

## Bilateral Exchange Rates and Risk Premia

EDUARD J. BOMHOFF AND KEES G. KOEDIJK\*

*Erasmus University Rotterdam, Burgemeester Oudlaan 50, PB 1738,  
3000 DR Rotterdam, The Netherlands*

The paper develops a theoretical model of the risk premium in a bilateral exchange rate. Representative agents in both countries are assumed to hold open positions in foreign exchange together with risky assets denominated in their own currencies. Also, past surpluses in the current account of the balance of payments lead to net foreign asset positions which may (partially) be covered in the forward markets. Our two-period mean-variance model for optimizing investors is combined with standard assumption about the behavior of real exchange rates to give a reduced-form equation for the discrepancies between spot rates and lagged forward rates. The model is tested for the dollar–DM, dollar–sterling and dollar–yen exchange rates using monthly data for the period 1976–86. The null hypothesis of no risk premium is rejected for each of the currencies reported.

Since the early 1980s one has been confronted in the field of empirical exchange rate research with a recurring conflict between theory and observation. In a recent study Meese and Rogoff (1985) compared the predictions of several economic models of exchange rate behavior and concluded that none of the models outperformed the lagged spot rate in predicting the current spot rate out of sample. However, it remains a major challenge to explain the persistent appreciation of the dollar since 1981 and the reversed movement of this currency since March 1985. The explanations that are given to explain the course of the dollar range from the non-clearing of financial markets, substantial short-term movements in the fundamentals, the existence of speculative bubbles, to the role of central market intervention by central banks. One variable which is often overlooked or dismissed when discussing the course of the exchange rate is the risk premium. This seems to be based on two major grounds. The first is the theoretical notion that conventional estimates of the degree of risk aversion imply that the risk premium is extremely small and hence is quantitatively negligible.<sup>1</sup>

This argument is convincing if one accepts the maintained hypothesis that the conditional variance of excess asset returns is constant over time. Recent research by Giovannini and Jorion (1987) shows that the assumption of conditional

\* A previous draft of this paper was presented in seminars at the University of Leuven and at UCLA. We are grateful to Stanley Black, Sebastian Edwards, Paul de Grauwe, Clemens Kool, Allan Meltzer, Patrick Minford, Manfred Neumann, Richard Sweeney and an anonymous referee for useful comments and suggestions. All remaining errors are our own.

homoskedasticity of returns is invalid and consequently the exchange risk premium can be much larger. Moreover in a recent study Frankel and Froot (1985) provide suggestive evidence with survey data that the exchange risk premium has varied on average between approximately 2 and 10 per cent on an annual basis. The second line of argument why risk has often been dismissed in empirical studies is that it has turned out to be very difficult to develop an economic model of the risk premium in the foreign exchange market which is also empirically relevant and tractable.

Statistical tests of the hypothesis that a risk premium exists in the foreign exchange market generally have taken the form of investigating the unbiasedness of the current forward rate as a predictor of the future spot rate.<sup>2</sup> In many cases the logarithmic difference between the future spot rate appears to have a mean value which differs significantly from zero. Moreover this difference often has non-zero autocorrelations. If we assume that spot and forward markets in foreign exchange are efficient, it follows from these tests that non-zero risk premia must be present in the foreign exchange market. Such statistical tests are unable, however, to deliver positive insights about the sources of risk in international investment or statements which could be useful for international investors or political authorities.

In this paper we develop a partial-equilibrium theoretical model for the risk premium in the foreign exchange market. Working in the tradition of the finance literature, we have specified stochastic processes for the forcing variables that drive the two respective economies and have assumed that risk-averse investors can augment their domestic portfolios by engaging in open positions in the foreign exchange market.

Besides voluntary exposure in the forward market, we also allow for exposure due to current account imbalances. Past surpluses in the current account of the balance of payments lead to net foreign asset positions which may be covered in the forward market. Using a simple mean-variance model we then derive a condition for the required risk premium in the foreign exchange market. The main determinants of the risk premium are the covariance between movements in the return on the domestic portfolio and changes in the exchange rate, the covariance between movements in the foreign market portfolio and changes in the exchange rate and the variance of changes in the exchange rate.

