then computed by multiplying the number of observations by the R squared from the regression. If there are no ARCH effects, this statistic will follow a Chi squared distribution with p degrees of freedom. Results on Table 3.3 show regressions for the pound, yen and deutschemark accompanied by the ARCH test results for p = 8. All three currencies show evidence of heteroskedasticity in the disturbance terms. Negative coefficients show up noticeably for some of the lags. Estimation by GARCH(1,1) eliminates this problem with its implicit non-negativity restriction.

Another test is to examine the correlation structure of the squared residuals accompanied by the modified Box-Pierce statistic (Engle & Bollerslev [1986, pp.23-24]). The modified Box-Pierce Statistics for all three countries reject the null hypotheses of no serial ARCH (at all levels of significance) as does an examination of the estimated autocorrelations and partial correlations. Table 3.4 shows that estimated autocorrelation and partial autocorrelation functions appear to die out slowly for the yen and deutschemark but not the pound. Engle & Bollerslev (1986, p. 24) note slow decay in the correlation structure of the Swiss franc/US dollar exchange rate. They attribute the phenomenon to persistence in the ARCH process. That is, shocks to the variance tend to have lingering effects over time.

[18] See for example Diebold & Nerlove (1985), Engle & Bollerslev (1986), and Baillie & Bollerslev (July 1987).

3.4. Estimation by ARCH-In-Mean

Solutions to the maximum likelihood functions of the ARCH-in-Mean models for the three countries are found by making use of the Berndt, Hall, Hall, Hausman (1974) algorithm.[19] The results are shown in Table 3.5. The moving average terms appear to be about the same as in the estimations without ARCH-in-Mean with the exception of the yen where the first two terms are now about equal to one. On the other hand, the constant b_0 terms have changed substantially. This is not too surprising as they were insignificant except possibly for the yen.

On the other hand, the ARCH coefficients are highly significant for all three currencies indicating the presence of time-varying heteroskedasticity in the error terms. Note that a_1 is a sizable magnitude for all currencies. Thus, a large squared forecast error in one period tends to be followed by a large forecast error in the next period. A similar situation occurs for small forecast errors. The size of the a_2 term is even larger, indicating the lingering but declining importance of all past information. The ARCH specification affords a pleasing economic interpretation to the lag structure (as previously mentioned) since one would expect agents to attribute less and less importance to innovations the further in the past they occurred.[20]

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[19] The FORTRAN programme used for estimation was graciously supplied by Ken Kroner, Department of Economics, University of Arizona.

[20] Table 3.5 presented results with the α_1 and α_2 GARCH(1,1) parameters estimated separately. These parameters almost sum to one, indicating the possibility of Integrated Garch-In-Mean. Previous examination of the squared residuals, for each currency before GARCH-in-Mean revealed estimated autocorrelation functions and partial correlation functions that appeared to die out slowly, even up to the 36th order of serial correlation. Engle and Bollerslev (1986) found that Integrated GARCH-in-Mean adequately modelled the differenced Swiss exchange rate. Thus, it is of interest to test the restriction $\alpha_1 + \alpha_2 = 1$ for each currency here.

Figures 3.7 through 3.9 permit visual inspection of the conditional estimates. Common to both the yen and the pound is a large blip of increased variance in the latter part of the sample period. However, the pound experiences this oddity around August 1985 whilst the yen follows the same pattern in January 1986. The deutschemark shows relatively little variability after a brief period in February 1979.

The ARCH-in-Mean term g is significant and negative only for the yen. Theory in Chapter Two indicates that variance would be important in the case where there is an insufficient supply of foreign exchange forward contracts, with some fraction of revenues by exporters pricing in US$ that is not covered in the forward exchange market. This is certainly a plausible situation here given that the US trade deficit with Japan has lingered on for quite some time. This situation might make it difficult for Japanese exporters to buy US dollars on the forward foreign exchange market for an amount equal to the expected future spot rate. The pound and deutschemark estimations yield insignificant variance estimates in the mean equations. These two currencies are widely traded (being an integral part of the European Economic Common Market) so one would expect the forward exchange rate to more nearly equal the expected future spot rate. Chapter Two, section 2.4 indicates that for such currencies variance will not be important in determining the forward forecast error.

Log-Likelihood Ratio Tests were computed for the three currencies with the Integrated GIM as the restricted hypothesis. The Pound and deutschemark rejected the Integrated GIM specification at the 10% level of significance whilst the Yen failed to reject. These results are puzzling as there would seem to be no economic reason why the Yen should exhibit persistent variance whilst the Pound and Yen do not. Therefore it seems wise at this stage to remain with the original estimations of Table 3.5 given these mixed results.

Time-varying risk premia can be derived from the estimates of Table 3.5 using the following equation:

(3.3) $$RP = b_0 + g\sigma_t^2$$

for each currency, where b_0 and g are previously defined.

However, this exercise is meaningful only for the yen which has a significant variance-in-mean term. Figure 3.10 plots the risk premium for the yen, which shows considerable negative to positive traversing. Domowitz and Hakkio (1985, p. 62) notice in their results the positive-negative risk-premium switching which they also attribute to the large movements in the conditional variances. Figure 3.7 shows the path of the risk premium beginning with generally positive values from mid 1974 to March 1978, then mostly negative until July 1983 when it again became positive. From September 1985 onwards the risk premium becomes enormously erratic and negative. In spite of the occasional positive stretches, the overall average is decidedly negative for the period as a whole.

The above results, combined with exchange-rate variance estimates, are now utilised in estimating a common form for exporters pricing in either domestic or foreign currencies.

TABLE 3.1

RISK PREMIUM MODELS WITHOUT ARCH

$$f_t - s_{t+4} = b_0 + b_1\varepsilon_{t-1} + b_2\varepsilon_{t-2} + b_3\varepsilon_{t-3} + b_4\varepsilon_{t-4}$$

POUND

COEF.	ESTIMATE	S. ERROR.	T-STATISTIC
b0	-0.0335	0.0640	-0.524
b1	0.937	0.0384	24.432
b2	0.850	0.0383	22.189
b3	0.806	0.0383	21.045
b4	0.0616	0.0383	1.610

YEN

COEF.	ESTIMATE	S. ERROR	T-STATISTIC
b0	0.117	0.068	1.725
b1	0.961	0.0383	25.093
b2	0.981	0.0383	25.647
b3	0.801	0.0383	20.947
b4	0.130	0.0382	3.411

DEUTSCHEMARK

COEF.	ESTIMATE	S. ERROR	T-STATISTIC
b0	-0.172	0.0682	-2.527
b1	0.933	0.0383	24.387
b2	0.947	0.0383	24.767
b3	0.807	0.0381	21.151
b4	0.0907	0.0376	2.412

SUMMARY STATISTICS

NUMBER OF OBSERVATIONS = 688

	POUND	**YEN**	**DM**
SUM OF SQUARED RESIDUALS =	1924.403	2158.266	2184.010
STANDARD ERROR OF THE REGRESSION	1.679	1.778	1.788
MEAN OF DEPENDENT VARIABLE	-0.0363	0.117	0.174
STANDARD DEVIATION	3.125	3.394	3.321
R-SQUARED	0.713	0.727	0.712
ADJUSTED R-SQUARED	0.711	0.726	0.710
DURBIN-WATSON STATISTIC	1.982	1.997	2.003

TABLE 3.2

CORRELATION STRUCTURE FOR RESIDUALS

POUND

```
==========================================================================
          Autocorrelations        Partial Autocorrelations     ac     pac
==========================================================================
   |          .|.        |          .|.          | 1  0.008  0.008
   |          .|.        |          .|.          | 2  0.028  0.028
   |          .|*        |          .|*          | 3  0.052  0.052
   |          .|*        |          .|*          | 4  0.075  0.074
   |          .|.        |          .|.          | 5  0.022  0.019
   |          .|*        |          .|*          | 6  0.066  0.059
   |          .|*        |          .|.          | 7  0.041  0.032
   |          *|.        |          *|.          | 8 -0.040 -0.051
==========================================================================
  Box-Pierce Q-Statistic (8 lags)   11.884      S.E. of Correlations  0.038
==========================================================================
```

YEN

```
==========================================================================
          Autocorrelations        Partial Autocorrelations     ac     pac
==========================================================================
   |          .|.        |          .|.          | 1  0.002  0.002
   |          .|.        |          .|.          | 2  0.012  0.012
   |          .|.        |          .|.          | 3  0.030  0.030
   |          .|*        |          .|*          | 4  0.050  0.050
   |          .|*        |          .|*          | 5  0.073  0.073
   |          *|.        |          *|.          | 6 -0.061 -0.064
   |          .|.        |          .|.          | 7  0.007  0.003
   |          .|.        |          .|.          | 8 -0.005 -0.010
==========================================================================
Box-Pierce Q-Statistic (8 lags)   8.820        S.E. of Correlations  0.038
==========================================================================
```

DEUTSCHEMARK

```
==========================================================================
          Autocorrelations        Partial Autocorrelations     ac     pac
==========================================================================
   |          .|.        |          .|.          | 1 -0.002 -0.002
   |          .|.        |          .|.          | 2  0.008  0.008
   |          .|.        |          .|.          | 3  0.014  0.014
   |          .|.        |          .|.          | 4  0.029  0.029
   |          .|.        |          .|.          | 5 -0.020 -0.020
   |          *|.        |          *|.          | 6 -0.055 -0.056
   |          .|*        |          .|*          | 7  0.086  0.086
   |          .|.        |          .|.          | 8  0.011  0.012
==========================================================================
Box-Pierce Q-Statistic (8 lags)   8.325        S.E. of Correlations  0.038
==========================================================================
```

TABLE 3.3

ARCH TESTS

$$res^2 = a_0 + a_1 res^2_{t-1} + a_2 res^2_{t-2} + a_3 res^2_{t-3} + a_4 res^2_{t-4} + a_5 res^2_{t-5} + a_6 res^2_{t-6} + a_7 res^2_{t-7} + a_8 res^2_{t-8}$$

POUND

COEF.	ESTIMATE	S. ERROR.	T-STATISTIC
a0	-2.830	0.411	6.884
a1	0.051	0.0386	1.311
a2	0.0636	0.0386	1.647
a3	0.137	0.0387	3.543
a4	0.0110	0.0388	0.284
a5	0.115	0.0388	2.954
a6	-0.00445	0.0387	-0.115
a7	0.0234	0.0386	0.620
a8	0.0304	0.0386	0.788

YEN

COEF.	ESTIMATE	S. ERROR	T-STATISTIC
a0	3.157	0.707	4.465
a1	0.314	0.0385	8.155
a2	-0.112	0.0403	-2.773
a3	0.257	0.0405	6.342
a4	0.0723	0.0417	1.736
a5	0.0231	0.0417	0.554
a6	-0.00622	0.0405	-0.154
a7	-0.0761	0.0403	-1.891
a8	0.0744	0.0385	1.933

DEUTSCHEMARK

COEF.	ESTIMATE	S. ERROR	T-STATISTIC
a0	3.124	0.501	6.230
a1	0.292	0.0385	7.593
a2	0.0693	0.0401	1.728
a3	0.0333	0.0401	0.829
a4	-0.00451	0.0401	-0.112
a5	0.0353	0.0401	0.879
a6	-0.00412	0.0401	-0.103
a7	-0.0223	0.0393	-0.566
a8	0.0764	0.0378	2.018

TABLE 3.3 (Cont.)

ARCH TESTS

SUMMARY STATISTICS

NUMBER OF OBSERVATIONS = 680

	POUND	YEN	DM
SUM OF SQUARED RESIDUALS =	25321.14	46904.22	31567.61
STANDARD ERROR OF THE REGRESSION	6.143	8.361	6.859
MEAN OF DEPENDENT VARIABLE	2.823	3.161	3.133
STANDARD DEVIATION	6.281	9.193	7.263
R-SQUARED	0.0547	0.183	0.119
ADJUSTED R-SQUARED	0.0435	0.173	0.108
DURBIN-WATSON STATISTIC	2.00163	1.997	1.994

LAGRANGE MULTIPLIER TEST FOR ARCH

	UK	JAPAN	FRG
$TR^2 \sim X^2_{.10}(8) = 13.36$	37.21	124.23	80.73

All currencies reject the null hypothesis of no ARCH.

TABLE 3.4
CORRELATION STRUCTURE FOR SQUARED RESIDUALS

POUND

```
=====================================================================
        Autocorrelations          Partial Autocorrelations     ac     pac
=====================================================================
   |            .|*          |           .|*          |  1  0.080  0.080
   |            .|*          |           .|*          |  2  0.103  0.098
   |            .|**         |           .|**         |  3  0.165  0.152
   |            .|*          |           .|.          |  4  0.051  0.021
   |            .|**         |           .|**         |  5  0.149  0.120
   |            .|*          |           .|.          |  6  0.044 -0.002
   |            .|*          |           .|.          |  7  0.058  0.025
   |            .|*          |           .|.          |  8  0.077  0.030
=====================================================================
Box-Pierce Q-Statistic (8 lags)  54.572      S.E. of Correlations  0.038
=====================================================================
```

YEN

```
=====================================================================
        Autocorrelations          Partial Autocorrelations     ac     pac
=====================================================================
   |            .|****       |           .|****       |  1  0.319  0.319
   |            .|*          |           .|.          |  2  0.076 -0.028
   |            .|***        |           .|****       |  3  0.259  0.271
   |            .|***        |           .|*          |  4  0.231  0.080
   |            .|**         |           .|*          |  5  0.121  0.039
   |            .|*          |           .|.          |  6  0.066 -0.031
   |            .|.          |           *|.          |  7  0.032 -0.054
   |            .|*          |           .|*          |  8  0.106  0.074
=====================================================================
Box-Pierce Q-Statistic (8 lags) 176.370      S.E. of Correlations  0.038
=====================================================================
```

DEUTSCHEMARK

```
=====================================================================
        Autocorrelations          Partial Autocorrelations     ac     pac
=====================================================================
   |            .|****       |           .|****       |  1  0.323  0.323
   |            .|**         |           .|*          |  2  0.179  0.083
   |            .|*          |           .|*          |  3  0.115  0.040
   |            .|*          |           .|.          |  4  0.065  0.007
   |            .|*          |           .|*          |  5  0.071  0.039
   |            .|*          |           .|.          |  6  0.042  0.001
   |            .|.          |           .|.          |  7  0.023 -0.004
   |            .|*          |           .|*          |  8  0.085  0.078
=====================================================================
Box Pierce Q-Statistic (8 lags) 114.644      S.E. of Correlations  0.038
=====================================================================
```

TABLE 3.5
ARCH-IN-MEAN RESULTS

$$\hat{f}_t - s_{t+4} = b_0 + g\hat{h}_t + b_1\varepsilon_{t-1} + b_2\varepsilon_{t-2} + b_3\varepsilon_{t-3} + b_4\varepsilon_{t-4}$$

$$\varepsilon_t \mid I_{t-1} \sim N(0,h_t)$$

$$\hat{h}_t = a_0 + a_1\varepsilon^2_{t-1} + a_2 h_{t-1}$$

POUND

COEF.	ESTIMATE	S. ERROR.	T-STATISTIC
b0	0.296	0.296	1.003
g	-0.0853	0.0848	-1.006
b1	0.964	0.0434	22.223
b2	0.977	0.0413	23.687
b3	0.892	0.0413	21.594
b4	0.0754	0.0401	1.883
a0	0.100	0.0317	3.168
a1	0.118	0.0249	4.749
a2	0.855	0.0272	31.472

YEN

COEF.	ESTIMATE	S. ERROR	T-STATISTIC
b0	0.509	0.311	1.639
g	-0.244	0.0921	-2.653
b1	1.011	0.0424	23.863
b2	1.00305	0.0465	21.572
b3	0.851	0.0498	17.0847
b4	0.110	0.0435	2.532
a0	0.0619	0.0180	3.434
a1	0.101	0.0145	7.006
a2	0.885	0.0166	53.189

DEUTSCHEMARK

COEF.	ESTIMATE	S. ERROR	T-STATISTIC
b0	0.0902	0.250	0.362
g	0.00842	0.0589	0.143
b1	0.982	0.0484	20.269
b2	0.952	0.0448	21.252
b3	0.855	0.0460	18.613
b4	0.0955	0.0416	2.296
a0	0.186	0.0621	3.00336
a1	0.164	0.0289	5.664
a2	0.786	0.0398	19.748

TABLE 3.5 (Cont.)

ARCH-IN-MEAN RESULTS

SUMMARY STATISTICS

NUMBER OF OBSERVATIONS = 687
FIRST 5 OBSERVATIONS DISCARDED

	POUND	**YEN**	**DM**
LIKELIHOOD FUNCTION	-1272.768	-1274.431	-1306.822
UNCONDITIONAL VARIANCE	2.766	2.947	3.127
MEAN OF $h^{.5}$	1.633	1.662	1.714
MEAN OF h	2.927	3.132	3.267

Figures 3.1 to 3.10 plot forward forecast errors, residuals from non-GARCH equations, and conditional variance estimates for the British Pound, Japanese yen, and Deutschemark from June 1974 to September 1988.

APPENDICES TO CHAPTER THREE

DESCRIPTION OF ARCH MODELS

Engle (1982) first provided a type of correction for heteroskedasticity within the context of time series observations. If a regression's ability to forecast varied in some systematic way with the behaviour of the regression disturbance, then past magnitudes of this disturbance provide "information about the variance of the current disturbance." Kmenta (1986, p. 288). Generalising from Kmenta's example, the model for an ARCH(p) process may be specified as:

(A3.1) $$\mathbf{y_t} = \alpha + \beta^{\mathbf{t}}\mathbf{X_t} + \varepsilon_t$$

(A3.2) $$\varepsilon_t = u_t\left[\lambda_0 + \lambda_1\varepsilon^2_{t-1} + \ldots + \lambda_p\varepsilon^2_{t-p}\right]^{\frac{1}{2}}$$

where $\mathbf{X_t}$ is the matrix of explanatory variables (including lagged dependent variables), $\beta^{\mathbf{t}}$ is a row vector of coefficients, and u_t is a normally distributed, serially uncorrelated disturbance term with mean zero and unconditional variance of one. Also, u_t and ε_t are uncorrelated.