The theoretical analysis is contained in Section I of the paper. In Section II we discuss a reduced-form equation for the difference between the log of the current spot rate and the log of the lagged forward rate, which combines the mean-variance model of Section I with the general notion that spot rates differ from lagged forward rates due to a combination of news and risk. Some additional structure is helpful here; we follow Isard (1983) and connect the current real exchange rate through its expected future rate of change to the long-term real exchange rate in equilibrium.

Section III contains empirical results for the dollar-DM, dollar-pound and dollar-yen exchange rates for the period 1976-86. The empirical findings suggest that at least some of the proxies for risk factors which follow from our theoretical model—the variance of unexpected movements in US interest rates and the variance of unexpected movements in US inflation—do contribute towards an explanation of the discrepancies between the spot rate and the lagged forward rate. Thus the paper not only provides additional evidence against the hypothesis that the forward rate is an unbiased predictor of the future spot rate but also evidence for the reasons. Section IV contains a summary and concluding remarks.

### I. The Risk Premium in a Bilateral Exchange Rate

In this section we apply a basic two-period mean-variance model to a bilateral international setting. Representative investors in each of the two countries hold a portfolio of domestic assets and try to improve the risk-return characteristics of this portfolio through forward exchange operations. Foreign investments are limited to open positions in the one-month forward currency market. We assume that a representative investor in the United States has the opportunity to bet with a representative investor in Germany about next period's exchange rate through assuming uncovered positions in the foreign exchange market.<sup>3</sup> The derivation takes the United States and Germany as the foreign and domestic countries, respectively. Identical models will be implemented empirically for the United Kingdom and Japan.

Assume that a representative investor in the United States holds a portfolio which consists of short-term (riskless) and risky domestic assets. Additionally, the representative investor may engage in bets on the forward market for foreign exchange. The representative US investors may, for instance, borrow short in the Germany money market, convert the proceeds to dollars and invest the dollars short term in his home country. At the end of the one-month investment period the US investor repays the loan and realizes a pure foreign exchange gain or loss. The two trades in the foreign exchange market require a German investor who is interested in the opposite set of transactions. Together the representative investors in the two countries determine the quantity of risk and the price of pure foreign exchange risk in the foreign exchange market. We define  $e_{t+1}$  as being the logarithm of the future spot rate, measured as marks per dollar, and  $f_t$  the currently quoted forward rate.

Equation <1> shows the optimization problem faced by the representative US investor who wishes to maximize his one-period total return.

$$\begin{aligned} \langle 1 \rangle \quad \max_{w, t, X} E & \left[ i_{US} + \frac{B_{US}}{W_{US}} q_{US} - \frac{X}{W_{US}} (e_{t+1} - f_t) - \frac{k}{W_{US}^2} \right. \\ & \left. \times \{ B_{US}^2 q_{US}^2 + X^2 \text{var}(e_{t+1} - f_t) - 2B_{US}X \text{cov}(q_{US}, e_{t+1}) \} \right]. \end{aligned}$$

$E[\dots]$  represents a mathematical expectation,  $i_{US}$  is the certain one-period nominal return,  $q_{US}$  is the uncertain part of the return on the risky assets of the domestic portfolio,  $W_{US}$  is aggregate nominal wealth of all US investors,  $B_{US}/W_{US}$  indicates the fraction of total US wealth that carries an uncertain rate of return and  $X/W_{US}$  indicates the extent to which the representative US investor seeks exposure to foreign exchange risk. With  $X$  equal to 0 the investor avoids foreign exchange risk, with  $X$  equal to  $W_{US}$  each US investor assumes foreign exchange rate risk to the full extent of his portfolio. The parameter  $k$  indicates the degree of relative risk aversion, which we assume to be equal for the representative investors in both countries,  $\text{var}(e_{t+1} - f_t)$  represents the variance of unexpected discrepancies between the future spot rate and the current forward rate, and  $\text{cov}(q_{US}, e_{t+1})$  represents the covariance between unexpected movements in the US domestic portfolio and the return on the open position in foreign currency.

In equation 1 the investor maximizes the expected utility of nominal wealth since we assume that short-term uncertainty regarding the price level in the next period

may be neglected.<sup>4</sup> By contrast, most portfolio balance models of exchange rate determination assume uncertainty about next period's price level but make the simplifying assumption that the only uncertain element in the nominal holding-period yields is the currency exposure.<sup>5</sup>

Equation <2> formalizes the corresponding optimization problem for the representative German investor. We assume that all international capital flows are denominated in dollars and that Germany has accumulated through past surpluses in the current account a net foreign asset position which at time  $t$  amounts to  $CCAB$  dollars for each representative German investor. The additional voluntary exposure for the German investor amounts to  $Y$  marks so that his total dollar exposure is equal to the dollar value of  $Y + E_t \cdot CCAB$  marks, where  $E_t$  denotes the level of the exchange rate.

The optimization problem for the German investor combines the uncertain return on the domestic German portfolio with the uncertain return on an open position in dollars:

$$\begin{aligned} \langle 2 \rangle \quad \max_{w, r, t, y} E & \left[ i_D + \frac{B_D}{W_D} q_D + \frac{Y}{W_D} (e_{t+1} - f_t) + \frac{E_t \cdot CCAB}{W_D} (e_{t+1} - f_t) - \frac{k}{W_D^2} \right. \\ & \times \{ B_D^2 q_D^2 + (Y + E_t \cdot CCAB)^2 \text{var}(e_{t+1} - f_t) \\ & \left. + 2B_D(Y + E_t \cdot CCAB) \text{cov}(q_D, e_{t+1}) \} \right], \end{aligned}$$

where  $W_D$  represents total wealth in marks of the representative German investor and  $\text{cov}(q_D, e_{t+1})$  represents the covariance between unexpected movements in the total return on the risky German assets and unexpected movements in the exchange rate.

Equations <1> and <2>, together with the equilibrium condition  $Y = E_t \cdot X$ , may be solved for the three unknowns  $X$ ,  $Y$  and  $E(e_{t+1} - f_t)$ , the expected value of the risk premium. The model derived here is a partial one, since domestic rates of return and their variance-covariance properties are assumed to be given. Also lacking is a feedback from changes in the exchange rate to domestic interest rates, other domestic rates of return and the inflation rate. On the other hand, the model avoids unattractive assumptions used in other models of exchange rate determination: there is no assumption of continuous purchasing power parity, investors in different countries may hold different portfolios, and the model posits an optimization problem not only for a US investor but also from a German perspective.

The solution for the risk premium equals:

$$\begin{aligned} \langle 3 \rangle \quad E(e_{t+1} - f_t) &= \frac{2kCCAB}{W^*} \text{var}(e_{t+1} - f_t) + \\ & 2k[b_{US} \text{cov}(q_{US}, e_{t+1}) + b_D \text{cov}(q_D, e_{t+1})], \end{aligned}$$

where  $W^*$  is world wealth denominated in dollars ( $W_{US} + W_D/E_t$ ),  $b_{US}$  is defined as  $B_{US}/(W_{US} + W_D/E_t)$  and  $b_D$  as  $B_D/(W_{US} \cdot E_t + W_D)$ .

Some interesting special cases are:

1.  $CCAB = 0$ ,  $B_D = 0$  and  $B_{US} \neq 0$ . In this case the sign of the risk premium is equal to the sign of  $\text{cov}(q_{US}, e_{t+1})$ . Thus, if factors which have a positive influence on

the unexpected part,  $q_{US}$ , of the *ex-post* returns in the United States also cause an appreciation of the dollar during the same time period, then the risk premium is positive and  $X$  and  $Y$  are also positive. In this case, the German investors enjoy the expectation of a positive return on their forward exchange bets; the Americans accept a negative expected return on their open position in marks, since their foreign exchange exposure improves the risk-return characteristics of their portfolio.