The unconditional variance becomes:

(A3.3) $$\mathrm{Var}(\varepsilon_t) = E(\varepsilon_t^2)$$

$$= E(u_t^2)E(\lambda_0 + \lambda_1\varepsilon^2_{t-1} + \ldots + \lambda_p\varepsilon^2_{t-p})$$

$$= 1(\lambda_0 + E(\lambda_1(\lambda_0 + \lambda_1\varepsilon^2_{t-2} + \ldots + \lambda_p\varepsilon^2_{t-2p})) + \ldots + E(\lambda_p(\lambda_0 + \lambda_1\varepsilon^2_{t-2p} + \ldots + \lambda_p\varepsilon^2_{t-2p})))$$

$$= \lambda_0\left[1 + (\lambda_1 + \ldots + \lambda_p)^1 + (\lambda_1 + \ldots + \lambda_p)^2 + (\lambda_1 + \ldots + \lambda_p)^n + \ldots\right]$$

$$\text{(A3.4)} \qquad = \frac{\lambda_0}{1-(\lambda_1+\ldots+\lambda_p)} \qquad \text{for } (\lambda_1 + \ldots + \lambda_p) < 1$$

So ordinary least squares is still the best linear unbiased estimator of equation 1 since the error term still has constant unconditional variance as mentioned by Kmenta (1986, P. 288) and Engle (1982, P. 995). However, efficiency can be improved by incorporating the conditional variance of the regression. (Engle [1982, p. 999]).

The conditional variance is:

$$\text{(A3.5) } var(\varepsilon_t | \varepsilon_{t-1,\ldots,}\varepsilon_{t-p}) = E(u_t^2 | \varepsilon_{t-1,\ldots,}\varepsilon_{t-p})E(\lambda_0 + \lambda_1\varepsilon_{t-1}^2 + \ldots + \lambda_p\varepsilon_{t-p}^2 | \varepsilon_{t-1}, \ldots, \varepsilon_{t-p})$$

$$= E(u_t^2 | \varepsilon_{t-1}, \quad , \varepsilon_{t-p})h_t$$

where $$h_t = \lambda_0 + \lambda_1\varepsilon_{t-1}^2 + \ldots + \lambda_p\varepsilon_{t-p}^2$$

To take account of the correction for the conditional heteroskedasticity, one may transform the OLS model as follows. Generalising Kmenta:

$$\text{(A3.6)} \qquad \mathbf{y}_t\left[\lambda_0+\lambda_1\varepsilon^2{}_{t-1}+\ldots+\lambda_p\varepsilon^2{}_{t-p}\right]^{-\frac{1}{2}}$$

$$= \alpha\left[\lambda_0+\lambda_1\varepsilon^2{}_{t-1}+\ldots+\lambda_p\varepsilon^2{}_{t-p}\right]^{-\frac{1}{2}} + \beta^{\mathbf{t}}\mathbf{X}_t[(\lambda_0 + \lambda_1\varepsilon_{t-1}^2 + \ldots + \lambda_p\varepsilon_{t-p}^2)^{-\frac{1}{2}}$$

$$+ \varepsilon_t\left[\lambda_0+\lambda_1\varepsilon^2{}_{t-1}+\ldots+\lambda_p\varepsilon^2{}_{t-p}\right]^{-\frac{1}{2}}$$

where the last term equals u_t by construction.

Knowledge of the distribution of the regressand $\mathbf{y}_t$ can be used to gain knowledge about the distribution of the error term ε_t *vía* change of variable technique. As Kmenta writes,

(A3.7) $$f(\mathbf{y}_t) = \left|\frac{du_t}{dy_t}\right| f(u_t)$$

Now since,

$$\mathbf{y}_t - \beta^t\mathbf{X}_t = u_t\left[\lambda_0+\lambda_1\varepsilon^2_{t-1}+\ldots+\lambda_p\varepsilon^2_{t-p}\right]^{-\frac{1}{2}}$$

then,

$$u_t = \mathbf{y}_t u_t\left[\lambda_0+\lambda_1\varepsilon^2_{t-1}+\ldots+\lambda_p\varepsilon^2_{t-p}\right]^{-\frac{1}{2}}$$

$$- \beta^t\mathbf{X}_t\left[\lambda_0+\lambda_1\varepsilon^2_{t-1}+\ldots+\lambda_p\varepsilon^2_{t-p}\right]^{-\frac{1}{2}}$$

and,

$$\frac{du_t}{d\mathbf{y}_t} = \left[\lambda_0+\lambda_1\varepsilon^2_{t-1}+\ldots+\lambda_p\varepsilon^2_{t-p}\right]^{-\frac{1}{2}}$$

so,

(A3.8) $$f(\mathbf{y}_t) = \left[\lambda_0+\lambda_1\varepsilon^2_{t-1}+\ldots+\lambda_p\varepsilon^2_{t-p}\right]^{-\frac{1}{2}} f(u_t)$$

Taking account of the above derivation and noting that the independent distributions of $\mathbf{y}_t$ can be summed logarithmically, the log-likelihood function becomes:

(A3.9) $$L = -\frac{1}{2}\sum_t \ln[\lambda_0 + \lambda_1(\mathbf{y}_{t-1} + \alpha - \beta^t\mathbf{X}_{t-1})^2 +\ldots+ \lambda_p(\mathbf{y}_{t-p} + \alpha - \beta^t\mathbf{X}_{t-p})^2$$

$$-\frac{n}{2}\ln(2\pi) - \frac{1}{2}\sum_t\left[\frac{(\mathbf{y}_t - \alpha - \beta^t\mathbf{X}_t)}{\lambda_0+\lambda_1(\mathbf{y}_{t-1}+\alpha-\beta^t\mathbf{X}_{t-1})^2+\ldots+\lambda_p(\mathbf{y}_{t-p}+\alpha-\beta^t\mathbf{X}_{t-p})^2}\right]$$

Estimation of the ARCH regression model is simplified if the necessary conditions for regularity and symmetry are satisfied. That is:

(A3.10) $\lambda_i \geq 0 \;\; \forall_i \quad 1,p$

(A3.11) $\sum_{i=1}^{p} \lambda_i < 1$

Equation (3.10) ensures that the predicted conditional variances $\hat{h}_t$ are always positive as noted in Engle (1982, p. 994). Equation (3.11) ensures that the process will not have infinite variance (Engle [1983, p. 288]). Given these conditions, one can estimate the variance equation separately from the mean regression equation "without asymptotic loss of efficiency." (Engle [1982, p. 996]). Engle (1982, pp. 997-998) proposes separate algorithms to improve the efficiency of the β and λ coefficients that can be done as iterative OLS procedures.

Testing for an ARCH process is straight forward, requiring the following procedure from Engle (1982, p. 1000). Estimate β by OLS; square the residuals from this initial estimation[21],. Run a

[21] Conditions 10 and 11 must be satisfied in order to undertake estimation. Before the introduction of Generalised ARCH, Engle (1982, p. 997 & p. 1002) suggested constraining the coefficients to be positive by squaring them as an effort to fulfil the first equation. This procedure was carried out by Domowitz & Hakkio (1985, pp. 58-59) in their exchange-rate estimation. Of course such action necessitated estimation by non-linear least squares. An alternative also suggested by Engle was to formulate the model with a linearly declining set of weights. The resulting variance model then only needed to be non-negative for two parameters. The second condition was more difficult to constrain *a priori* in this manner. See Hsieh (1987, p. 13) where his variance model of the British Pound and Japanese Yen suggest "that the effects of a large variance on future variances will be amplified, which is clearly undesirable."

regression of these squared residuals on an intercept and p lags of the regressand.[22] Then the following statistic is asymptotically equivalent to a LaGrange Multiplier test statistic.

(A3.12) $$TR^2 \sim \chi^2_p$$

where T is the number of observations, R^2 is the percentage variability explained by the regression, and χ^2_p is a chi square distribution with p degrees of freedom for a true null hypothesis of no ARCH.

Additions to ARCH have developed since Engle's seminal article. Bollerslev (1986) has generalised ARCH by allowing for past conditional variances in the variance model. This extension is analogous to adding moving average terms to an auto-regressive model. Specifically, a, say, G-ARCH(1,1) process would appear as,

(A3.13) $$\mathbf{y}_t = \alpha_0 + \beta^{\mathbf{t}}\mathbf{X}_t + \varepsilon_t$$

with variance modelled as,

(A3.14) $$h_t = \lambda_0 + \lambda_1\varepsilon^2_{t-1} + \gamma_1 h_{t-1}$$

But since

(A3.15) $$h_t \equiv E(\varepsilon^2_t | \psi_{t-1})$$ (being the conditional variance),

one may write,

(A3.16) $$\varepsilon^2_t = h_t + u_t$$

---

22 This procedure is carried out regardless of how the variance model is ultimately estimated.

which implies,

(A3.17) $$\varepsilon_t^2 = \lambda_0 + \lambda_1\varepsilon_{t-1}^2 + \gamma_1(\varepsilon_{t-1}^2 - u_{t-1}) + u_t$$

(A3.18) $$\varepsilon_t^2 = \lambda_0 + (\lambda_1 + \gamma_1)\varepsilon_{t-1}^2 + (u_t - \gamma_1 u_{t-1})$$

where $u_t - \gamma_1 u_{t-1}$ is a moving average process of order one.

Testing for G-ARCH is more complicated than for ARCH. Bollerslev (1986, p. 318) notes that there is no feasible general test for G-ARCH(p,q) as the null hypothesis would now include, say, the possibility of an ARCH(q) process. However, in this last instance, the LaGrange Multiplier "test for G-ARCH(r,q) and ARCH(q + r) alternatives coincide." Bollerslev (1986, p. 318). Estimation is also more difficult; Bollerslev (1986, p. 317) suggests use of the Berndt, Hall, Hall, and Hausman algorithm to obtain maximum likelihood estimates.

An important extension of autoregressive models is ARCH-in-Mean (ARCH-M) developed by Engle, Lilien, and Robins (1987) in which the variance of each observation also affects its mean value (p. 395). The equations would appear as:

(A3.19) $$\mathbf{y_t} = \alpha + \beta^{\mathbf{t}}\mathbf{X_t} + h_t\theta + \varepsilon_t$$

(A3.20) $$h_t = \lambda_0 + \lambda_1\varepsilon_{t-1}^2 + \ldots + \lambda_p\varepsilon_{t-p}^2$$

where

$$\varepsilon_t = \mathbf{y_t} - \alpha - \beta^{\mathbf{t}}\mathbf{X_t} - h_t\theta \quad \text{and}$$

θ is a parameter measuring the importance of variance in the mean equation.

The log likelihood function becomes:

$$\text{(A3.21)} L = -\frac{1}{2}\sum_t \ln[\lambda_0 + \lambda_1(\mathbf{y}_{t-1} + \alpha - \beta^{\mathbf{t}}\mathbf{X}_{t-1} - h_t\theta)^2 + \ldots + \lambda_p(\mathbf{y}_{t-p} + \alpha - \beta^{\mathbf{t}}\mathbf{X}_{t-p} - h_t\theta)^2$$

$$-\frac{n}{2}\ln(2\pi)$$

$$-\frac{1}{2}\sum_t\left[\frac{(\mathbf{y}_t - \alpha - \beta^{\mathbf{t}}\mathbf{X}_t - h_t\theta)}{\lambda_0 + \lambda_1(\mathbf{y}_{t-1} + \alpha - \beta^{\mathbf{t}}\mathbf{X}_{t-1} - h_t\theta)^2 + \ldots + \lambda_p(\mathbf{y}_{t-p} + \alpha - \beta^{\mathbf{t}}\mathbf{X}_{t-p} - h_t\theta)^2}\right]$$

If θ does not equal zero, then α, β, and θ must be estimated simultaneously with the λ parameters; the information matrix will not be block-diagonal as in the case of ARCH. Engle, Lilien, and Robins (1987, pp. 396-397) adopt the Berndt, Hall, Hall, Hausman algorithm to maximise the log likelihood function.

Further additives to ARCH are developed by Baba, Engle, Kraft, and Kroner (1987) which involve simultaneous estimation of systems of equations (known as Multivariate Simultaneous Generalised ARCH or MSG-ARCH). The paper develops the theoretical under-pinnings of the above, positing a parameterisation of the conditional covariance matricies guaranteeing positive definiteness. There is also discussion on methods of estimation making use of instrumental variables and limited information estimators.

DATA SOURCES

Data for ARCH Estimates of Exchange-Rate Volatility

The spot and 1 month forward exchange rates for the British pound, Japanese yen, and German deutschemark (day 7, 14, 21, and 28) are from the *Wall Street Journal.* "The New York selling rates apply to trading among banks in amounts of US$1 million and more, as quoted at 3:00 PM Eastern time by Banker's Trust Company..." The data alignment problem has been treated in a consistent manner. The spot transactions in foreign exchange markets are for the value date two business days following the transactions days. Also, n-day forward contracts are for delivery n-days after the spot value date; the relevant future spot rate for this forward contract is contracted two business days before the forward value date. If the delivery date falls on a holiday or weekend, it takes place the next business day (see Riehl and Rodriguez [1977]). To be a value date, it must be a business day in both countries. This requires a knowledge of all the holidays in all the countries in the study. The assumption of an American investor with access to the U.S. foreign exchange market on U.S. business days surmounts this problem; data adjustments are only necessary for weekends and U.S. holidays.

Table A3.1 presents variance estimates for the three currencies.

TABLE A3.1

WEEKLY EXCHANGE-RATE VARIANCE ESTIMATES: POUND (PP1HT), YEN (PY1HT), AND DEUTSCHEMARK (PM1HT)
7 June 1974 TO 28 September 1988 (days 7,14,21, and 28)

	obs	PP1HT	PY1HT	PM1HT
7 Jun '74	13	2.791701	2.968634	3.155323
	14	2.502492	2.719214	3.298038
	15	2.242596	2.471238	3.622268
	16	2.093151	2.269841	3.120492
	17	2.044683	2.071710	2.819970
	18	1.898426	1.994506	3.072114
	19	1.733959	1.893386	2.829476
	20	1.616580	1.756907	2.909858
	21	1.482289	1.929291	2.494508
	22	1.577743	2.528554	3.867633
	23	1.457804	2.332072	3.386896
	24	1.585107	2.132912	2.860436
	25	1.455638	1.965276	2.434238
	26	1.395821	1.813295	2.804858
	27	1.294334	1.696658	2.399608
	28	1.291891	1.757426	2.328782
	29	1.211912	1.620106	2.036176
	30	1.141406	1.527208	1.960325
	31	1.076142	1.433008	1.727118
	32	1.037375	1.333054	1.747173
	33	0.987154	1.242585	1.765234
	34	0.962580	1.184766	1.662648
	35	1.055440	1.178501	1.552604
	36	1.066925	1.112689	1.414369
	37	1.016348	1.060237	2.721425
	38	0.975808	1.002928	2.826752
	39	0.935134	0.964065	2.522136
	40	1.003756	0.918359	2.732687
	41	1.023037	0.886110	2.409697
	42	0.974887	0.868080	2.224317
	43	1.045896	0.836944	2.147562
	44	1.049668	0.806498	3.013799
	45	1.323208	0.968697	2.706522
	46	1.437069	0.982221	2.675771
	47	1.612234	0.966699	2.787216
	48	1.512110	1.142502	2.492328
	49	1.536367	1.196249	2.314005
	50	1.513811	1.123172	2.761631
	51	1.486660	1.102749	2.387855
	52	1.383313	1.043954	2.069020
	53	1.329739	1.180375	2.438188
	54	1.318386	1.108665	2.111005
	55	1.319307	1.056720	2.201813
	56	1.234802	1.044010	1.977358

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 May '75	57	1.182804	0.986045	1.770114
	58	1.111358	0.978328	2.038497
	59	1.201400	0.934699	1.841175
	60	1.134975	0.889222	1.681148
	61	1.097082	0.906407	1.512127
	62	1.040995	0.913636	1.422266
	63	1.121565	0.873465	1.350720
	64	1.171859	0.854528	1.283623
	65	1.605162	0.827632	1.208680
	66	1.725950	0.794971	1.917338
	67	1.692014	0.765541	2.129201
	68	1.776615	0.742707	3.029553
	69	1.621106	0.722226	3.416997
	70	2.621343	0.714294	2.969254
	71	2.357670	0.699073	2.521592
	72	2.115806	0.681172	2.229207
	73	1.912512	0.668515	2.063824
	74	1.840280	0.657438	1.816874
	75	1.700631	0.643919	1.721251
	76	1.782369	0.748441	1.949125
	77	2.040439	0.725759	1.891665
	78	1.891823	0.709950	2.391629
	79	1.717476	0.690334	2.070913
	80	1.637817	0.785775	2.253164
	81	1.602134	0.836657	1.966266
	82	1.469711	0.879778	1.817878
	83	1.477464	0.861303	1.808657
	84	1.389606	0.830028	2.304889
	85	1.297244	0.799146	3.138484
	86	1.211085	0.814571	2.719615
	87	1.136099	0.787514	2.323666
	88	1.071450	0.759448	2.826896
	89	1.063120	0.736643	2.560553
	90	1.059301	0.784600	2.205045
	91	1.010116	0.841835	1.944677
	92	0.965633	0.866444	1.764122
	93	0.969926	0.838219	1.604655
	94	0.930779	0.963304	1.475828
	95	0.897892	0.978482	1.669233
	96	0.872067	1.091420	1.522183
	97	0.854318	1.028204	1.420576
	98	1.866151	0.992917	1.421487
	99	2.173250	0.970171	1.304563
	100	1.969878	0.922875	2.250654
	101	1.803947	0.878999	2.190161
	102	2.609260	0.878216	1.918976
	103	2.334530	0.863913	1.732883
	104	2.191044	0.885495	1.553688