2.  $CCAB=0$  and both covariances  $\text{cov}(q_{US}, e_{t+1})$  and  $\text{cov}(q_D, e_{t+1})$  equal to zero. In this special case the risk premium must be zero and open positions in foreign currency are unattractive at all nonnegative prices. Both  $X$  and  $Y$  are zero.
3.  $CCAB=0$ ,  $b_{US}=b_D$  and  $\text{cov}(q_{US}, e_{t+1})$  equals  $-\text{cov}(q_D, e_{t+1})$ . This situation applies if both economies are equal in size and if the domestic returns in each country fluctuate *ex-post* in step with changes in the (real) exchange rate. In this special case the risk premium equals zero but  $X$  and  $Y$  are generally not zero; open positions in foreign exchange are helpful in the context of risk diversification and the non-zero covariances with the unexpected parts of the domestic rates return make foreign exchange risk acceptable at a non-zero price.

## II. Testable Implications

Equation <3> in the preceding section relates the exchange risk premium to a weighted average of two covariance terms and the cumulated current account term. Since the risk premium cannot be observed in isolation, one has to embed one's model for the risk premium in a testable specification for one or more observable variables. A useful framework connects changes in the current real exchange rate to either corresponding changes in the long-term equilibrium value of the real exchange rate or to changing perceptions of the speed with which the current real exchange rate approaches its long-term equilibrium. Let the long-term equilibrium real exchange rate be  $er_x$ . Agents hold homogeneous views on this long-term real exchange rate ('the anchor') and on the speed at which the current real exchange rate will move towards its long-term value ('the rope')—illuminating metaphors taken from Isard (1983) and Edwards (1983).

We postulate that the difference between the log of the current real exchange rate and the log of its expected long-term value is a linear function of the differential between the two current *ex-ante* real interest rates on the one hand and the current assessment of the risk premium on the other.<sup>6</sup>

$$\langle 4 \rangle \quad e_t - P_D + P_{US} - A(r_{US} - r_D) + B_t E(e_{t+1} - f_t) = {}_t E(er_x)$$

current  
real  
exchange  
rate

real  
interest  
differential

risk premium

long-run  
real  
exchange  
rate

with  $A, B > 0$ .

The formulation in equation <4> is appropriate if agents expect both the real interest differential and the current risk premium to converge towards zero. We do not impose the restriction that the real interest rate differential and the risk premium disappear with the same speed. In our empirical analysis, we find some evidence for an effect of the variability of US interest rates on the risk premium and there is no *a priori* reason why such a risk factor would have to disappear over time at the same speed with which any current real interest differential converges towards zero.<sup>7</sup>

The relationship between the current real exchange rate, the real interest rate differential, the risk premium and the long-term real exchange rate must also hold in terms of the expectations of these four variables as held by economic agents during the period preceding period  $t$ . Rewriting equation <4> in terms of these expectations and subtracting, we obtain:

$$\begin{aligned} \langle 5 \rangle \quad e_t - e'_t = & P_D^r - P_{US}^r + A(r_{US}^r - r_D^r) - B[E(e_{t+1} - f_t) - {}_{t-1}E_t E(e_{t+1} - f_t)] \\ & + {}_t E e r_x - {}_{t-1} E e r_x, \end{aligned}$$

where  $P_D^r$  represents the unexpected change in the current German price level. It may be advantageous in practical applications to define the current price level in this context as the equilibrium value of the price level which corresponds to the current value of its macroeconomic determinants.  $P_{US}^r$  represents the unexpected change in the US price level. Similarly,  $r_{US}^r$  represents the unanticipated change in the real rate of interest in the USA and  $r_D^r$  stands for the unexpected change in the German real rate of interest. The remaining two terms in equation <5> refer to revisions of expected values. We may rewrite equation <5> in the following way:

$$\langle 6 \rangle \quad e_t - e'_t = P_D^r - P_{US}^r + A(r_{US}^r - r_D^r) - B r p^r + e r_x^r,$$

with  $r p^r$  representing news about the risk premium.

Next we combine equation <6> with the general notion that spot rates differ from lagged forward rates due to a combination of news and risk:

$$\langle 7 \rangle \quad e_{t+1} - f_t = (e_{t+1} - e'_{t+1}) + (e'_{t+1} - f_t).$$

spot rate – lagged forward rate = news + risk.

If we shift equation <7> one period backwards in time and add it to equation <6>, we obtain the following expression:

$$\langle 8 \rangle \quad e_t - f_{t-1} = P_D^r - P_{US}^r + A(r_{US}^r - r_D^r) - B r p_t^r + r p_{t-1} + e r_x^r,$$

in which  $r p_{t-1}$  is the lagged level of the risk premium.

Equation <8> thus has the observable difference between the log of the current spot rate and the log of last period's forward rate on the left-hand side and a combination of 'news' and 'risk' on the right-hand side. Note that changes in the risk premium, multiplied by  $B$  are one element in the 'news' of the current period. Since  $B$  is a positive constant, the unexpected change in the assessment of the risk premium and last period's estimated risk premium have different signs in the expression for  $e_t - f_{t-1}$ . In our view this is one fundamental reason why it is so difficult to test empirically hypotheses about risk premia in the foreign exchange market. Formally, the situation where both the level and the first difference of an unobservable variable are important, but affect the dependent variable in different directions, is similar to the determination of share prices if we make the simplifying assumption that the shareholder gets his return in the form of capital gains. If the required real rate of return on a share is high, share prices may be expected to increase rapidly. If, however, the required real rate of return increases unexpectedly without a corresponding change in the expected stream of future earnings, current share prices have to fall. In the foreign exchange market, a high positive risk premium on our definition implies a weak dollar, because the dollar is expected to appreciate a little more each period than would be indicated by the forward premium. A low initial value of the dollar is then required. If the risk premium

increases unexpectedly the dollar has to depreciate further in order to reach its expected long-term equilibrium value on a rational expectations path. It follows that the expected value of  $e_t - f_{t-1}$  is positive if there is no change in the assessment of the risk premium, but the *ex-post* realizations may be strongly negative if there is a strong increase in the risk premium. If the empirical counterparts to the risk premium incorporate measurement errors or are included with inappropriate lags then statistical tests will be biased towards no rejection of the null hypothesis of a negligible risk premium.

Next we link the dynamics of the price levels of both countries to movements in their respective inflation rates. From empirical test it appears that inflation has a unit root. Consequently we adopt the following *time-varying* ARIMA specifications:

$$\langle 9 \rangle \quad \Delta E_t \hat{p}_{US} = \theta_{US} (\hat{p}_{US} - E_{t-1} \hat{p}_{US}) = \gamma_{US} (P_{US} - E_{t-1} P_{US})$$

and

$$\Delta E_t \hat{p}_D = \theta_D (\hat{p}_D - E_{t-1} \hat{p}_D) = \gamma_D (P_D - E_{t-1} P_D)$$

Now let us define  $\psi_{US} = 1/\gamma_{US}$  and  $\psi_D = 1/\gamma_D$ . Then, as is the case with univariate Box-Jenkins models, changes in the expected rate of inflation are seen to be directly proportional to unexpected movements in the price level:

$$\langle 10 \rangle \quad P_{US}^u = \psi_{US} \Delta E \hat{p}_{US}$$

and

$$P_D^u = \psi_D \Delta E \hat{p}_D.$$

The time-varying character of this equation is implemented by using a so-called Multi-State Kalman Filter.<sup>8</sup>

In addition to news regarding the domestic and foreign price levels, equation  $\langle 8 \rangle$  also includes news about the domestic and foreign real rates of interest, news about the risk premium in the foreign exchange market and news about the future equilibrium value of the real exchange rate. From empirical tests it appears that interest rates follow approximately a random walk. Consequently we assume that news about interest rates can be adequately described by the first difference of  $i_{US}$  and  $i_D$  respectively.