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 May '76	105	2.025596	0.860274	1.409976
	106	1.836141	0.833145	1.319338
	107	1.680297	0.799644	1.409875
	108	2.221660	0.772755	1.330624
	109	2.075465	0.746458	1.258315
	110	2.042412	0.725258	1.186396
	111	1.846767	0.716572	1.120838
	112	1.704102	0.701113	1.068574
	113	1.559336	0.817627	1.028056
	114	1.826812	0.786284	1.025579
	115	1.732340	0.986029	1.002403
	116	1.612636	1.989591	0.976196
	117	1.494364	2.558625	0.972787
	118	1.382456	2.342371	1.064977
	119	1.297039	2.135972	1.044614
	120	1.210797	2.055387	1.101065
	121	1.162297	2.283133	1.051694
	122	1.100304	2.112528	1.049837
	123	1.305830	1.938776	1.244900
	124	1.310025	1.855751	1.382808
	125	3.032340	1.771263	1.372860
	126	2.696093	1.633097	1.303182
	127	2.405064	2.009871	1.220224
	128	2.170225	1.876814	1.169263
	129	3.546379	1.750615	1.462559
	130	3.695193	1.617523	1.661289
	131	3.739579	1.493678	1.512993
	132	3.605831	1.437527	1.375856
	133	5.069299	1.357655	1.304915
	134	4.466580	1.264456	1.223237
	135	4.184864	1.186305	1.153927
	136	4.953316	1.114706	1.373219
	137	8.178988	1.171051	1.276513
	138	7.186203	1.101590	1.190815
	139	6.290392	1.038252	1.404916
	140	5.925598	0.993503	1.309911
	141	6.322850	0.967833	1.430725
	142	5.542357	1.031259	1.362502
	143	4.984715	1.393420	1.476397
	144	4.499059	1.357311	1.351350
	145	5.098236	1.275603	1.266780
	146	4.466017	1.271176	1.189660
	147	3.937060	1.201959	1.121171
	148	3.705751	1.219339	1.069876
	149	3.669743	1.244420	1.033353
	150	3.237012	1.400610	1.001361

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
21 Apr '77	151	2.867049	1.305742	1.023198
	152	2.624547	1.367813	0.991578
	153	2.497931	1.275375	1.022307
	154	2.235409	1.191261	1.025141
	155	2.011204	1.131949	1.063511
	156	1.879805	1.076810	1.039881
	157	1.793441	1.017120	1.005010
	158	1.640619	1.002892	0.985103
	159	1.504054	1.062738	0.982499
	160	1.396531	1.002888	0.963434
	161	1.385825	1.029709	0.944570
	162	1.288900	1.533389	1.687796
	163	1.206150	1.425126	1.704611
	164	1.142994	1.325775	1.628945
	165	1.397229	1.240209	1.515173
	166	1.316464	1.166433	1.510768
	167	1.231445	1.107208	1.952004
	168	1.152986	1.043473	1.741207
	169	1.095189	1.007310	1.661269
	170	1.059655	0.974107	1.576100
	171	1.006239	0.924108	1.426053
	172	0.965597	0.886956	1.314596
	173	0.932393	0.863338	1.230012
	174	1.054417	1.750172	1.440481
	175	1.029462	1.985003	1.491169
	176	0.981830	1.845002	1.358862
	177	0.989863	2.149196	1.304884
	178	1.248057	1.981264	1.238496
	179	1.177123	1.920312	1.185330
	180	1.109633	2.151510	1.206927
	181	1.056543	2.074827	1.349816
	182	1.028085	2.067305	1.910540
	183	1.087543	2.133474	2.011824
	184	1.405602	2.110104	1.793497
	185	1.528027	1.931177	1.742188
	186	1.513563	1.771292	1.916759
	187	1.459579	1.775860	1.815222
	188	1.349478	1.676467	1.617823
	189	1.368579	1.570104	1.463550
	190	1.345996	1.458940	1.364717
	191	1.253600	1.361667	1.270948
	192	1.281447	1.517945	2.544599
	193	1.206932	1.410104	2.446305
	194	1.133560	1.440260	2.108949
	195	1.362160	1.405534	2.204479
	196	1.307978	1.413940	1.930338

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 Apr '78	197	1.249242	2.875086	1.754097
	198	1.205328	2.611408	1.616847
	199	1.145490	2.393588	1.461138
	200	1.806903	3.074666	2.768490
	201	1.646490	2.807325	2.365373
	202	1.513943	2.563656	2.045493
	203	1.425019	2.427809	2.417418
	204	1.339072	2.211166	2.086454
	205	1.246923	2.023738	1.851500
	206	1.170193	2.081925	1.799435
	207	1.152011	2.494405	1.706787
	208	1.336097	3.316889	1.579644
	209	1.257334	3.164345	1.470951
	210	1.305287	3.128755	1.403291
	211	1.271099	2.850245	1.338412
	212	1.568459	2.954116	1.266332
	213	1.474356	3.645805	1.183396
	214	1.374028	3.492183	1.364002
	215	2.425979	4.036236	4.258217
	216	2.869445	4.584742	4.869338
	217	2.649368	5.243493	4.470789
	218	2.557315	4.768545	3.880246
	219	2.375501	4.282918	3.248802
	220	2.281486	4.392327	3.794513
	221	2.050469	4.169899	3.529288
	222	1.865005	3.851356	2.960192
	223	1.695324	3.736386	3.478248
	224	1.769777	4.035743	3.801152
	225	3.411997	3.845609	23.31351
	226	6.081045	6.195332	32.56570
	227	5.397837	5.906394	26.11267
	228	4.760685	5.989768	25.70720
	229	4.260983	6.317556	23.00040
	230	4.014153	5.655649	18.46771
	231	3.575560	5.081494	14.84614
	232	3.559898	4.560899	11.85162
	233	3.213403	4.102938	12.64788
	234	2.918420	3.762650	10.17514
	235	3.062456	3.639218	8.708984
	236	2.762302	3.283175	7.200161
	237	2.668601	3.465467	5.879401
	238	2.955857	3.995238	5.643703
	239	2.661123	4.628529	5.389042
	240	2.377690	4.303287	4.928113
	241	2.185663	3.882794	4.575438
	242	2.130346	3.768801	3.798156

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
21 Mar '79	243	1.931295	3.531525	4.309916
	244	1.752230	3.189911	3.579724
	245	1.617775	3.027211	3.024351
	246	2.011537	3.786607	2.733565
	247	1.819687	3.414160	3.155303
	248	1.689844	3.526042	2.747885
	249	1.677555	3.385103	2.345748
	250	1.775671	4.178819	2.104123
	251	1.826263	3.779882	2.080075
	252	1.665802	3.940190	1.872193
	253	1.563986	3.628206	1.657431
	254	1.443631	3.306908	1.531348
	255	1.941463	2.992519	1.437457
	256	2.350703	2.926770	3.085179
	257	2.285020	2.661060	2.634652
	258	2.275659	2.547113	2.297031
	259	2.363834	2.325650	2.010908
	260	2.871119	2.126939	1.773314
	261	2.818426	1.983432	1.582737
	262	4.867285	1.900056	1.518093
	263	4.418271	1.744893	1.383979
	264	4.052428	1.631378	1.337334
	265	3.643802	1.824556	1.249115
	266	3.372414	1.676900	1.590976
	267	4.766887	1.700866	1.546257
	268	4.180425	1.575270	2.503992
	269	3.769829	1.529248	2.407228
	270	3.348434	1.419984	2.167569
	271	2.964501	1.484914	2.413487
	272	2.685561	1.683532	2.344455
	273	3.337411	2.361650	2.039240
	274	2.970583	2.485610	1.943348
	275	2.966897	2.474744	1.861559
	276	3.307183	2.695443	1.668208
	277	2.941123	2.649580	1.592271
	278	2.615927	4.316399	1.467562
	279	3.190324	4.324508	1.589772
	280	2.888444	4.126657	1.479124
	281	2.643503	3.732102	1.402672
	282	2.910119	4.219960	1.526453
	283	2.698476	4.105587	1.491787
	284	2.449063	4.335196	1.525140
	285	2.338663	3.986527	1.420832
	286	2.907078	4.071045	1.320120
	287	2.598385	3.679563	1.225353
	288	2.403620	3.465425	1.233787

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 Mar '80	289	2.155143	3.217874	1.284309
	290	2.186318	3.084744	2.076812
	291	2.344617	2.800667	2.551324
	292	2.245701	2.543175	3.143739
	293	2.035843	2.323640	4.398124
	294	2.423446	5.406089	5.946397
	295	3.251057	6.044321	11.01310
	296	3.379517	5.478224	9.154510
	297	3.346686	5.747019	7.995388
	298	3.039772	7.521107	6.679411
	299	2.701273	6.732706	5.590518
	300	2.675424	6.423474	4.636920
	301	2.606891	5.748187	3.835679
	302	2.328799	5.631325	3.268520
	303	2.090835	5.110410	2.922200
	304	1.901212	4.608475	2.513216
	305	1.791732	4.144346	2.165681
	306	2.203712	3.750419	2.308251
	307	2.005080	3.456523	2.044660
	308	1.831041	3.123622	1.913183
	309	1.665990	3.834466	1.881926
	310	1.572162	3.490428	2.006696
	311	1.444371	3.151415	1.785124
	312	1.341120	2.851462	1.729505
	313	1.324762	4.359641	1.574404
	314	1.619388	4.143272	1.459944
	315	1.494679	4.176902	1.335189
	316	1.430910	4.118168	1.238927
	317	1.327860	3.745641	1.445056
	318	1.320199	3.535118	1.322834
	319	1.268064	3.201051	1.419545
	320	1.518152	2.895315	2.161380
	321	1.429518	3.200044	2.451844
	322	1.345773	2.946695	3.720333
	323	1.256234	2.681337	3.850203
	324	1.603284	2.435357	3.212583
	325	1.494734	2.289542	2.918339
	326	1.404764	2.282459	2.779786
	327	1.345226	2.083387	4.058375
	328	1.407588	2.170401	4.356641
	329	1.313345	2.071811	3.614621
	330	1.537943	2.168363	3.026940
	331	1.415062	2.184214	3.449300
	332	1.371492	2.279120	3.082029
	333	1.349476	2.311108	5.556021
	334	2.311061	2.327950	5.565716
	335	2.640041	2.383166	7.035717

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
28 Feb '81	336	2.465580	2.174672	9.279846
	337	5.527470	1.990193	7.746037
	338	4.940670	2.166880	6.276156
	339	4.741945	3.040298	6.034368
	340	4.232078	3.912871	4.964943
	341	3.747200	3.543305	4.303512
	342	3.581314	3.519053	3.578035
	343	3.370602	3.177067	3.744855
	344	3.008192	3.546336	3.905565
	345	2.681864	3.585996	3.399379
	346	3.118934	3.949939	5.525492
	347	3.081210	3.719118	4.675553
	348	2.848999	3.535842	4.880561
	349	2.552455	3.327265	4.055725
	350	9.183753	3.413006	5.612443
	351	8.062778	3.264742	4.737263
	352	7.015973	2.953782	3.966026
	353	6.377175	2.825038	3.322408
	354	5.834061	2.796887	3.165240
	355	5.706904	2.618146	2.681486
	356	5.910476	2.981256	3.565792
	357	5.331077	3.096394	3.151313
	358	5.546194	2.954307	3.587405
	359	4.909925	2.703691	3.046891
	360	6.885179	3.309089	3.956174
	361	6.900121	3.030073	3.487067
	362	6.016184	2.817044	4.811462
	363	6.285022	2.613340	4.201479
	364	5.680575	3.446338	6.559850
	365	5.710358	6.921309	7.590040
	366	8.671726	6.271660	11.92464
	367	7.713084	5.642460	9.558342
	368	9.203581	5.867956	12.04137
	369	8.807832	5.262457	10.25392
	370	8.170070	4.782228	9.056394
	371	7.544124	4.404518	7.302136
	372	6.788046	5.814637	6.874504
	373	7.573673	5.231847	7.483781
	374	6.753728	5.186847	6.962419
	375	7.543789	4.683922	5.920722
	376	6.551188	4.209155	4.852238
	377	5.825130	3.843004	4.074812
	378	5.307379	3.653811	3.388496
	379	5.274030	3.310834	3.412941
	380	4.608874	3.212304	2.875605

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 Feb '82	381	4.046633	3.430544	2.652687
	382	3.728848	3.651098	2.584946
	383	3.287630	3.627895	2.583647
	384	2.931175	3.720544	2.324865
	385	2.957438	3.811725	2.171654
	386	2.706317	3.451626	2.216936
	387	2.637297	3.234831	2.044164
	388	2.394231	4.087321	1.953969
	389	2.176419	3.708269	2.500661
	390	2.466837	3.844075	2.173290
	391	2.387387	3.503460	1.953144
	392	2.147644	3.380349	1.735187
	393	1.949329	3.857677	1.581749
	394	2.620671	3.485685	4.062296
	395	2.340538	3.155327	3.381435
	396	2.588755	3.141973	2.916189
	397	2.356551	3.232472	3.743447
	398	2.114536	3.821018	3.615458
	399	2.073141	3.612772	3.077809
	400	2.093826	3.991375	3.792448
	401	1.939503	3.626071	3.375886
	402	2.201993	3.627459	3.218573
	403	2.227259	3.575761	3.169633
	404	2.152900	3.447143	3.262178
	405	1.954403	3.404649	3.152319
	406	2.152796	3.603788	2.908411
	407	1.954045	3.325458	2.476024
	408	2.398256	3.992198	2.688053
	409	2.175835	3.787755	2.517729
	410	1.995854	3.458750	2.164746
	411	1.857879	3.403581	2.035944
	412	1.694477	3.398026	1.876823
	413	1.566635	3.143601	1.678118
	414	1.445952	2.941577	1.508547
	415	1.368469	2.762884	1.393423
	416	1.376907	3.182428	1.490821
	417	1.319077	2.955087	1.398271
	418	1.493773	2.677546	1.522557
	419	1.378813	3.235843	1.384814
	420	1.932995	4.344648	1.504153
	421	1.992238	4.548267	1.770106
	422	2.263726	5.194573	3.869318
	423	2.088892	4.774597	3.256430
	424	1.906394	4.326507	2.891759
	425	1.808826	4.748578	2.893673
	426	1.792653	4.548405	2.621642

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
21 Jan '83	427	1.847423	4.090182	2.247705
	428	1.705236	4.499895	5.047207
	429	2.029681	4.058662	4.219765
	430	1.928526	3.908676	4.003272
	431	1.836429	3.798891	4.042611
	432	1.678419	3.543650	3.563622
	433	1.793495	4.084301	3.642461
	434	1.672614	3.784253	3.556292
	435	1.674614	3.411475	3.061768
	436	3.100206	3.663948	3.108275
	437	2.778091	3.364260	2.630338
	438	3.468312	3.039803	2.276566
	439	3.590724	2.796457	2.245096
	440	3.228883	2.883215	1.951143
	441	3.183665	2.698771	1.724973
	442	2.855157	2.489114	1.541846
	443	2.679131	2.441497	1.405462
	444	2.396609	2.419710	1.520765
	445	3.811913	2.247577	1.510726
	446	4.240598	2.414947	2.957023
	447	5.041499	2.421655	2.510833
	448	4.474817	2.798270	2.473934
	449	3.937084	2.594053	2.147340
	450	3.519066	2.425383	2.131719
	451	3.217745	2.209157	1.960072
	452	2.853383	2.043387	1.727195
	453	2.550311	1.892780	2.021408
	454	3.552929	1.911835	2.349199
	455	3.138859	1.884043	2.708512
	456	3.375375	1.753390	2.993224
	457	3.078477	1.629128	2.549145
	458	2.841922	1.504143	2.288540
	459	2.551234	1.422195	1.991973
	460	2.293892	1.339526	1.787278
	461	2.061255	2.066370	1.948914
	462	1.920398	2.423921	3.429738
	463	1.766863	2.278919	3.621957
	464	1.616202	2.079206	3.093221
	465	1.484394	1.904604	2.797183
	466	1.444913	2.373484	3.637968
	467	1.347805	2.446008	3.238271
	468	1.568699	2.244940	3.307664
	469	1.460973	2.068810	2.821708
	470	1.507775	1.958763	2.452007
	471	1.677097	1.833412	2.290619
	472	1.542887	1.685394	2.215035

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 Jan '84	473	1.514715	1.579380	2.168773
	474	1.753342	1.474570	2.547518
	475	1.606387	1.371466	2.234425
	476	1.577341	1.321344	2.233478
	477	1.448807	1.231552	1.950935
	478	1.475673	1.153387	2.804901
	479	1.507965	1.087943	2.854933
	480	1.580015	1.028395	2.443216
	481	2.486174	0.972181	4.403203
	482	2.283740	2.953493	4.217593
	483	2.230705	2.788396	3.580869
	484	2.355437	2.549523	3.580374
	485	2.115113	2.434402	3.069839
	486	1.950883	2.483433	2.817142
	487	1.768541	2.280022	2.411441
	488	1.634552	2.129101	2.099559
	489	2.048476	2.052356	3.396875
	490	1.866060	2.176294	3.545979
	491	1.696202	2.089158	2.986372
	492	1.555387	1.943301	2.559589
	493	1.609096	1.820832	2.241069
	494	1.745677	1.703247	2.231964
	495	1.697050	1.571196	2.323899
	496	1.736883	1.504528	2.247938
	497	1.803406	1.617980	2.201537
	498	2.413636	1.916821	2.559829
	499	2.174001	1.769640	2.199716
	500	1.967343	1.760863	1.973720
	501	1.961721	1.629996	2.191258
	502	1.777381	1.510224	1.918119
	503	1.704985	1.477727	1.714255
	504	1.580055	1.373298	1.553825
	505	1.461695	1.315421	1.414932
	506	1.931675	1.796019	2.529185
	507	2.081949	1.689143	3.569638
	508	2.027336	1.751567	3.053134
	509	2.048159	1.842402	2.743706
	510	1.977372	1.692814	2.876652
	511	2.139316	1.633139	3.698124
	512	2.711547	1.512419	3.248080
	513	2.476334	1.506354	2.876758
	514	6.580762	1.661567	4.760853
	515	5.981059	1.614129	4.082660
	516	5.859606	1.625837	4.016299
	517	6.552173	1.518571	3.948151
	518	5.759338	1.630091	3.454488

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
21 Dec '84	519	5.092260	1.507558	2.951767
	520	4.572207	1.415937	2.726585
	521	4.487318	1.460280	2.405606
	522	4.280618	1.920768	2.489476
	523	4.596871	1.762053	2.173467
	524	4.229084	1.658406	1.911340
	525	3.821626	1.529980	1.779231
	526	3.366724	2.001837	2.882498
	527	3.169343	1.841017	2.743698
	528	2.962250	1.707830	3.072555
	529	2.638897	1.607451	2.602960
	530	2.639714	1.486026	2.533839
	531	2.972070	1.392353	2.206571
	532	13.31192	2.119087	8.296161
	533	12.11516	1.949265	7.284092
	534	11.11706	1.791199	5.949374
	535	14.22677	1.824968	6.920601
	536	12.45164	1.773965	6.463503
	537	16.07640	2.238708	10.20835
	538	13.96426	2.084350	8.228907
	539	14.27513	2.009923	7.712806
	540	12.47324	1.938085	6.512861
	541	10.88863	1.784106	5.350068
	542	9.812413	1.881753	5.151060
	543	8.540137	1.731712	4.426623
	544	7.437333	1.602626	3.761931
	545	7.342991	1.500437	4.228103
	546	6.731841	1.471176	3.715854
	547	8.063718	1.871160	4.635315
	548	6.992693	1.731086	3.843832
	549	6.600550	1.634333	4.444362
	550	8.664809	1.521727	3.692930
	551	8.280262	1.417272	3.127635
	552	7.183785	1.316686	2.691143
	553	6.262133	1.264724	2.380895
	554	6.639755	1.540394	5.132584
	555	6.689478	1.520163	5.312173
	556	7.270873	1.527137	6.541375
	557	8.224316	8.218947	10.61422
	558	7.426978	7.696842	10.28856
	559	6.894886	6.882670	8.697719
	560	6.165820	6.204513	7.075256
	561	5.462383	5.572551	5.948604
	562	4.977713	6.390309	5.633349
	563	4.356200	5.753963	4.622893
	564	3.830585	5.396891	3.833699

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 Dec '85	565	3.748347	4.841504	3.466046
	566	4.512577	4.794116	3.573421
	567	6.169985	4.329072	2.994158
	568	5.591208	3.934006	2.540836
	569	4.988957	3.549532	2.396502
	570	4.573216	3.205918	2.715503
	571	4.017763	2.911279	2.441182
	572	4.443198	2.660072	2.112154
	573	3.957237	3.355518	2.550645
	574	3.496605	3.320749	2.193360
	575	3.594623	5.841537	3.953586
	576	3.546237	5.273366	3.550446
	577	3.357465	15.38342	3.835974
	578	3.648855	22.99092	3.293861
	579	3.280482	20.75454	2.908001
	580	3.727863	18.43617	2.536428
	581	3.913045	24.94950	6.648752
	582	3.502682	22.54452	5.905321
	583	3.554395	20.12188	7.683406
	584	3.276174	18.84781	8.933327
	585	4.342925	17.08110	7.516027
	586	3.813466	17.12357	6.118702
	587	3.390252	15.24184	5.011581
	588	3.856711	16.13527	7.709309
	589	3.475260	15.21944	6.468306
	590	3.317067	14.23315	7.843011
	591	3.091747	12.68462	6.357206
	592	3.401978	11.71198	6.111663
	593	3.613136	10.45467	6.052905
	594	3.277274	11.88339	5.023080
	595	4.154766	11.02586	4.189271
	596	3.695869	11.00324	4.847171
	597	3.530845	10.13204	3.997451
	598	3.124377	9.051162	4.294950
	599	3.460453	8.104661	3.731109
	600	3.148669	7.242867	3.996896
	601	3.017539	6.985737	3.371695
	602	3.005778	6.252981	2.848001
	603	2.742193	5.629788	2.646953
	604	2.479875	5.214970	5.157264
	605	3.006183	4.821020	5.306792
	606	2.669813	4.352558	4.981452
	607	2.405685	3.977944	4.464823
	608	2.188471	3.987485	4.040447
	609	2.007312	4.161142	3.433583
	610	1.889227	4.638184	3.839137
	611	1.736063	4.373718	4.146826
	612	1.584212	4.584984	3.652426

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 Dec '86	613	1.743368	4.522150	5.613199
	614	1.630794	4.067567	4.876781
	615	1.498115	3.865411	4.851203
	616	1.391993	3.487346	4.143199
	617	1.738837	3.162022	4.312904
	618	1.767108	3.798856	4.467837
	619	2.271970	4.199881	6.573326
	620	2.146592	3.892180	5.352870
	621	2.163846	3.917224	6.754231
	622	2.253511	3.888569	5.920483
	623	2.216314	3.561980	5.267298
	624	2.012611	3.257608	4.464227
	625	1.875093	2.947819	3.867116
	626	3.272907	2.699772	4.156343
	627	3.068573	2.462536	5.679254
	628	3.263436	2.352832	5.203136
	629	2.890498	2.818289	4.289090
	630	2.709975	2.837694	4.022818
	631	2.644919	3.202530	3.357553
	632	2.363457	2.949380	2.959201
	633	2.308112	2.826341	2.602834
	634	2.360212	2.651222	3.237787
	635	2.127953	2.584781	3.218747
	636	1.921228	2.351789	2.811164
	637	2.904459	2.706231	3.374613
	638	2.583455	2.463899	2.990433
	639	2.588528	2.331360	2.656538
	640	3.112310	2.125954	2.476094
	641	2.775314	2.074474	2.161858
	642	2.479118	2.670385	1.909047
	643	2.274462	2.634959	2.006371
	644	2.052263	2.399206	1.803291

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
7 Aug '87	645	1.872276	2.248808	1.630803
	646	2.424860	2.207585	1.827713
	647	2.329771	2.032098	1.625997
	648	3.449116	4.901055	3.336326
	649	3.051472	4.871043	2.807818
	650	3.102535	4.783784	2.898863
	651	3.007644	4.652476	2.835697
	652	2.783640	4.200024	2.445553
	653	2.506228	4.017929	2.171092
	654	2.253919	3.620085	1.942635
	655	2.139774	4.030024	1.857973
	656	2.008520	4.756836	1.979066
	657	4.750991	5.684549	5.857350
	658	5.546766	6.181867	7.493031
	659	4.961307	5.655154	6.265172
	660	4.406961	5.072712	5.161531
	661	3.943190	4.586047	4.244315
	662	3.502893	4.436076	3.579745
	663	4.247502	5.560862	4.957375
	664	3.731869	5.003163	4.084666
	665	3.398826	4.900527	3.682844
	666	3.764488	6.329348	4.505991
	667	3.363885	5.885188	3.852394
	668	3.094783	5.292895	3.696723
	669	3.098947	4.956961	3.322887
	670	2.767316	4.471673	2.907421
	671	2.777878	5.244187	2.960831
	672	2.656800	4.796417	2.639709
	673	2.406044	4.317514	2.264289
	674	3.629480	4.202574	2.424283
	675	3.477145	3.782204	2.108935
	676	3.169556	3.433284	2.082768
	677	2.981386	3.478332	2.066718
	678	2.889055	3.173413	1.875570
	679	2.605895	2.974916	1.680263
	680	2.750509	2.705408	1.557099
	681	2.771632	2.636294	1.793422
	682	2.490087	2.527725	1.617962
	683	2.453835	2.374127	1.604541
	684	2.340039	2.484912	1.499943
	685	2.142427	2.475880	1.887375
	686	2.460912	2.305654	1.824970
	687	2.716774	2.200689	2.815570
	688	2.480356	2.140476	2.398681
	689	5.036329	4.903550	5.034231
	690	4.416000	4.526314	4.142040
	691	4.187702	4.082942	3.818617

TABLE A3.1 (Cont.)

	obs	PP1HT	PY1HT	PM1HT
28 Jul '88	692	3.980525	3.791327	3.219171
	693	3.633884	3.417756	2.878939
	694	3.874108	3.650395	3.337273
	695	3.661569	3.349886	2.989580
	696	3.359004	3.062872	2.851908
	697	2.975423	2.783207	2.915141
	698	2.864640	2.531621	2.749683
	699	3.044916	2.382841	2.793819
28 Sept '88	700	2.734242	2.171314	2.381696

CHAPTER FOUR

4. Pass-Through Estimation

Theory developed in Chapter Two combined with the exchange-rate volatility estimates of Chapter Three provide the requisite backdrop for estimating the basic pass-through equation. Recall that the static model developed in Chapter Two (with slightly modified notation) is:

$$P_{m,t} = \alpha_0 + \alpha_1(p_t^* - E_{t-1}s_t) + (1 - \alpha_1)p_{d,t} + \alpha_2\sigma_{u,t}^2 \quad (4.1)$$

where:

p_t^* = foreign marginal costs.

$p_{m,t}$ = Import price expressed in U.S. currency.

$p_{d,t}$ = U.S. domestic price.

s_t = spot exchange-rate: foreign currency per domestic currency (U.S. dollar).

$\sigma_{u,t}^2$ = variance of the forecast error in s_t. i.e.

$$\sigma_{u,t}^2 \equiv E_{t-1}(s_t - E_{t-1}s_t)^2$$

4.1 Recasting Equation 4.1 into Purchasing Power Parity Form

Several changes are necessary before equation (4.1) can be estimated. Firstly, the equation must be expressed in terms of observable variables. Specifically a relationship between s_t and $E_{t-1}s_t$ is defined with the assumption of rational expectations:

$$s_t = E_{t-1}s_t + \varepsilon_t$$

That is, the spot exchange rate is equal to what agents expect it to be last period, plus a random forecast error ε_t.

The above equation can be rearranged conveniently as:

$$E_{t-1}s_t = s_t - \varepsilon_t$$

which can then be substituted into equation (4.1) to obtain:

(4.2) $$P_{m,t} = \alpha_0 + \alpha_1(p_t^* - s_t) + (1 - \alpha_1)p_{d,t} + \alpha_2\sigma_{u,t}^2 + \alpha_1\varepsilon_t$$

Notice that the explanatory variable s_t and the error term $\alpha_1\varepsilon_t$ are contemporaneously correlated. Estimation by Ordinary Least Squares would be biased and inconsistent. Method of instrumental variables could alleviate this situation but would do so at the expense of less precise coefficient estimates. An alternative, used here, is to recast equation (4.2) into Purchasing Power Parity (PPP) form so that the spot exchange rate s_t is on the left hand side. The PPP form also allows comparison with findings of Frenkel (1981) and Hakkio (1984), as well as other authors who have investigated the relationship between prices and exchange rates. Equation (4.2) may be rearranged as:

(4.3) $$s_t = \beta_0 + (p_t^* - p_{d,t}) + \beta_1(p_{d,t} - p_{m,t}) + \beta_2\sigma_{u,t}^2 + \varepsilon_t$$

Where:

$$\beta_0 = \left[\frac{\alpha_0}{\alpha_1}\right], \beta_1 = \left[\frac{1}{\alpha_1}\right] > 1 , \beta_2 = \left[\frac{\alpha_2}{\alpha_1}\right], \ \sigma_{u,t}^2 = E_{t-1}\left[\varepsilon_t^2\right],$$

The coefficient on the first explanatory variable of equation (4.3) is unity because the coefficients on foreign marginal costs ($p_t^* - s_t$) and domestic prices ($p_{d,t}$) in equation (4.2) sum to one. This is a consequence of the implicit linearly homogeneous profit function discussed in Chapter Two; optimal import price rises for proportionate increases in $p_{d,t}$ and p_t^*.

4.2 Estimation using Aggregate Data

The United States is the 'domestic' country whilst three major industrialised countries (United Kingdom (UK), Japan, and the Federal Republic of Germany (FRG)) exporting goods to the United States comprise the 'foreign' countries. Exports from these countries to the United States are mostly heterogeneous manufactured goods. The pass-through equation derived in Chapter Two specifically addresses these types of goods as it is premissed on price-setting behaviour by exporters.

Aggregate quarterly data (generally from *IFS Statistics* and *Survey of Current Business* -- see Appendix A for details) from 1974:3 to 1988:1 (53 observations) comprise the sample period.[23] Several reasons explain the exclusion of prior years. Firstly, the Bretton Woods system fell apart by March 1973, being replaced with the present day floating exchange-rate system; Estimation would not be meaningful under the fixed exchange-rate regime prior to 1973. It is also likely that for most of the first two years of floating exchange-rates, agents spent time adjusting to the new system. Secondly, wage and price controls were implemented under different phases of the US President Nixon's economic policies. As Woo (1984, p. 518) has pointed out, these phases may bias the parameters of the structural equations.

[23] Similar data have been used in other pass-through studies such as Mann (1986 & 1987), Baldwin (1988), Krugman & Baldwin (1987) and Woo (1984). Baldwin (January 1988, pp. 3-4) mentions how results using aggregate data can partially explain the persistence of the US trade deficit in discussing his models. The results here have the added feature of yielding a pleasing micro explanation of exchange-rate pass-through.

Variables of equation (4.3) for the three countries are as follows. The dependent variable (s_t) is the average quarterly spot rate of foreign currency per US dollar. Period averages seem more reasonable than using end-of-quarter figures since exporters ship goods throughout the period. Foreign marginal costs (p_t^*) are wholesale price indices of the respective foreign countries as is the US domestic price ($p_{d,t}$). These indices provide uniformity in comparing results across countries.[24]

The US import price variable ($p_{m,t}$) used is a Divisia index whose construction is outlined in the appendix to this chapter. The following categories of imports are excluded from the index. 1.) Food, feeds, and beverages; 2.) Petroleum products; and 3.) Automobiles. One would not expect the structural relationship implied by equation (4.3) to hold for these excluded sectors. As Woo (1984, pp. 515-516) mentions, the world oil industry had been effectively cartelised during most of this period by OPEC (which sets price in US dollars). Thus any relationship between imported oil prices and exchange-rate change and variance is broken.

At the opposite extreme is the perfectly competitive agricultural sector. Again, as Woo (1984, pp. 515-516) notes, exchange-rate pass-through is probably larger for these goods than for manufactured products.[25] Additionally, commodity futures markets are available for agricultural commodities which is not accounted for in the model.

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[24] Other indices were tried such as the respective GDP deflators, consumer price indices and unit labour values. Results with these indices were less precise than with the wholesale price indices.

[25] Specifically, Woo (1984, pp. 515-516) writes:

> If the US market is only a small part of the global market, it may be appropriate to think of these products as having world price fixed in terms of a basket of currencies and of each country as being a price-taker. Then the degree to which exchange rate changes are passed through should be larger for agricultural products than for manufactured goods.

Automobiles are affected significantly by voluntary export restraints (VERs) and quotas and therefore would not be expected to exhibit the same degree of pass-through as other manufacturers.[26] As a rough approximation, one finds that the combined importance of the excluded goods account for an average 45% of total US imports, leaving 55% to be explained by the model.[27]

The last variable of equation (4.3) is the estimate of exchange-rate variance ($\sigma^2_{u,t}$) which is obtained from ARCH estimates in Chapter Three. The estimated coefficient α_2 can be either negative or positive as discussed in Chapter Two, section 2.3.

4.3 Dynamic Specification: The L.S.E. Approach

Theory seldom provides a precise dynamic specification for estimation; equation (4.3) in its static form is no exception. A search for the correct dynamic specification begins with an "unrestricted" model that nests alternative "restricted" models. The restricted models are then subjected to quasi-likelihood ratio tests. The most parsimonious representation that adequately models the process is selected on the basis of these tests. An autoregressive-distributed (AD(1,1)) model as defined by Hendry (1980) describes the unrestricted specification in levels:

$$(4.4) \quad s_t = \gamma_1 + \gamma_2(p^*_t - p_{d,t}) + \gamma_3(p^*_t - p_{d,t})_{t-1} + \gamma_4(p_{d,t} - p_{m,t}) + \gamma_5(p_{d,t} - p_{m,t})_{t-1} + \gamma_6 s_{t-1} + \gamma_7\sigma^2_{u,t} + \gamma_8\sigma^2_{u,t-1} + v_t$$

[26] Ideally textiles and steel should be excluded as well. Unfortunately no specific price indices for these items were available which prevented excluding them from the Divisia index.

[27] Figure based on the average of the sample period 1974.3 to 1988.1. The relative importance of the excluded goods ranged from 46% to 64% with a standard deviation of 5.24%.

An obvious dynamic specification to test is the Cochrane-Orcutt correction for first-order serial correlation--i.e. where the error term ε_t from the static model follows

$$\varepsilon_t = \rho\varepsilon_{t-1} + v_t$$

where, v_t is white noise.

Both Hendry (1980) and Hoover (1988, p. 126) show how one can restrict equation (4.4) to obtain an equivalent Cochrane-Orcutt correction. Imposing the common factor restrictions, $\gamma_3 = -\gamma_2\gamma_6$, $\gamma_5 = -\gamma_4\gamma_6$, and $\gamma_8 = -\gamma_7\gamma_6$ results in:

$$(4.5) \qquad s_t = \gamma_1 + \gamma_2(p_t^* - p_{d,t}) + -\gamma_2\gamma_6(p_t^* - p_{d,t})_{t-1} + \gamma_4(p_{d,t} - p_{m,t})$$

$$+ -\gamma_4\gamma_6(p_{d,t} - p_{m,t})_{t-1} + \gamma_6 s_{t-1} + -\gamma_7\gamma_6\sigma_{u,t}^2 + v_t$$

where γ_6 is the extent of first-order autocorrelation ρ.

Prices and the exchange rate are determined simultaneously, causing results obtained by OLS to be biased and inconsistent. Estimation by instrumental variables (IV) and/or three stage least squares (3SLS) overcomes this difficulty. The problem of selecting the "correct" instruments which are highly correlated with the regressors but uncorrelated with the error term is always a thorny issue. The approach here is to use the exogenous variables from the equation (Constant and $\sigma_{u,t}^2$) along with lagged values. Lagged endogenous variables are also included ($(p_t^* - p_{d,t})_{t-1}$, $(p_{d,t} - p_{m,t})_{t-1}$, and s_{t-1}). Hakkio (1984, p. 271) suggests including instruments meant to "represent the exogenous variables of any asset market theory of the exchange rate." These variables include both current and lagged values of money (m1) and real GDP (or GNP) for the US, UK, Japan, and FRG. Finally time and time-squared are included since the levels of the price variables are heavily trended.

Equation (4.5) was estimated for Great Britain, Japan, and Federal Republic of Germany (FRG). Quasi-Likelihood Ratio (QLR) tests were computed using the relevant country's unrestricted model as maintained hypothesis.[28] Both Great Britain and FRG yield chi-squared statistics (with three degrees of freedom) of 13.9 and 18.5 respectively. Clearly these values indicate rejection of the Cochrane-Orcutt specification at the ten per cent level of significance. Japan, on the other hand, yields a chi-squared statistic of 4.0 which fails to reject the restriction even at the twenty per cent significance level.