With respect to the determinants of the long-run equilibrium real exchange rate and the dynamics therein, very little is known. In a recent study, Huizinga (1987) did apply cointegration tests on real exchange rates and several macroeconomic variables and found very little evidence for the hypothesis that the long-run movements of the real exchange rate are restricted by the movements of other observable variables. Since the long-term equilibrium value of the real exchange rate is an unobservable variable, any assumptions regarding its stochastic behavior and its macroeconomic determinants have to be tested jointly with the other assumptions embedded in the exchange rate model. We hypothesize that the real exchange rate in future equilibrium is a function of the long-run differences in inflation and economic growth between the two countries.<sup>9</sup> If rates of inflation and economic growth converge over the long run, then the long-run value of the real exchange rate should correspond to purchasing power parity.<sup>10</sup> However, if the long-run characteristics of the countries differ in important respects there may be persistent capital flows. In such a case, the real exchange rate would settle at a level

which would induce a long-run capital flow and a corresponding non-zero value for the current account. There is, however, no direct empirical evidence to bear on these assumptions regarding the determinants of the long-run real exchange rate. Also we do not know with what speed the real exchange rate moves towards its long-run equilibrium value. We therefore opt for a flexible specification in which the coefficients  $C$  and  $D$  are proportional to the 'length' of the 'rope' and the movements in the 'anchor':

$$\langle 11 \rangle \quad \Delta e_{t,t} = C(\Delta_t E \hat{y}_{US} - \Delta_t E \hat{y}_D) - D(\Delta_t E \hat{p}_{US} - \Delta_t E \hat{p}_D) + u_t.$$

This implies that all movements in the equilibrium value of the real exchange rate are unexpected.

Substitution of equations  $\langle 10 \rangle$  and  $\langle 11 \rangle$  and some rearrangement gives:

$$\begin{aligned} \langle 12 \rangle \quad e_t - f_{t-1} = & A(\Delta_t i_{US} - \Delta_t i_D) + (-A - D - \psi_{US}) \Delta_t E \hat{p}_{US} \\ & + (A + D + \psi_D) \Delta_t E \hat{p}_D + C \Delta_t E \hat{y}_{US} - C \Delta_t E \hat{y}_D \\ & + r p_{t-1} - B r p_t^e + u_t. \end{aligned}$$

For convenience we assume that in each country the first differences of interest rates, expected inflation rates and expected economic growth are independent of each other. Statistical tests of this hypothesis show that the assumption of statistical independence does not need to be rejected for either country. It now remains to specify the causes of non-zero changes in  $q_{US}$  and  $q_D$ . In selecting the determinants of the expected return on the market portfolio, we follow Fama and Gibbons (1982) who found that the expected return on bonds and stocks is negatively correlated with expected inflation and positively correlated with real activity represented by the expected economic growth rates:<sup>11</sup>

$$\begin{aligned} \langle 13 \rangle \quad \Delta q_{US} = & \varepsilon(q_{US}, i_{US}) \Delta_t i_{US} + \varepsilon(q_{US}, p_{US}) \Delta_t E \hat{p}_{US} \\ & + \varepsilon(q_{US}, y_{US}) \Delta_t E \hat{y}_{US} + u_{q,US}, \end{aligned}$$

and

$$\begin{aligned} \langle 14 \rangle \quad \Delta q_D = & \varepsilon(q_D, i_D) \Delta_t i_D + \varepsilon(q_D, p_D) \Delta_t E \hat{p}_D \\ & + \varepsilon(q_D, y_D) \Delta_t E \hat{y}_D + u_{q,D}, \end{aligned}$$

where all  $\varepsilon$  coefficients are elasticities. Unexpected rates of return decrease if interest rates or expected rates of inflation go up and increase or remain unchanged if the expected future rate of economic growth increases.