The unfavourable results for Great Britain and FRG necessitate further exploration of the dynamic process behind equation (4.3). Hendry *et al* (1984, p.1070) suggest remoulding the unrestricted model in an equivalent difference-level form which would nest an error correction mechanism (ECM) as well as a simple difference specification. Advantages of this type of specification include retaining long-run information but circumventing "the most basic 'spurious' regressions problem" [Hendry (1984, p.1070)]. Indeed raw exchange rate data are well-known to be nonstationary (i.e. have unit roots) as noted in Meese and Singleton (1982). Hypothesis testing in

[28] Use of a quasi-likelihood ratio test (TSP User's Guide, version 4,1. pp. 59-60) afforded comparisons between the above models. The test used is as follows:

$$\text{Test} = n \frac{(QDR\text{-}QD1)}{s^2}$$

Where,
QDR is the value of the minimum distance criterion (E^tHH^tE) for the null hypothesis whilst,
QD1 is its value for the alternative hypothesis (i.e. the "unrestricted" regression).
s^2 is the standard error, squared of the unrestricted regression.
n is the number of observations.
Test $\sim\chi^2(k)$ where k is the number of restricted parameters.
This test is appropriate for estimation by instrumental variables.

the presence of unit roots can lead to misleading results as pointed out in Stock (1987). Equation (4.4) reformulated would appear as:

(4.6) $$\Delta s_t = \gamma_2\Delta(p_t^* - p_{d,t}) + \gamma_3(p_t^* - p_{d,t})_{t-1} + \gamma_4\Delta(p_{d,t} - p_{m,t}) + \gamma_5(p_{d,t} - p_{m,t})_{t-1} + \gamma_6 s_{t-1} + \gamma_7\sigma^2_{u,t} + \gamma_8\sigma^2_{u,t-1} + v_t$$

An ECM specification is easily nested within the above model as:

(4.7) $$\Delta s_t = \gamma_2\Delta(p_t^* - p_{d,t}) + \gamma_3[(p_t^* - p_{d,t})_{t-1} - s_{t-1}] + \gamma_4\Delta(p_{d,t} - p_{m,t}) + \gamma_5(p_{d,t} - p_{m,t})_{t-1} + \gamma_7\sigma^2_{u,t} + v_t$$

An advantage of the ECM is that it allows short-run adjustment of regressors to their respective steady-state values. Pass-through theory derived in Chapter Two intimates that the long-run relationship between the exchange-rate and $(p_t^* - p_{d,t})$ should be unity; it imparts no information about the nature of short-run deviations from that relationship. Likewise theory dictates a greater than unity long-run relationship between s_t and $(p_{d,t} - p_{m,t})$. Again information about short-run deviations is absent. Thus, for the short run, the ECM "measures the 'error' in the previous period and agents 'correct' their decision about (s_t) in light of this *initial disequilibrium*" [Hendry (1980, p. 19)].

Equation (4.7) can be re-expressed to highlight the feedback effect of the EC terms on the exchange rate.

(4.8) $$\Delta s_t = \gamma_2\Delta(p_t^* - p_{d,t}) + \gamma_4\Delta(p_{d,t} - p_{m,t}) +$$

$$\gamma_3\left[(p^*_{t-1} - p_{d,t-1} - s_{t-1}) + \left[\frac{\gamma_5}{\gamma_3}\right](p_{d,t-1} - p_{m,t-1}) + \left[\frac{\gamma_7}{\gamma_3}\right]\sigma^2_{u,t}\right] + v_t$$

or,

(4.9) $$\Delta s_t = \gamma_2\Delta(p^*_t - p_{d,t}) + \gamma_4\Delta(p_{d,t} - p_{m,t}) + \gamma_7\Delta\sigma^2_{u,t} +$$

$$\gamma_3\left[-s_{t-1} + (p^*_{t-1} - p_{d,t-1}) + \left[\frac{\gamma_5}{\gamma_3}\right](p_{d,t-1} - p_{m,t-1}) + \left[\frac{\gamma_7}{\gamma_3}\right]\sigma^2_{u,t-1}\right] + v_t$$

The final bracketed term of equation (4.9) groups together components of the error-correction mechanism. Intuition is gained by examining changes in individual variables. For example suppose that foreign factor prices increase faster than domestic prices causing $(p^*_t - p_{d,t})$ to increase. The responsiveness of the spot exchange rate to a change in this argument is γ_2, its short-run elasticity. But now suppose that after one period $(p^*_t - p_{d,t})$ stays at its new level. Then $\Delta(p^*_t - p_{d,t}) = 0$. Nevertheless, the exchange rate will continue to change due to feedback from the error-correction term. In fact the EC term equals zero if and only if the exchange rate is at its long-run level as shown below in equation (4.10). So, if now the exchange rate is above (below) its long-run level, the EC term will be negative (positive), lowering (raising) the exchange rate in the next period (for $\gamma_3 > 0$).

Similar arguments can be made for the other variables. The short-run elasticity for a change in $(p_{d,t} - p_{m,t})$ is (γ_4) whilst the short-run elasticity for a change in exchange-rate variance $\sigma^2_{u,t}$ is (γ_7).

The long-run relationship implied by equation (4.7) is found by setting all changes in variables equal to zero and by combining current and lagged variables. This results in:

$$s_t = 1(p_t^* - p_{d,t}) + \frac{\gamma_5}{\gamma_3}(p_{d,t} - p_{m,t}) + \frac{\gamma_7}{\gamma_3}\sigma_{u,t}^2 \qquad (4.10)$$

where the parameters are obtained from estimating equation (4.7). Notice the similarity between equation (4.10) and equation (4.3). The ECM preserves the static relationship in the long run (when variables have attained their equilibrium values) whilst simultaneously affording a flexible lag structure in the short run. Estimates from equation (4.10) can be inverted in order to obtain the pass- through relationship of equation (4.2).

The table below summarises short-run and long-run elasticities for the variables.

Variable	Short Run	Long Run
$(p^*_t - p_{d,t})$	γ_2	1
$(p_{d,t} - p_{m,t})$	γ_4	$\frac{\gamma_5}{\gamma_3}$
$\sigma^2_{u,t}$	γ_7	$\frac{\gamma_7}{\gamma_3}$

A more restrictive specification than the ECM would be a difference model. That is, if $\gamma_3 = \gamma_5 = 0$ in equation (4.7) only the relationships between differenced variables would hold, appearing as:

$$(4.11) \qquad \Delta s_t = \gamma_2 \Delta(p^*_t - p_{d,t}) + \gamma_4 \Delta(p_{d,t} - p_{m,t}) + \gamma_7 \sigma^2_{u,t} + e_t$$

Generally a pure difference model "throws" away information about long-run relationships between variables. However, Hendry (1980, p. 20) notes that if the model fluctuates around the static equilibrium, then the adjustment regressor $[(p^*_t - p_{d,t})_{t-1} + (p_{d,t} - p_{m,t})_{t-1} - s_{t-1}]$ will have low explaining power. If sequential testing shows the regressor to be insignificant, it can be "dropped." Hence one can infer the long-run relationship from the pure difference model. So equation (4.11) shows that a change in $(p^*_t - p_{d,t})$ or $(p_{d,t} - p_{m,t})$ will have an immediate effect on the exchange rate of γ_2 and γ_4 respectively, with no error-correction feedback effects. Thus, the short-run and long-run elasticities are the same in the difference specification. However, movements in exchange-rate variance $(\sigma^2_{u,t})$ now affect the rate of change of the exchange rate (as indicated by the elasticity γ_7) rather than its level because this variable is not differenced.[29]

[29] Theoretical derivation of exchange-rate variance in section 2.4.2.1 is the motivating force behind not differencing it in equation (4.11). Recall that the ARCH-IN-MEAN equation has as dependent variable the log difference of the forward and expected exchange rates. So, in effect, the variance variable is already in differenced

Selection of the appropriate dynamic specification for each country proceeds as follows: The unrestricted model is estimated for each of the countries by instrumental variables, using instruments discussed above. Then the restricted models above are estimated (i.e. nested in the unrestricted model but successively more restrictive). Quasi-likelihood ratio (QLR) tests [Gallant & Jorgenson (1979)] are used to chose amongst the different specifications for each country. QLR tests are performed by testing country by country each restricted model against the unrestricted model (maintained hypothesis).

4.4 Results of Estimation and Hypothesis Testing

Results of the instrumental variables estimation are presented in Tables 4.1 and 4.3. The unrestricted estimation (Table 4.1) exhibits short-run PPP coefficients ranging from 1.04 (insignificant) for the UK to 2.62 and 2.52 for Japan and FRG respectively (both significant at the 5% level). In general one would expect to find a wide variety of coefficient magnitudes (with accompanying large standard errors) in this model; it is bound to exhibit a high degree of multicollinearity in the effort to nest competing dynamic specifications.

Recall that the specific functional form for exchange-rate pass-through derived in Chapter Two implied a less than unitary responsiveness of import prices to $\left[\frac{p*}{s}\right]$, foreign factor prices

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form. However, differencing exchange-rate variance would make elasticities from equation (4.11) identical to the short-run elasticities of equation (4.9). The appendix at the end of this chapter presents results of the alternative specification. There do not appear to be any substantial differences in estimates although there appears to be a slight decline in efficiency. This is to be expected as a differenced UK variance is no doubt much more variable than its level counterpart.

expressed in the importing country's currency. When recast in PPP form this implies a coefficient greater than one for the $\Delta(p_{d,t} - p_{m,t})$ regressor. The estimates D4, D12, and D20 for the UK, Japan and FRG respectively obey this. All coefficients appear significant. Interestingly, the $\sigma^2_{u,t}$ (variance) coefficients across the three countries (D7, D15, and D23) are all negative and within the same order of magnitude, although not significant for Japan.

QLR values are presented in Table 4.2 for restricted models estimated based on equations (4.7) and (4.11). All countries fail to reject the ECM specification for a chi-squared statistic with two degrees of freedom at the ten percent significance. On the other hand, only the UK and Japan fail to reject the difference specification at an acceptable level of significance. As a further refinement, the PPP coefficients (γ_2) for the UK and Japan are restricted to equal one. The resulting chi-squared statistics show acceptance for both the UK and Japan. Thus, the UK seems adequately modelled by differences whilst Germany is characterised better by the ECM. Japan appears amenable to either the ECM or differences specifications. The ECM, however, yields more plausible parameter estimates for Japan. These selected specifications imply long-run PPP coefficients equal to one. The fact that the implied PPP restriction is not rejected should not be too surprising as Hakkio (1984) has found the PPP hypothesis to hold when contemporaneous correlation across countries is taken into account.[30]

Table 4.3 presents the instrumental variables estimates of the preferred restricted model for each country. The UK model appears well-specified, with coefficients significant, with the expected signs and magnitudes. An examination of residual plots indicates serial correlation and heteroskedasticity to be minimal.[31] Japan and FRG also appear well-specified with little

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30 Brenton and Parikh (1987) also find PPP to hold for aggregate data in the long run but not in the short run. Preliminary testing here showed that PPP does not hold in the short run for Germany and Japan but does for the U.K.

31 The Durbin-Watson statistic is not valid for estimation without a constant. However, the estimation with intercept fails to reject the null of no first-order serial correlation.

indication of first-order serial correlation. The variance term for Japan (D15) appears insignificant however. Summary statistics also are presented in Table 4.3.

Together, the above models are estimated simultaneously by three-stage least squares (3SLS). Estimation in this fashion allows incorporation of cross-country correlation. Hakkio (1984, pp. 268-269) has noted its importance in his multi-currency estimation of purchasing power parity. He argues that shocks to the US economy will affect the exchange rates of the different countries since they are all quoted relative to the US dollar. This information is ignored if a single-equation technique is used. Table 4.4 shows the unrestricted 3SLS estimation for the three countries which can be directly compared with the IV estimates of Table 4.1. Noticeable are the changes in the parameter estimates as well as the sign reversal on the lagged variance term, D24, for FRG. Again, this is to be expected as these models possess collinear variables. Noticeable too are the dramatic reductions in standard errors, both for the individual parameters as well as for each country regression. Taking account of cross-country correlation has a pronounced effect on the efficiency of the parameter estimates.

Reduction in the standard errors carries over to Table 4.5 which presents results of the selected restricted models. The QLR test statistic indicates adequate representation of the data by the selected model as a whole. Coefficients of these models do not change dramatically from IV to 3SLS estimation, except for the PPP short-run parameters (D10 and D18) for Japan and Germany which are closer to one.[32] Even so, they are still quite large, indicating an initial over-reaction of the exchange-rate to changes in relative foreign to domestic prices. Most short-run elasticities are significant and possess the correct signs. The variance terms continue to be negative but this time

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[32] The long-run PPP parameters are restricted as implied by the respective error correction models.

significant for all three currencies. Notice the positive feedback effects of the error-correction terms D11 and D19 for Japan and Germany respectively. The rate of change of the exchange rate depends on the level of the exchange rate, relative prices, and variance, lagged all of which are part of the ECM in equation (4.9).

Table 4.5 also shows long-run elasticities.[33] These estimates result when the exchange rate has reached its equilibrium value with no further changes. Note how the short-run and long-run elasticities for PPP are identical for the U.K. but different for Japan and Germany. The long-run coefficient estimate on ($p_{d,t}$ - $p_{m,t}$) is reasonable for Japan but perversely less than one for Germany. It is perverse because it implies that an *increase* in domestic prices *negatively* affects US import prices when plugged back into equation 4.1--clearly a nonsensical result. Implied variance coefficients differ dramatically for the two countries although both are still negative. It is also noticeable that the estimate for Japan is insignificant. The theory developed in Chapter Two suggests that if exporters are unable to cover much of their US dollar revenues, then variance should *positively* affect the price they set in US dollars for their goods. As noted in Chapter Three on ARCH the variance coefficient in the mean equation for Japan was significant, implying inability of agents to cover completely. The resulting risk premium turned out to be predominantly negative for the period. Hence one would expect variance to *positively* affect US import prices. The fact that the variance coefficient is insignificant here suggests that this positive influence might be competing equally with the negative impact of exporters who price in their own currency. The negative and significant signs for the U.K. and Germany are also consistent with pass-through theory as exporters in these countries pricing in US dollars can fully cover. What remains is the negative effect of exporters pricing in their own currencies.

[33] The estimates and accompanying standard errors are computed using the "ANALYZ" command in TSP version 4.1. Implied coefficient variances are linearly approximated combinations of estimated variances and covariances.

Overall stability of the parameters was tested by splitting the sample evenly into two sub-samples, 1975.Q1 to 1981.Q2 and 1981.Q3 to 1988.Q1. The breakdown in pass-through relationships seems to occur around 1981 (Mann, 1986), so the split is particularly appropriate. Instrumental variables estimation was used since the combined set of instruments exceeded the number of observations in each of the sub-sample periods. The Chow test results are listed on Table 4.6. Only the restricted UK model appears to fail to reject the null hypothesis of parameter stability. Thus the dynamic process occurring during this time frame appears to change significantly for Japan and Germany or at least is not fully accounted for in the above specifications.

Table 4.7 gives some idea of the extent to which the short-run elasticities have changed over the two periods. The PPP coefficients D10 and D18 for Japan and Germany seem to grow in magnitude although they remain significant. The elasticities D4, D12, and D20 associated with rates of change of domestic to import prices, $\Delta(p_{d,t} - p_{m,t})$ remain stable except for the U.K. Significance also remains stable except for Japan. Finally, the variances seem to show the largest degree of change. Statistical significance increases in the period 1981:3 to 1988:1 for the U.K. and Germany but decreases for Japan. So it appears that the latter sample period is more influenced by variance in the predicted manner than the earlier period. The other variables influence the exchange rate in both periods but have slightly differing effects. The overall joint ability of the variables to explain regression variability increases for the latter sample period substantially as noted by increases in the adjusted r-squares. Indeed the adjusted r-square for the U.K. more than doubles.

4.5 Implications for Pass Through

Long-run elasticities in Table 4.5 can be reformulated in terms of the original pass-through coefficients of equation 4.1. The UK and Japan are obvious candidates for this exercise since their parameter estimates are well-behaved. They are also interesting since the UK is a difference specification (equation 4.11) whilst Japan is that of an error correction mechanism (equation 4.7).

The pass-through relationship implied by the UK and Japanese long-run elasticities are presented in Table 4.8. Note that the coefficients for $(p^*_t - \hat{s}_t)$ and $p_{d,t}$ are both about equal to one half for both countries which was an implication of the functional form discussed in Chapter Two. The equations predict that a 1% increase in foreign factor prices (measured by the UK and Japanese wholesale price indices) relative to the respective expected exchange rates, increase US import prices by 0.532 % and 0.602 % respectively. 0.468% and 0.398 % respective increases in US import prices are predicted by a 1% increase in prices of US produced goods for the two countries. The effect of variance is negative for both countries. The point estimates imply a modest 0.00290 % decrease in US import prices for a 1% increase in exchange-rate variance for the UK but a rather hefty 0.139 % decrease for Japan. The negative relationship is expected in the aggregate since exporting firms pricing in US dollars can cover in the foreign exchange market. Covering is greater for the British pound than the Japanese yen which explains, in part why the variance coefficient, while still negative is insignificant for Japan. However, the magnitude for Japan is odd since it is quite a bit larger than for the U.K. The most likely explanation is that it is due to the high sampling variability, indicated by the large standard error. Confidence intervals at both the 90 and 95 per cent levels for these estimates are also presented in Table 4.8. The extent to which variance for Japan varies shows up starkly whilst other estimates stay within plausible ranges.

TABLE 4.1

INSTRUMENTAL VARIABLES ESTIMATES: UNRESTRICTED MODEL

$$\Delta s_t = D_2\Delta(p_t^{*i} - p_{d,t}) + D_3(p_t^{*i} - p_{d,t})_{t-1} + D_4\Delta(p_{d,t} - p_{m,t}) + D_5(p_{d,t} - p_{m,t})_{t-1} +$$

$$D_7\sigma^2_{u,i,t} + D_8\sigma^2_{u,i,t-1}$$

(The above equation is for the UK. For Japan add 8 to each subscript; for FRG add 16)

INSTRUMENTS: Constant, Time, Time^2, $(P_t^{*i} - P_{d,t})_{t-1}$, $(P_{d,t} - P_{m,t})_{t-1}$, $\sigma^2_{u,i,t}$, $\sigma^2_{u,i,t-1}$, $Y_{i,t}$, $Y_{i,t-1}$, Y_{ust}, Y_{ust-1}, $M1_{i,t}$, $M1_{i,t-1}$, $M1_{ust}$, $M1_{ust-1}$. For i = UK, Japan, and FRG. "us" = United States. Real income and money are in logs.

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1988:1

PARAMETER	ESTIMATE	STANDARD ERROR	T-STATISTIC
UNITED KINGDOM			
D2	1.041	0.935	1.113
D3	0.0382	0.129	0.296
D4	2.275	0.833	2.730*
D5	-0.000745	0.0162	-0.0460
D6	-0.0120	0.0697	-0.173
D7	-0.00906	0.00479	-1.890**
D8	0.00151	0.00469	0.323
JAPAN			
D10	2.62	0.861	3.042*
D11	0.458	0.368	1.247
D12	2.33	1.072	2.169*
D13	0.324	0.251	1.289
D14	-0.209	0.163	-1.287
D15	-0.00461	0.00383	-1.202
D16	0.00360	0.00319	1.130
FEDERAL REPUBLIC OF GERMANY			
D18	2.521	0.813	3.100*
D19	0.0393	0.0838	0.469
D20	2.300	0.478	4.814*
D21	0.0411	0.0125	3.283*
D22	-0.164	0.0550	-2.988*
D23	-0.00633	0.00221	-2.866*
D24	0.0000152	0.00224	0.00679

STANDARD ERRORS COMPUTED FROM QUADRATIC FORM OF ANALYTIC FIRST DERIVATIVES (GAUSS)

TABLE 4.1 (Cont.)

SUMMARY STATISTICS

UNITED KINGDOM

VALUE OF THE MIN. DIST. CRITERION (E'HH'E) = 0.0406
NUMBER OF OBSERVATIONS = 53
SUM OF SQUARED RESIDUALS = 0.1113
STANDARD ERROR OF THE REGRESSION = 0.0495
MEAN OF DEPENDENT VARIABLE = 0.00490
STANDARD DEVIATION = 0.0543
R-SQUARED = 0.278
ADJUSTED R-SQUARED = 0.184
DURBIN-WATSON STATISTIC (with constant) = 1.671

JAPAN

VALUE OF THE MIN. DIST. CRITERION (E'HH'E) = 0.0343
NUMBER OF OBSERVATIONS = 53
SUM OF SQUARED RESIDUALS = 0.0767
STANDARD ERROR OF THE REGRESSION = 0.0408
MEAN OF DEPENDENT VARIABLE = -0.0161
STANDARD DEVIATION = 0.0534
R-SQUARED = 0.500
ADJUSTED R-SQUARED = 0.434
DURBIN-WATSON STATISTIC (with constant) = 2.195

FEDERAL REPUBLIC OF GERMANY

VALUE OF THE MIN. DIST. CRITERION (E'HH'E) = 0.0161
NUMBER OF OBSERVATIONS = 53
SUM OF SQUARED RESIDUALS = 0.0589
STANDARD ERROR OF THE REGRESSION = 0.0358
MEAN OF DEPENDENT VARIABLE = -0.00772
STANDARD DEVIATION = 0.050781
R-SQUARED = 0.561
ADJUSTED R-SQUARED = 0.504
DURBIN-WATSON STATISTIC (with constant) = 1.951

* Significant at $t_{53-21,\ 0.05}$ (Two-tailed) = 1.960

** Significant at $t_{53-21,\ 0.1}$ (Two-tailed) = 1.645

TABLE 4.2

TWO-STAGE LEAST SQUARES: QUASI-LIKELIHOOD RATIO TESTS ON RESTRICTED MODELS

(Null hypothesis)	UNRESTRICTED MODEL (Alternative hypothesis)
1. RESTRICTED MODEL: ERROR CORRECTION	
UNITED KINGDOM	$0.78 < \chi^2_{.10}(2) = 4.61$
JAPAN	$3.28 < \chi^2_{.10}(2) = 4.61$
F. REPUBLIC OF GERMANY	$4.17 < \chi^2_{.10}(2) = 4.61$
2. RESTRICTED MODEL: DIFFERENCES	
UNITED KINGDOM	$0.78 < \chi^2_{.10}(4) = 7.78$
JAPAN	$4.44 < \chi^2_{.10}(4) = 7.78$
F. REPUBLIC OF GERMANY	$13.56 > \chi^2_{.10}(4) = 7.78$
3. RESTRICTED MODEL: DIFFERENCES: PPP =1	
UNITED KINGDOM	$0.80 < \chi^2_{.10}(5) = 9.24$
JAPAN	$5.81 < \chi^2_{.10}(5) = 9.24$
F. REPUBLIC OF GERMANY	$13.68 > \chi^2_{.10}(5) = 9.24$

TABLE 4.3
INSTRUMENTAL VARIABLES ESTIMATES: RESTRICTED MODELS

COUNTRY	PARAMETER SR	LR	SHORT-RUN ELASTICITY (S. Error) [T Statistic]	LONG-RUN ELASTICITY (S. Error) [T Statistic]
U.K.	D4	Same	2.171	-
			(0.599)	(-)
			[3.623]*	[-]
	D7		-0.00601	-
			(0.00191)	(-)
			[-3.149]*	[-]
JAPAN	D10	1	1.757	-
			(0.520)	(-)
			[3.378]*	[-]
	D11		0.0361	-
			(0.0360)	(-)
			[1.002]	[-]
	D12	$\left[\frac{D_{13}}{D_{11}}\right]$	1.335	1.596
			(0.635)	(0.0995)
			[2.136]*	[16.038]*
	D13		0.0576	-
			(0.0561)	(-)
			[1.027]	[-]
	D15	$\left[\frac{D_{15}}{D_{11}}\right]$	-0.00450	-0.125
			(0.00275)	(0.124)
			[-1.640]	[-1.005]
FRG	D18	1	2.810	-
			(0.824)	(-)
			[3.409]*	[-]
	D19		0.164	-
			(0.0568)	(-)
			[2.893]*	[-]
	D20	$\left[\frac{D_{21}}{D_{19}}\right]$	2.398	0.227
			(0.489)	(0.0164)
			[4.908]*	[13.824]*
	D21		0.0373	-
			(0.0126)	(-)
			[2.970]*	[-]
	D23	$\left[\frac{D_{23}}{D_{19}}\right]$	-0.00515	-0.0313
			(0.00216)	(0.0174)
			[-2.383]*	[-1.801]**

TABLE 4.3 (Cont.)

SUMMARY STATISTICS

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1988:1

	UK	JAPAN	FRG
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	0.0426	0.0397	0.0214
NUMBER OF OBSERVATIONS	53	53	53
SUM OF SQUARED RESIDUALS	0.114	0.0758	0.0654
STANDARD ERROR OF THE REGRESSION	0.0473	0.0398	0.0369
MEAN OF DEPENDENT VARIABLE	0.00490	-0.0161	-0.0077
STANDARD DEVIATION	0.0544	0.0534	0.0508
R-SQUARED	0.272	0.491	0.514
ADJUSTED R-SQUARED	0.258	0.448	0.474
DURBIN-WATSON STATISTIC (with constant)	1.793	2.060	1.897

ESTIMATED EQUATIONS

UK: $\Delta s_t = 1\Delta(p_t^{*uk} - p_{d,t}) + D_4\Delta(p_{d,t} - p_{m,t}) + D_7\sigma^2_{u,t,uk}$

JAPAN: $\Delta s_t = D_{10}\Delta(p_t^{*j} - p_{d,t}) + D_{11}[(p_t^{*j} - p_{d,t})_{t-1} - s_{t-1}] +$

$D_{12}\Delta(p_{d,t} - p_{m,t}) + D_{13}(p_{d,t} - p_{m,t})_{t-1} + D_{15}\sigma^2_{u,t,j}$

FRG: $\Delta s_t = D_{18}\Delta(p_t^{*frg} - p_{d,t}) + D_{19}[(p_t^{*frg} - p_{d,t})_{t-1} - s_{t-1}]+$

$D_{20}\Delta(p_{d,t} - p_{m,t}) + D_{21}(p_{d,t} - p_{m,t})_{t-1} + D_{23}\sigma^2_{u,t,frg}$

INSTRUMENTS: Constant, Time, Time^2, $(P_t^{*i} - P_{d,t})_{t-1}$, $(P_{d,t} - P_{m,t})_{t-1}$, $\sigma^2_{u,i,t}$, $\sigma^2_{u,i,t-1}$, $Y_{i,t}$,

$Y_{i,t-1}$, Y_{ust}, Y_{ust-1}, $M1_{i,t}$, $M1_{i,t-1}$, $M1_{ust}$, $M1_{ust-1}$. For i = UK, Japan, and FRG (relevant country in each equation). "us" = United States. All variables are expressed in logs.

* Significant at $t_{53-21,\ 0.05}$ (Two-tailed) = 1.960

** Significant at $t_{53-21,\ 0.1}$ (Two-tailed) = 1.645

TABLE 4.4

THREE-STAGE LEAST SQUARES ESTIMATES: UNRESTRICTED MODEL

$$\Delta s_t = D_2\Delta(p_t^{*i} - p_{d,t}) + D_3(p_t^{*i} - p_{d,t})_{t-1} + D_4\Delta(p_{d,t} - p_{m,t}) + D_5(p_{d,t} - p_{m,t})_{t-1} +$$

$$D_7\sigma^2_{u,t,i} + D_8\sigma^2_{u,t,i-1}$$

(The above equation is for the UK. For Japan add 8 to each subscript; for FRG add 16)

INSTRUMENTS: Constant, Time, Time^2, $(P_t^{*i} - P_{d,t})_{t-1}$, $(P_{d,t} - P_{m,t})_{t-1}$, $\sigma^2_{u,i,t}$, $\sigma^2_{u,i,t-1}$, $Y_{i,t}$, $Y_{i,t-1}$, Y_{ust}, Y_{ust-1}, $M1_{i,t}$, $M1_{i,t-1}$, $M1_{ust}$, $M1_{ust-1}$. For i = UK, Japan, and FRG (used in all three equations). "us" = United States. Real income and money are in logs.

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1988:1

PARAMETER	ESTIMATE	STANDARD ERROR	T-STATISTIC
UNITED KINGDOM			
D2	1.622	0.671	2.420*
D3	0.108	0.0990	1.095
D4	2.289	0.626	3.658*
D5	-0.00682	0.0126	-0.0541
D6	-0.0303	0.0552	-0.550
D7	-0.00810	0.00382	-2.119*
D8	0.000888	0.00373	0.238
JAPAN			
D10	1.931	0.403	4.794*
D11	0.153	0.195	0.784
D12	1.389	0.536	2.591*
D13	0.125	0.131	0.956
D14	-0.0804	0.0845	-0.951
D15	-0.00610	0.00244	-2.499*
D16	0.00340	0.00226	1.503
FEDERAL REPUBLIC OF GERMANY			
D18	1.434	0.544	2.636*
D19	0.0220	0.0660	0.333
D20	2.221	0.379	5.854*
D21	0.0299	0.00884	3.383*
D22	-0.106	0.0390	-2.729*
D23	-0.00613	0.00158	-3.887*
D24	-0.00231	0.00157	-1.465

STANDARD ERRORS COMPUTED FROM QUADRATIC FORM OF ANALYTIC FIRST DERIVATIVES (GAUSS)

TABLE 4.4 (Cont.)

SUMMARY STATISTICS

VALUE OF THE MIN. DIST. CRITERION (E'HH'E) = 115.13
NUMBER OF OBSERVATIONS = 53

UNITED KINGDOM

SUM OF SQUARED RESIDUALS = 0.114
STANDARD ERROR OF THE REGRESSION = 0.0464
MEAN OF DEPENDENT VARIABLE = 0.00490
STANDARD DEVIATION = 0.0544
R-SQUARED = 0.265
ADJUSTED R-SQUARED = 0.279
DURBIN-WATSON STATISTIC (with constant) = 1.775

JAPAN

SUM OF SQUARED RESIDUALS = 0.0710
STANDARD ERROR OF THE REGRESSION = 0.0366
MEAN OF DEPENDENT VARIABLE = -0.0161
STANDARD DEVIATION = 0.0534
R-SQUARED = 0.525
ADJUSTED R-SQUARED = 0.534
DURBIN-WATSON STATISTIC (with constant) = 2.089

FEDERAL REPUBLIC OF GERMANY

SUM OF SQUARED RESIDUALS = 0.0592
STANDARD ERROR OF THE REGRESSION = 0.0334
MEAN OF DEPENDENT VARIABLE = -0.00772
STANDARD DEVIATION = 0.0508
R-SQUARED = 0.558
ADJUSTED R-SQUARED = 0.567
DURBIN-WATSON STATISTIC (with constant) = 2.015

* Significant at $t_{53-29,\ 0.05}$ (Two-tailed) = 2.064
** Significant at $t_{53-21,\ 0.1}$ (Two-tailed) = 1.711

TABLE 4.5
THREE-STAGE LEAST SQUARES ESTIMATES: RESTRICTED MODELS

COUNTRY	PARAMETER SR	LR [T Statistic]	SHORT-RUN ELASTICITY (S. Error) [T Statistic]	LONG-RUN ELASTICITY (S. Error)
U.K.	D4	Same	1.881 (0.487) [3.860]*	- (-) [-]
	D7		-0.00545 (0.00176) [-3.089]*	- (-) [-]
JAPAN	D10	1	1.719 (0.321) [5.349]*	- (-) [-]
	D11		0.0211 (0.0256) [0.824]	- (-) [-]
	D12	$\left[\frac{D_{13}}{D_{11}}\right]$	1.081 (0.438) [2.469]*	1.660 (0.168) [9.902]*
	D13		0.0350 (0.0399) [0.877]	- (-) [-]
	D15	$\left[\frac{D_{15}}{D_{11}}\right]$	-0.00487 (0.00196) [-2.493]*	-0.231 (0.263) [-0.879]
FRG	D18	1	1.589 (0.540) [2.944]*	- (-) [-]
	D19		0.0912 (0.0371) [2.457]*	- (-) [-]
	D20	$\left[\frac{D_{21}}{D_{19}}\right]$	2.315 (0.374) [6.188]	0.230 (0.0218) [10.545]*
	D21		0.0210 (0.00823) [2.552]*	- (-) [-]
	D23	$\left[\frac{D_{23}}{D_{19}}\right]$	-0.00559 (0.00149) [-3.755]*	-0.0613 (0.0303) [-2.0232]**

TABLE 4.5 (Cont.)

SUMMARY STATISTICS

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1988:1

	UK	JAPAN	FRG
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	123.76	123.76	123.76
NUMBER OF OBSERVATIONS	53	53	53
SUM OF SQUARED RESIDUALS	0.112	0.0754	0.0642
STANDARD ERROR OF THE REGRESSION	0.0460	0.0377	0.0348
MEAN OF DEPENDENT VARIABLE	0.00490	-0.0161	-0.0077
STANDARD DEVIATION	0.0544	0.0534	0.0508
R-SQUARED	0.273	0.496	0.521
ADJUSTED R-SQUARED	0.287	0.506	0.530
DURBIN-WATSON STATISTIC (with constant)	1.829	1.925	1.844

QLR TEST: $8.64 < \chi^2_{.10}(12) = 18.55$

ESTIMATED EQUATIONS

$$\textbf{UK:}\quad \Delta s_t = 1\Delta(p_t^{*uk} - p_{d,t}) + D_4\Delta(p_{d,t} - p_{m,t}) + D_7\sigma^2_{u,t,uk}$$

$$\textbf{JAPAN:}\quad \Delta s_t = D_{10}\Delta(p_t^{*j} - p_{d,t}) + D_{11}[(p_t^{*j} - p_{d,t})_{t-1} - s_{t-1}] +$$

$$D_{12}\Delta(p_{d,t} - p_{m,t}) + D_{13}(p_{d,t} - p_{m,t})_{t-1} + D_{15}\sigma^2_{u,t,j}$$

$$\textbf{FRG:}\quad \Delta s_t = D_{18}\Delta(p_t^{*frg} - p_{d,t}) + D_{19}[(p_t^{*frg} - p_{d,t})_{t-1} - s_{t-1}] +$$

$$D_{20}\Delta(p_{d,t} - p_{m,t}) + D_{21}(p_{d,t} - p_{m,t})_{t-1} + D_{23}\sigma^2_{u,t,frg}$$

INSTRUMENTS: Constant, Time, Time^2, $(P_t^{*i} - P_{d,t})_{t-1}$, $(P_{d,t} - P_{m,t})_{t-1}$, $\sigma^2_{u,i,t}$, $\sigma^2_{u,i,t-1}$, $Y_{i,t}$, $Y_{i,t-1}$, Y_{ust}, Y_{ust-1}, $M1_{i,t}$, $M1_{i,t-1}$, $M1_{ust}$, $M1_{ust-1}$. For i = UK, Japan, and FRG (in all three equations). "us" = United States. All variables are expressed in logs.

* Significant at $t_{53-29,\, 0.05}$ (Two-tailed) = 2.064

** Significant at $t_{53-29,\, 0.1}$ (Two-tailed) = 1.711

TABLE 4.6

CHOW TESTS OF COEFFICIENT STABILITY

PERIOD SPLIT: I. 1975.Q1 TO 1981.Q2
II. 1981.Q3 TO 1988.Q1

1. UNRESTRICTED MODEL BASED ON TABLE 4.1, USING 2SLS ESTIMATION.	
UNITED KINGDOM	$6.51 > F_{.05,8,45} = 2.16$
JAPAN	$19.21 > F_{.05,8,45} = 2.16$
W. GERMANY	$6.17 > F_{.05,8,45} = 2.16$
2. RESTRICTED MODEL BASED ON TABLE 4.3, USING 2SLS ESTIMATION.	
UNITED KINGDOM	$1.48 < F_{.05,2,49} = 3.19$
JAPAN	$11.51 > F_{.05,5,43} = 2.44$
W. GERMANY	$5.17 > F_{.05,5,41} = 2.44$

TABLE 4.7

INSTRUMENTAL VARIABLES CHOW TESTS: RESTRICTED MODELS

COUNTRY	PARAMETER SR	SHORT-RUN ELASTICITY 1975:1 to 1981:2 (S. Error) [T Statistic]	SHORT-RUN ELASTICITY 1981:3 to 1988:1 (S. Error) [T Statistic]
U.K.	D4	1.333 (0.619) [2.154]**	2.871 (0.771) [3.726]*
	D7	-0.00488 (0.00383) [-1.274]	-0.00622 (0.00215) [-2.891]*
JAPAN	D10	2.090 (0.487) [4.291]*	3.353 (0.885) [3.787]*
	D11	0.0365 (0.113) [3.221]*	0.0343 (0.0697) [0.493]
	D12	1.106 (0.534) [2.071]**	1.052 (1.311) [0.802]
	D13	0.0585 (0.182) [3.213]*	0.0561 (0.102) [0.549]
	D15	-0.0175 (0.00777) [-2.259]*	-0.00322 (0.00354) [-0.909]
FRG	D18	2.188 (1.211) [1.807]**	3.146 (1.054) [2.986]*
	D19	0.226 (0.168) [1.348]	0.125 (0.0728 [1.722]**
	D20	2.043 (0.557) [3.671]*	2.099 (0.876) [2.395]*
	D21	0.0452 (0.0334) [1.355]	0.0394 (0.0154) [2.561]*
	D23	-0.00267 (0.00249) [-1.069]	-0.0161 (0.00538) [-2.985]*

TABLE 4.7 (Cont.)