The only variables of equation  $\langle 12 \rangle$  that have not been dealt with so far in this section are the risk terms. In the preceding section we showed that  $\text{cov}(q_{US}, e_{t+1})$ ,  $\text{cov}(q_D, e_{t+1})$  and  $\text{var}(e_{t+1})$  are the theoretical determinants of the risk premium. We get an expression for  $\text{cov}(q_{US}, e_{t+1})$  and  $\text{cov}(q_D, e_{t+1})$  by multiplying expression  $\langle 12 \rangle$  with expressions  $\langle 13 \rangle$  and  $\langle 14 \rangle$ . We assume with this computation that the exogenous variables are not serially correlated.<sup>12</sup> The resulting determinants of the risk premium in the foreign exchange market are: the variance of unexpected movements in US and German interest rates, the variance of unexpected movements in US and German inflation, and the variance of unexpected movements in US and German growth rates. In Table 1 we report the theoretical signs of the determinants of the risk premium.

With these determinants of the risk premium we are able to estimate equation



TABLE 1. Theoretical signs of the determinants of the risk premium in equation for difference between log of the spot rate and the lagged forward rate.

---

$\text{Var}(\Delta i_m) < 0$
$\text{Var}(\Delta \tilde{p}_m) > 0$
$\text{Var}(\Delta \tilde{y}_m) > 0$
$\text{Var}(\Delta i_p) > 0$
$\text{Var}(\Delta \tilde{p}_p) < 0$
$\text{Var}(\Delta \tilde{y}_p) < 0$
$\text{Var}(e) \cdot (CCAB/W^*) > 0$

---

<12> empirically and to test the effects of changes in long-term real exchange rates, interest rates, inflation rates and risk premia on the observed difference between the spot rate and the lagged forward rate.

### III. Empirical Results

In this section, the implications of the model derived in Section II are empirically tested using monthly data for the dollar-DM, dollar-pound and dollar-yen exchange rates for the period January 1976 to March 1986. We omitted four large outliers in the exchange rate data: October and November 1978 and March and April 1985. During the fall of 1978 the dollar was continuously depreciating despite actions by the monetary authorities to stop this depreciation. On November 1, the Federal Reserve Board announced a series of policy actions which led to a sharp rise in the value of the dollar. In early 1985, quite the opposite occurred. The Federal Reserve became increasingly concerned by the negative impact of an exceptionally strong dollar on manufacturing output, employment and profitability and began to ease aggressively, leading to a sharp drop in the exchange rate.

With respect to the estimation we used the seemingly unrelated regressions procedure (SUR) since all exchange rates are bilateral exchange rates *vis-à-vis* the US dollar and we expect the exchange rate movements to be highly correlated. It is also known that exchange rates are characterized by periods of relative calm and turbulence so that exchange rate regressions typically exhibit conditional heteroskedasticity. We used White's method (1980) to make the covariance matrix robust to heteroskedasticity.<sup>13</sup>

In implementing our theoretical model, we have tried to incorporate in every equation the determinants of the long-run real exchange rate, the expected inflation differential and economic growth differential as well as the real interest rate differential between the United States and the other country. For econometric reasons we inserted the nominal interest rate and expected inflation separately. In addition to these factors, we have tested for all the determinants of the risk premium that follow from our model: the variance of the change in the short-term interest rate, the variance of the change in the expected inflation, the variance of the change in expected economic growth and the variance of the exchange rates times

TABLE 2. SUR estimates for dollar-DM, dollar-pound and dollar-yen exchange rates. January 1976 to March 1986.

$$e - f_{-1} = \alpha_0 + \alpha_1 \Delta(i_{us} - i_s) + \alpha_2 \Delta(\hat{p}_{us} - \hat{p}_s) + \alpha_3 \text{var}(\Delta i_{us})_{-1} \\ + \alpha_4 \text{var}(\Delta \hat{p}_{us})_{-1} + \alpha_5 (\text{var}(e) \cdot CCIBW^*)_{-1} + \alpha_6 \cdot \text{DUMMY}$$