SUMMARY STATISTICS

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1981:2

	UK	**JAPAN**	**FRG**
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	0.0404	0.0156	0.0233
NUMBER OF OBSERVATIONS	26	26	26
SUM OF SQUARED RESIDUALS	0.0513	0.0287	0.0258
STANDARD ERROR OF THE REGRESSION	0.0462	0.0370	0.0351
MEAN OF DEPENDENT VARIABLE	0.00433	-0.0119	-0.00396
STANDARD DEVIATION	0.0499	0.0498	0.0458
R-SQUARED	0.175	0.537	0.507
ADJUSTED R-SQUARED	0.140	0.449	0.413
DURBIN-WATSON STATISTIC (with constant)	2.165	2.200	2.381

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1981:3 TO 1988:1

	UK	**JAPAN**	**FRG**
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	0.0320	0.0219	0.0174
NUMBER OF OBSERVATIONS	27	27	27
SUM OF SQUARED RESIDUALS	0.0561	0.0229	0.0282
STANDARD ERROR OF THE REGRESSION	0.0474	0.0323	0.0358
MEAN OF DEPENDENT VARIABLE	0.00545	-0.0201	-0.0113
STANDARD DEVIATION	0.0594	0.0574	0.0558
R-SQUARED	0.388	0.733	0.652
ADJUSTED R-SQUARED	0.363	0.684	0.588
DURBIN-WATSON STATISTIC (with constant)	1.530	2.134	2.307

* Significant at $t_{26-15,\ 0.05}$ (Two-tailed) = 2.201

** Significant at $t_{27-15,\ 0.1}$ (Two-tailed) = 1.796

TABLE 4.8

PASS THROUGH ESTIMATES IMPLIED BY LONG-RUN ELASTICITIES OF TABLE 4.5

U. K. $\hat{p}_{m,t} = 0.532{*}(p^{*}_{t} - \hat{s}_{t}) + (1-.532){*}p_{d,t} - .00290{*}\sigma^{2}_{u,t},$

(0.138)	(0.138)	(0.00105)
[3.860]	[3.401]	[-2.750]

JAPAN $\hat{p}_{m,t} = 0.602{*}(p^{*}_{t} - \hat{s}_{t}) + (1-0.602){*}p_{d,t} - 0.139{*}\sigma^{2}_{u,t}$

(0.0608)	(0.0608)	(0.146)
[9.902]	[6.537]	[-0.951]

(Standard errors are in parentheses whilst t statistics are in brackets.)

CONFIDENCE INTERVALS FOR PASS-THROUGH COEFFICIENTS

COUNTRY VARIABLE POINT 90%
CONFIDENCE 95% CONFIDENCE
ESTIMATE INTERVAL INTERVAL

U.K.	$(p^{*}_{t} - \hat{s}_{t})$	0.535	0.296 to 0.768	0.247 to 0.817
	$p_{d,t}$	0.468	0.232 to 0.704	0.183 to 0.753
	$\sigma^{2}_{u,t}$	-0.00290	-0.00470 to -0.00110	-0.00507 to -0.000733
JAPAN	$(p^{*}_{t} - \hat{s}_{t})$	0.602	0.498 to 0.706	0.477 to 0.727
	$p_{d,t}$	0.398	0.294 to 0.502	0.273 to 0.523
	$\sigma^{2}_{u,t}$	-0.139	-0.389 to 0.111	-0.440 to 0.162

APPENDICES TO CHAPTER FOUR

DATA SOURCES

1. Data for Exchange-Rate Variances

Variance estimates based on these series are then averaged and aggregated into quarters to form exchange-rate variances for pass-through estimation. The quarterly estimates are presented in Table A4.1.

TABLE A4.1

QUARTERLY EXCHANGE-RATE VARIANCE ESTIMATES: POUND (PP1HQ), YEN (PY1HQ), AND DEUTSCHEMARK (PM1HQ) 1974.Q3 TO 1988.Q1

obs	PP1HQ	PY1HQ	PM1HQ
1974.3	1.569523	1.989333	2.850698
1974.4	1.039165	1.214792	2.055721
1975.1	1.324855	0.993656	2.499144
1975.2	1.188689	0.977175	1.802336
1975.3	1.895955	0.722161	2.247741
1975.4	1.495196	0.790022	2.292810
1976.1	1.219369	0.917926	1.761965
1976.2	2.030935	0.805153	1.458304
1976.3	1.416186	1.821840	1.078743
1976.4	3.630397	1.542793	1.344460
1977.1	5.511436	1.168525	1.287552
1977.2	2.279779	1.173302	1.011364
1977.3	1.187389	1.138650	1.555257
1977.4	1.091712	1.919292	1.460153
1978.1	1.342575	1.561107	1.868823
1978.2	1.353059	2.573472	1.954390
1978.3	1.950805	3.878642	2.712357
1978.4	3.536895	4.945507	15.80282
1979.1	2.551616	3.796128	6.402972
1979.2	1.781993	3.491035	2.314555
1979.3	3.492964	1.974843	1.785699
1979.4	3.082185	2.629356	1.914485
1980.1	2.490058	3.603489	1.683527
1980.2	2.648396	5.564581	5.662832
1980.3	1.643746	3.716722	1.786958
1980.4	1.393450	2.788862	2.808077
1981.1	2.820514	2.417554	5.469307
1981.2	4.354440	3.461288	4.365368
1981.3	5.948575	2.932634	3.794715
1981.4	7.585934	5.356583	8.318377
1982.1	3.808749	3.586295	2.690394
1982.2	2.276303	3.561204	2.877759
1982.3	2.058767	3.554220	2.737193
1982.4	1.677823	3.673963	1.972360
1983.1	1.905677	4.011743	3.500691
1983.2	3.479117	2.667940	2.062392
1983.3	3.075856	1.884085	2.221301
1983.4	1.616605	2.113653	2.904524
1984.1	1.818358	1.625969	2.918352
1984.2	1.785326	2.015656	2.660972
1984.3	1.907099	1.634058	2.239929
1984.4	4.312511	1.596735	3.448677
1985.1	4.373036	1.707257	2.924783
1985.2	11.94818	1.884222	6.497515

TABLE A4.1 (CONT)

obs	PP1HQ	PY1HQ	PM1HQ
1985.3	7.226908	1.526358	4.145517
1985.4	5.613416	5.834616	5.774063
1986.1	3.886042	8.973584	2.873970
1986.2	3.577975	17.15789	6.858884
1986.3	3.270898	8.581780	4.179729
1986.4	1.979270	4.236626	4.445823
1987.1	2.337567	3.345107	5.168252
1987.2	2.542925	2.654122	3.166406
1987.3	2.633539	3.306325	2.274112
1987.4	3.666660	4.883776	4.132829
1988.1	3.133762	4.801065	3.037423

2. Data Construction and Sources for Pass-Through Estimation

A. Construction of the Divisia Index of US Import Prices

The formula for constructing a Divisia price index is as follows

$$P_D(P^t, P^{t-1}) = \exp\left[\sum_{i=1}^{n}\left[\frac{1}{2}(S_i^t + S_i^{t-1})(\ln P_i^t - \ln P_i^t)\right]\right]$$

where, i = good i

P_i^t = price of good i at time t.

$$S_i = \frac{V_t^i}{\sum_i V_t^i}$$

where, V_t^i = value of good i at time t. Hence S_i is the proportionate value of good i relative to the total value of goods.

The cumulative Divisia index then becomes:

$$P_D(P^{t+k}, P^t) = P_D(P^{t+1}, P^t)P_D(P^{t+2}, P^{t+1})...P_D(P^{t+k}, P^{t+1})$$

The Divisia index can be rewritten for comparison with a fixed-weight index as:

$$P_D = \prod_i (P_i^t / P_i^{t-1})^{\frac{1}{2}(S_i^t + S_i^{t-1})}$$

The weighted shares change over time. On the other hand, the fixed weight index would appear as:

$$P^t = \prod_i (P_i^t)^{\bar{S}_i}$$

where $\bar{S}_i$ is constant over the entire time period.

B. Data Sources: Import Price Index

Sources for Divisia price index construction are the Citibase Machine-readable magnetic tape file and various issues of *Survey of Current Business.* Imports are given in both current and constant (1980) US dollars on a quarterly basis from 1967.I to 1988.I Implicit prices are derived by dividing current by constant dollar imports. The following categories are used in the Divisia index construction.

1.) Industrial supplies and materials excluding petroleum
    a.) Durable goods
    b.) Nondurable goods
2.) Industrial supplies and materials excluding petroleum

a.) Durable goods
b.) Nondurable goods
3.) Capital goods, except autos
4.) Consumer Goods
a.) Durable
b.) Nondurable
5.) Other Goods
a.) Durable
b.) Nondurable

Excluded from the index are:

1.) Foods, feeds, and beverages
2.) Petroleum products
3.) Autos

The price Divisia index is found in Table A4.2 along with the total US import price index for comparison.

C.) Data Sources: Independent Variables of the Structural Equations

Domestic price, money, income, and exchange-rate indices are from IFS Statistics for 1967.I to 1988.I as outlined in Table A4.3.

TABLE A4.2

**DIVISIA PRICE (PDBC) INDEX; IMPLICIT TOTAL US IMPORT PRICE INDEX (PGIMM67) FOR COMPARISON
1967.Q1 TO 1988.Q1**

obs	PDBC	PGIMM67
1967.1	1.000000	1.000000
1967.2	0.992484	0.985829
1967.3	0.984019	1.021747
1967.4	0.982722	1.002022
1968.1	0.992975	1.009632
1968.2	1.007245	1.025259
1968.3	1.022760	1.027839
1968.4	1.012375	1.017680
1969.1	1.017934	1.005169
1969.2	1.026014	1.037095
1969.3	1.039059	1.044266
1969.4	1.054738	1.059447
1970.1	1.069906	1.068807
1970.2	1.085883	1.090564
1970.3	1.126311	1.132561
1970.4	1.146418	1.126446
1971.1	1.152168	1.171719
1971.2	1.149067	1.147563
1971.3	1.168981	1.139939
1971.4	1.172848	1.111684
1972.1	1.215431	1.191545
1972.2	1.246529	1.213711
1972.3	1.262961	1.215960
1972.4	1.284342	1.240857
1973.1	1.323358	1.260601
1973.2	1.429142	1.306310
1973.3	1.487932	1.358550
1973.4	1.569535	1.444107
1974.1	1.679621	1.793329
1974.2	1.837131	1.987409
1974.3	1.975687	2.101461
1974.4	2.062859	2.160937
1975.1	2.099682	2.196442
1975.2	2.116469	2.184051
1975.3	2.031509	2.112403
1975.4	2.006569	2.110744
1976.1	2.014645	2.164980
1976.2	2.056388	2.193821
1976.3	2.088703	2.231447
1976.4	2.090332	2.247023
1977.1	2.148006	2.284537
1977.2	2.203202	2.387378
1977.3	2.258275	2.415966

TABLE A.2 (CONT.)

obs	PDBC	PGIMM67
1977.4	2.276007	2.463729
1978.1	2.327107	2.551909
1978.2	2.403483	2.608567
1978.3	2.438401	2.646792
1978.4	2.477665	2.697136
1979.1	2.556848	2.800883
1979.2	2.649485	2.958842
1979.3	2.682797	3.222860
1979.4	2.819317	3.462473
1980.1	2.964504	3.791882
1980.2	3.030662	3.950343
1980.3	3.103334	4.062213
1980.4	3.099610	4.140059
1981.1	3.103218	4.248176
1981.2	3.106067	4.271799
1981.3	3.065545	4.147953
1981.4	3.080428	4.144664
1982.1	3.094425	4.161798
1982.2	3.068477	4.081074
1982.3	3.013256	4.043538
1982.4	2.985153	4.032354
1983.1	2.960761	3.971978
1983.2	2.941175	3.908631
1983.3	2.921603	3.908474
1983.4	2.887927	3.905296
1984.1	2.888286	3.907306
1984.2	2.888919	3.916195
1984.3	2.852150	3.874416
1984.4	2.819240	3.838596
1985.1	2.754371	3.773110
1985.2	2.737441	3.762721
1985.3	2.726824	3.735450
1985.4	2.717961	3.762257
1986.1	2.718330	3.698115
1986.2	2.742343	3.531746
1986.3	2.766909	3.471805
1986.4	2.798046	3.584120
1987.1	2.822188	3.704289
1987.2	2.879989	3.787223
1987.3	2.908497	3.781690
1987.4	2.936572	3.817277
1988.1	3.020152	3.843412

TABLE A4.3

Domestic Price Indices

Country	*IFS Line*	*Specific Index*
United Kingdom	63	Prices: Industrial Output
Japan	63	Wholesale Prices
Federal Republic of Germany	63	Wholesale Prices: Industrial Share Prices
United States	63	Wholesale Prices

Money Supply

United Kingdom	34	Money
Japan	34	Money
Federal Republic of Germany	34	Money (M1)
United States	34	Money

Real GDP (GNP)

United Kingdom	99b.p	GDP 1980 prices
Japan	99a.r	GNP 1980 prices
Federal Republic of Germany	99a.r	GNP 1980 prices
United States	99a.r	GNP 1980 prices

Exchange Rates

United Kingdom	rh	US$/£ Period average (inverted)
Japan	rf	¥/US$ Period average
Federal Republic of Germany	rf	DM/US$ Period average

ALTERNATIVE ESTIMATIONS FOR CHAPTER FOUR

TABLE A.4

TWO-STAGE LEAST SQUARES: QUASI-LIKELIHOOD RATIO TESTS ON RESTRICTED MODELS

(Null hypothesis)	UNRESTRICTED MODEL (Alternative hypothesis)
1. RESTRICTED MODEL: ERROR CORRECTION	
UNITED KINGDOM	$0.21 < \chi^2_{.10}(2) = 4.61$
JAPAN	$3.28 < \chi^2_{.10}(2) = 4.61$
F. REPUBLIC OF GERMANY	$4.17 < \chi^2_{.10}(2) = 4.61$
2. RESTRICTED MODEL: DIFFERENCES	
UNITED KINGDOM	$5.34 < \chi^2_{.10}(4) = 7.78$
JAPAN	$2.65 < \chi^2_{.10}(4) = 7.78$
F. REPUBLIC OF GERMANY	$19.83 > \chi^2_{.10}(4) = 7.78$
3. RESTRICTED MODEL: DIFFERENCES: PPP =1	
UNITED KINGDOM	$8.42 < \chi^2_{.10}(5) = 9.24$
JAPAN	$9.68 > \chi^2_{.10}(5) = 9.24$
F. REPUBLIC OF GERMANY	$20.52 > \chi^2_{.10}(5) = 9.24$

TABLE A4.5
INSTRUMENTAL VARIABLES ESTIMATES: RESTRICTED MODELS

COUNTRY	PARAMETER SR	PARAMETER LR	SHORT-RUN ELASTICITY (S. Error) [T Statistic]	LONG-RUN ELASTICITY (S. Error) [T Statistic]
U.K.	D4	Same	1.810	-
			(0.633)	(-)
			[2.858]*	[-]
	D7	Same	-0.00485	-
			(0.00417)	(-)
			[-1.162]	[-]
JAPAN	D10	1	1.757	-
			(0.520)	(-)
			[3.378]*	[-]
	D11		0.0361	-
			(0.0360)	(-)
			[1.002]	[-]
	D12	$\left[\frac{D_{13}}{D_{11}}\right]$	1.335	1.596
			(0.635)	(0.995)
			[2.136]*	[16.038]*
	D13		0.0576	-
			(0.0561)	(-)
			[1.027]	[-]
	D15	$\left[\frac{D_{15}}{D_{11}}\right]$	-0.00450	-0.125
			(0.00275)	(0.124)
			[-1.640]	[-1.005]
FRG	D18	1	2.810	-
			(0.824)	(-)
			[3.409]*	[-]
	D19		0.164	-
			(0.0568)	(-)
			[2.893]*	[-]
	D20	$\left[\frac{D_{21}}{D_{19}}\right]$	2.398	0.227
			(0.489)	(0.0164)
			[4.908]*	[13.824]*
	D21		0.0373	-
			(0.0126)	(-)
			[2.970]*	[-]
	D23	$\left[\frac{D_{23}}{D_{19}}\right]$	-0.00515	-0.0313
			(0.00216)	(0.0174)
			[-2.383]*	[-1.801]**

TABLE A4.5 (Cont.)

SUMMARY STATISTICS

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1988:1

	UK	**JAPAN**	**FRG**
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	0.0613	0.0397	0.0214
NUMBER OF OBSERVATIONS	53	53	53
SUM OF SQUARED RESIDUALS	0.113	0.0758	0.0654
STANDARD ERROR OF THE REGRESSION	0.0504	0.0398	0.0369
MEAN OF DEPENDENT VARIABLE	0.00490	-0.0161	-0.0077
STANDARD DEVIATION	0.0544	0.0534	0.0508
R-SQUARED	0.156	0.491	0.514
ADJUSTED R-SQUARED	0.140	0.448	0.474
DURBIN-WATSON STATISTIC (with constant)	1.793	2.060	1.897

ESTIMATED EQUATIONS

UK: $\Delta s_t = 1\Delta(p_t^{*uk} - p_{d,t}) + D_4\Delta(p_{d,t} - p_{m,t}) + D_7\sigma^2_{u,t,uk}$

JAPAN: $\Delta s_t = D_{10}\Delta(p_t^{*j} - p_{d,t}) + D_{11}[(p_t^{*j} - p_{d,t})_{t-1} - s_{t-1}] +$

$D_{12}\Delta(p_{d,t} - p_{m,t}) + D_{13}(p_{d,t} - p_{m,t})_{t-1} + D_{15}\sigma^2_{u,t,j}$

FRG: $\Delta s_t = D_{18}\Delta(p_t^{*frg} - p_{d,t}) + D_{19}[(p_t^{*frg} - p_{d,t})_{t-1} - s_{t-1}]+$

$D_{20}\Delta(p_{d,t} - p_{m,t}) + D_{21}(p_{d,t} - p_{m,t})_{t-1} + D_{23}\sigma^2_{u,t,frg}$

INSTRUMENTS: Constant, Time, Time^2, $(P_t^{*i} - P_{d,t})_{t-1}$, $(P_{d,t} - P_{m,t})_{t-1}$, $\sigma^2_{u,i,t}$, $\sigma^2_{u,i,t-1}$, $Y_{i,t}$, $Y_{i,t-1}$, Y_{ust}, Y_{ust-1}, $M1_{i,t}$, $M1_{i,t-1}$, $M1_{ust}$, $M1_{ust-1}$. For i = UK, Japan, and FRG (relevant country in each equation). "us" = United States. All variables are expressed in logs.

* Significant at $t_{53-21,\ 0.05}$ (Two-tailed) = 1.960

** Significant at $t_{53-21,\ 0.1}$ (Two-tailed) = 1.645

TABLE A4.6
THREE-STAGE LEAST SQUARES ESTIMATES: RESTRICTED MODELS

COUNTRY	PARAMETER SR	LR	SHORT-RUN ELASTICITY (S. Error) [T Statistic]	LONG-RUN ELASTICITY (S. Error) [T Statistic]
U.K.	D4	Same	1.642	-
			(0.482)	(-)
			[3.405]*	[-]
	D7	Same	-0.00416	-
			(0.00323)	(-)
			[-1.286]	[-]
JAPAN	D10	1	1.732	-
			(0.321)	(-)
			[5.391]*	[-]
	D11		0.0227	-
			(0.0256)	(-)
			[0.887]	[-]
	D12	$\left[\frac{D_{13}}{D_{11}}\right]$	0.976	1.715
			(0.437)	(0.206)
			[2.234]*	[8.343]*
	D13		0.0389	-
			(0.0399)	(-)
			[0.976]	[-]
	D15	$\left[\frac{D_{15}}{D_{11}}\right]$	-0.00477	-0.210
			(0.00195)	(0.222)
			[-2.441]*	[-0.946]
FRG	D18	1	1.578	-
			(0.540)	(-)
			[2.923]	[-]
	D19		0.0833	-
			(0.0371)	(-)
			[2.248]*	[-]
	D20	$\left[\frac{D_{21}}{D_{19}}\right]$	2.150	0.251
			(0.371)	(0.0272)
			[5.802]*	[9.231]*
	D21		0.0209	-
			(0.00823)	(-)
			[2.540]*	[-]
	D23	$\left[\frac{D_{23}}{D_{19}}\right]$	-0.00536	-0.0643
			(0.00149)	(0.0344)
			[-3.597]*	[-1.871]**

TABLE A4.6 (Cont.)

SUMMARY STATISTICS

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1988:1
R-SQUARED 0.512
ADJUSTED R-SQUARED 0.471

	UK	JAPAN	FRG
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	131.66	131.66	131.66
NUMBER OF OBSERVATIONS	53	53	53
SUM OF SQUARED RESIDUALS	0.129	0.0761	0.0658
STANDARD ERROR OF THE REGRESSION	0.0494	0.0379	0.0352
MEAN OF DEPENDENT VARIABLE	0.00490	-0.0161	-0.0077
STANDARD DEVIATION	0.0544	0.0534	0.0508
DURBIN-WATSON STATISTIC (with constant)	1.790	1.951	1.886

QLR TEST: $16.53 < \chi^2_{.10}(12) = 18.55$

ESTIMATED EQUATIONS

UK: $\Delta s_t = 1\Delta(p_t^{*uk} - p_{d,t}) + D_4\Delta(p_{d,t} - p_{m,t}) + D_7\Delta\sigma^2_{u,t,uk}$

JAPAN: $\Delta s_t = D_{10}\Delta(p_t^{*j} - p_{d,t}) + D_{11}[(p_t^{*j} - p_{d,t})_{t-1} - s_{t-1}] +$

$D_{12}\Delta(p_{d,t} - p_{m,t}) + D_{13}(p_{d,t} - p_{m,t})_{t-1} + D_{15}\sigma^2_{u,t,j}$

FRG: $\Delta s_t = D_{18}\Delta(p_t^{*frg} - p_{d,t}) + D_{19}[(p_t^{*frg} - p_{d,t})_{t-1} - s_{t-1}] +$

$D_{20}\Delta(p_{d,t} - p_{m,t}) + D_{21}(p_{d,t} - p_{m,t})_{t-1} + D_{23}\sigma^2_{u,t,frg}$

INSTRUMENTS: Constant, Time, $Time^2$, $(P_t^{*i} - P_{d,t})_{t-1}$, $(P_{d,t} - P_{m,t})_{t-1}$, $\sigma^2_{u,i,t}$, $\sigma^2_{u,i,t-1}$, $Y_{i,t}$, $Y_{i,t-1}$, Y_{ust}, Y_{ust-1}, $M1_{i,t}$, $M1_{i,t-1}$, $M1_{ust}$, $M1_{ust-1}$. For i = UK, Japan, and FRG (in all three equations). "us" = United States. All variables are expressed in logs.

* Significant at $t_{53-29,\ 0.05}$ (Two-tailed) = 2.064

** Significant at $t_{53-29,\ 0.1}$ (Two-tailed) = 1.711

TABLE A4.7
THREE-STAGE LEAST SQUARES ESTIMATES: RESTRICTED MODELS COEFFICIENT ON VARIANCE SAME ACROSS COUNTRIES

COUNTRY	PARAMETER SR	LR [T Statistic]	SHORT-RUN ELASTICITY (S. Error) [T Statistic]	LONG-RUN ELASTICITY (S. Error)
Common	DH	Same	-0.00504 (0.00122) [-4.119]*	- (-) [-]
U.K.	D4	Same	1.667 (0.475) [3.511]*	- (-) [-]
JAPAN	D10	1	1.717 (0.316) [5.425]*	- (-) [-]
	D11		0.0247 (0.0240) [1.0267]	- (-) [-]
	D12	$\left[\frac{D_{13}}{D_{11}}\right]$	0.959 (0.425) [2.257]*	1.709 (0.184) [9.278]*
	D13		0.0422 (0.0370) [1.139]	- (-) [-]
	-	$\left[\frac{D_{H}}{D_{11}}\right]$	- (-) [-]	-0.204 (0.199) [-1.030]
FRG	D18	1	1.563 (0.537) [2.912]*	- (-) [-]
	D19		0.0830 (0.0370) [2.242]*	- (-) [-]
	D20	$\left[\frac{D_{21}}{D_{19}}\right]$	2.150 (0.371) [5.802]*	0.247 (0.0247) [10.005]*
	D21		0.0205 (0.00814) [2.522]*	- (-) [-]
	-	$\left[\frac{D_{H}}{D_{19}}\right]$	- (-) [-]	-0.0608 (0.0319) [-1.904]**

TABLE A4.7 (Cont.)

SUMMARY STATISTICS

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1988:1

	UK	**JAPAN**	**FRG**
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	131.82	131.82	131.82
NUMBER OF OBSERVATIONS	53	53	53
SUM OF SQUARED RESIDUALS	0.129	0.0762	0.0659
STANDARD ERROR OF THE REGRESSION	0.0494	0.0379	0.0353
MEAN OF DEPENDENT VARIABLE	0.00490	-0.0161	-0.0077
STANDARD DEVIATION	0.0544	0.0534	0.0508
DURBIN-WATSON STATISTIC (with constant)	1.781	1.934	1.887

QLR TEST: $16.69 < \chi^2_{.10}(14) = 21.06$

UK: $\Delta s_t = 1\Delta(p_t^{*uk} - p_{d,t}) + D_4\Delta(p_{d,t} - p_{m,t}) + D_H\Delta\sigma^2_{u,t,uk}$

JAPAN: $\Delta s_t = D_{10}\Delta(p_t^{*j} - p_{d,t}) + D_{11}[(p_t^{*j} - p_{d,t})_{t-1} - s_{t-1}] +$

$D_{12}\Delta(p_{d,t} - p_{m,t}) + D_{13}(p_{d,t} - p_{m,t})_{t-1} + D_H\sigma^2_{u,t,j}$

FRG: $\Delta s_t = D_{18}\Delta(p_t^{*frg} - p_{d,t}) + D_{19}[(p_t^{*frg} - p_{d,t})_{t-1} - s_{t-1}] +$

$D_{20}\Delta(p_{d,t} - p_{m,t}) + D_{21}(p_{d,t} - p_{m,t})_{t-1} + D_H\sigma^2_{u,t,frg}$

INSTRUMENTS: Constant, Time, Time^2, $(P_t^{*i} - P_{d,t})_{t-1}$, $(P_{d,t} - P_{m,t})_{t-1}$, $\sigma^2_{u,i,t}$, $\sigma^2_{u,i,t-1}$, $Y_{i,t}$, $Y_{i,t-1}$, Y_{ust}, Y_{ust-1}, $M1_{i,t}$, $M1_{i,t-1}$, $M1_{ust}$, $M1_{ust-1}$. For i = UK, Japan, and FRG (in all three equations). "us" = United States. All variables are expressed in logs.

* Significant at $t_{53-29,\ 0.05}$ (Two-tailed) = 1.960

** Significant at $t_{53-29,\ 0.1}$ (Two-tailed) = 1.645

TABLE A4.8

CHOW TESTS OF COEFFICIENT STABILITY

PERIOD SPLIT: I. 1975.Q1 TO 1981.Q2
II. 1981.Q3 TO 1988.Q1

1. UNRESTRICTED MODEL BASED ON TABLE 4.1, USING 2SLS ESTIMATION.	
UNITED KINGDOM	$6.51 > F_{.05,8,45} = 2.16$
JAPAN	$19.21 > F_{.05,8,45} = 2.16$
W. GERMANY	$6.17 > F_{.05,8,45} = 2.16$
2. RESTRICTED MODEL BASED ON TABLE 4.3, USING 2SLS ESTIMATION.	
UNITED KINGDOM	$1.07 < F_{.05,2,49} = 3.19$
JAPAN	$11.51 > F_{.05,5,43} = 2.44$
W. GERMANY	$5.17 > F_{.05,5,41} = 2.44$

TABLE A4.9

INSTRUMENTAL VARIABLES CHOW TESTS: RESTRICTED MODELS

COUNTRY	**PARAMETER** **SR** [T Statistic]	**SHORT-RUN** **ELASTICITY** **1975:1 to 1981:2** (S. Error) [T Statistic]	**SHORT-RUN** **ELASTICITY** **1981:3 to1988:1** (S. Error)
U.K.	D4	1.056 (0.644) [1.641]	2.574 (0.851) [3.025]*
	D7	-0.000517 (0.00857) [-0.603]	-0.00602 (0.00485) [-1.241]
JAPAN	D10	2.090 (0.487) [4.291]*	3.353 (0.885) [3.787]*
	D11	0.0365 (0.113) [3.221]*	0.0343 (0.0697) [0.493]
	D12	1.106 (0.534) [2.071]**	1.052 (1.311) [0.802]
	D13	0.0585 (0.182) [3.213]*	0.0561 (0.102) [0.549]
	D15	-0.0175 (0.00777) [-2.259]*	-0.00322 (0.00354) [-0.909]
FRG	D18	2.188 (1.211) [1.807]**	3.146 (1.054) [2.986]*
	D19	0.226 (0.168) [1.348]	0.125 (0.0728 [1.722]
	D20	2.043 (0.557) [3.671]*	2.099 (0.876) [2.395]*
	D21	0.0452 (0.0334) [1.355]	0.0394 (0.0154) [2.561]*
	D23	-0.00267 (0.00249) [-1.069]	-0.0161 (0.00538) [-2.985]*

TABLE A4.9 (Cont.)

SUMMARY STATISTICS

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1975:1 TO 1981:2

	UK	**JAPAN**	**FRG**
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	0.0439	0.0156	0.0233
NUMBER OF OBSERVATIONS	26	26	26
SUM OF SQUARED RESIDUALS	0.0545	0.0287	0.0258
STANDARD ERROR OF THE REGRESSION	0.0477	0.0370	0.0351
MEAN OF DEPENDENT VARIABLE	0.00433	-0.0119	-0.00396
STANDARD DEVIATION	0.0499	0.0498	0.0458
R-SQUARED	0.123	0.537	0.507
ADJUSTED R-SQUARED	0.0863	0.449	0.413
DURBIN-WATSON STATISTIC (with constant)	2.150	2.200	2.381

CONVERGENCE ACHIEVED AFTER 1 ITERATION: SAMPLE : 1981:3 TO 1988:1

	UK	**JAPAN**	**FRG**
VALUE OF THE MIN. DIST. CRITERION (E'HH'E)	0.0465	0.0219	0.0174
NUMBER OF OBSERVATIONS	27	27	27
SUM OF SQUARED RESIDUALS	0.0698	0.0229	0.0282
STANDARD ERROR OF THE REGRESSION	0.0528	0.0323	0.0358
MEAN OF DEPENDENT VARIABLE	0.00545	-0.0201	-0.0113
STANDARD DEVIATION	0.0594	0.0574	0.0558
R-SQUARED	0.238	0.733	0.652
ADJUSTED R-SQUARED	0.208	0.684	0.588
DURBIN-WATSON STATISTIC (with constant)	1.398	2.134	2.307

* Significant at $t_{27-15,\ 0.05}$ (Two-tailed) = 2.179

** Significant at $t_{27-15,\ 0.1}$ (Two-tailed) = 1.782

TABLE A4.10

PASS THROUGH ESTIMATES IMPLIED BY LONG-RUN ELASTICITIES OF TABLE A4.6

U. K.

$$\hat{p}_{m,t} = 0.609*(p_t^* - \hat{s}_t) + (1-.609)*p_{d,t} - .00253*\sigma^2_{u,t},$$

(0.179)	(0.179)	(0.00197)
[3.405]	[2.186]	[-1.286]

JAPAN

$$\hat{p}_{m,t} = 0.583*(p_t^* - \hat{s}_t) + (1-0.583)*p_{d,t} - 0.122*\sigma^2_{u,t}$$

(0.0700)	(0.0700)	(0.116)
[8.343]	[5.962]	[-1.06]

(Standard errors are in parentheses whilst t statistics are in brackets.)

CONFIDENCE INTERVALS FOR PASS-THROUGH COEFFICIENTS

COUNTRY	VARIABLE	POINT ESTIMATE	90% CONFIDENCE INTERVAL	95% CONFIDENCE INTERVAL
U.K.	$(p_t^* - \hat{s}_t)$	0.609	0.303 to 0.915	0.240 to 0.978
	$p_{d,t}$	0.391	0.0848 to 0.697	0.0215 to 0.760
	$\sigma^2_{u,t}$	-0.00253	-0.00590 to -0.000824	-0.00660 to 0.00154
JAPAN	$(p_t^* - \hat{s}_t)$	0.602	0.482 to 0.722	0.456 to 0.746
	$p_{d,t}$	0.398	0.278 to 0.518	0.254 to 0.542
	$\sigma^2_{u,t}$	-0.139	-0.337 to 0.059	-0.378 to 0.100

CHAPTER 5

5. Conclusions

5.1 Concluding Remarks

Chapter Two began with profit-maximising models of exporting firms, building upon existing theoretical literature. The assumption of a stochastic exchange rate led to differing effects depending on which currency the exporter set price. Invoicing in the importing country's currency led to a positive relationship between exchange-rate variance and import prices whilst invoicing in the home currency had the opposite effect.

Unlike the theoretical literature discussed in Chapter One, these models were forged into a single estimable equation. Aggregate data for the United Kingdom, Japan and Federal Republic of Germany, representative countries which have a substantial share of the export market to the US, comprised the basis of testing.

But before the pass-through equations could be estimated, several key issues needed to be addressed. Firstly, there was the question of forward covering. Risk-averse exporters pricing in US dollars could fully cover revenues and not be affected by exchange-rate variances. However, it was shown that they would not cover fully if the forward price of foreign exchange was less than the expected future spot rate. Some tradeoff between higher expected profit and risk would be optimal.

The second problem that needed remedy was how to obtain exchange-rate variances for the three countries. Fortunately, both problems were solved simultaneously through use of an ARCH-In-Mean model. The mean equation consisted of the forward forecast error being regressed chiefly on a constant plus exchange-rate variance. Exchange-rate variance was estimated simultaneously as an ARCH model. Estimation based on quasi-weekly data (1974 to 1988) revealed a significant and negative coefficient for exchange-rate variance as well as a predominantly negative risk premium for Japan (i.e. forward rate less than expected future rate). On the other hand, the UK and Germany exhibited insignificant coefficients on exchange-rate variance. Notably all currencies exhibited strong evidence of ARCH effects; the exchange-rate variances which were by-products of ARCH-In-Mean could be used in subsequent estimation of the pass-through models.

Efficient estimation dictated recasting the pass-through equation in purchasing power parity (PPP) form. That is, with the exchange rate as dependent variable. Additionally the three equations were embedded within error-correction mechanisms so as to take account of short-run deviations from equilibrium. Three stage least squares afforded incorporation of cross-country correlation as well as endogeneity of some of prices and exchange rates. Interestingly the PPP restriction held for all three countries in the long run whilst only for the UK in the short run.

The long-run coefficients for the UK and Japan were acceptable enough to be reworked into the original pass-through form. They provided interesting representative cases. Previously it had been found that a significant and negative risk premium existed for the Yen. Theory suggested that exporters pricing in US currency would optimally cover only a portion of revenues in this situation. So the positive influence of exchange rate variance on US import prices should be felt. Since there are approximately equal numbers of exporters invoicing in either currency the negative and positive effects of exchange-rate variance would be expected to cancel each other out. This in fact was supported by the reworked pass-through equation for Japan where exchange-rate variance was statistically insignificant. Notably the situation differed for the UK where it was significant and negative. Again this was the predicted outcome based on theory from Chapter Two. Exporters invoicing in US dollars would find it optimal to cover as evidence in Chapter

Three showed no significant risk premium. Thus the negative impact of variance on US import prices was expected. In fact the UK pass-through equation did exhibit a latently significant and negative coefficient for exchange-rate variance.

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