Rate	$\alpha_0$	$\alpha_1$	$\alpha_2$	$\alpha_3$	$\alpha_4$	$\alpha_5$	$\alpha_6$	D.W.	s.e.e.
Dollar-DM	0.11 (0.03)	1.21 (0.50)	-2.17 (1.44)	-0.47 (0.87)	1.94** (2.96)	—	—	1.72	0.030
	-8.03** (2.14)	1.25 (0.52)	-2.00 (1.36)	-0.79 (1.51)	1.61** (2.47)	—	14.76** (2.24)	1.79	0.030
Dollar-pound	0.74 (0.19)	-1.35 (0.82)	-1.51* (1.72)	-1.30** (2.76)	1.77** (3.23)	0.52* (1.96)	—	1.69	0.030
	-2.84 (0.53)	-1.36 (0.83)	-1.49* (1.67)	-1.45** (2.98)	1.63** (2.90)	0.52* (1.71)	6.48 (0.81)	1.72	0.030
Dollar-yen	-3.73 (0.99)	-0.75 (0.30)	-0.43 (0.42)	-1.51* (1.85)	2.04** (2.80)	—	—	1.65	0.033
	-6.69** (1.37)	-0.74 (0.30)	-0.45 (0.43)	-1.63* (1.98)	1.92** (2.54)	—	5.37 (0.72)	1.65	0.033

*t*-statistics are in parentheses.

\*\* = significant at 5 per cent confidence level.

\* = significant at 10 per cent confidence level.

TABLE 3. SUR estimates for the dollar-DM, dollar-pound and dollar-yen exchange rates. January 1976 to October 1979.

$$e - f_{-1} = \alpha_0 + \alpha_1 \Delta(i_{us} - i_s) + \alpha_2 \Delta(\hat{p}_{us} - \hat{p}_s) + \alpha_3 \text{var}(\Delta i_{us})_{-1} \\ + \alpha_4 \text{var}(\Delta \hat{p}_{us})_{-1} + \alpha_5 (\text{var}(e) \cdot CCIBW^*)_{-1}$$

Rate	$\alpha_0$	$\alpha_1$	$\alpha_2$	$\alpha_3$	$\alpha_4$	$\alpha_5$	D.W.	s.e.e.
Dollar-DM	-8.24** (2.24)	-12.19** (5.26)	1.83 (1.61)	-11.07 (0.82)	3.60** (4.30)	—	1.84	0.016
Dollar-pound	-1.59 (0.22)	-7.40** (2.73)	0.57 (0.54)	9.66 (0.45)	-0.69 (0.38)	0.54 (0.87)	1.49	0.027
Dollar-yen	-13.55** (3.27)	-7.52* (2.28)	2.96** (2.90)	19.08 (0.88)	6.25* (1.79)	—	1.33	0.025

*t*-statistics are in parentheses.

\*\* = significant at 5 per cent confidence level.

\* = significant at 10 per cent confidence level.

the cumulated current account.<sup>14</sup> This implies for each bilateral exchange rate a total of seven potential risk variables. The risk factors were modelled separately for each country since according to equation <3> the weights will differ.

The empirical results are presented in Tables 2 to 4. Table 2 contains the full sample results. In Table 2 we also allow for a structural change in the relationship for the exchange rate during the final quarter of 1979, in view of the potentially important changes in the American monetary policy announced at that time. We inserted a dummy variable for November 1979 and all subsequent months.<sup>15</sup> Tables 3 and 4 contain estimates covering the two subperiods, January 1976 to October 1979 and November 1979 to March 1986.

TABLE 4. SUR estimates for dollar-DM, dollar-pound and dollar-yen exchange rates. November 1979 to March 1986.

$$e - f_{-1} = \alpha_0 + \alpha_1 \Delta(i_{us} - i_x) + \alpha_2 \Delta(\hat{p}_{us} - \hat{p}_x) + \alpha_3 \text{var}(\Delta i_{us})_{-1} \\ + \alpha_4 \text{var}(\Delta \hat{p}_{us})_{-1} + \alpha_5 (\text{var}(e) \cdot CCAB/W^*)_{-1}$$

Rate	$\alpha_0$	$\alpha_1$	$\alpha_2$	$\alpha_3$	$\alpha_4$	$\alpha_5$	D.W.	s.e.e.
Dollar-DM	6.79 (1.16)	4.70** (2.04)	-4.34** (2.13)	-0.57 (1.00)	1.34** (2.29)	—	1.60	0.033
Dollar-pound	3.17 (0.57)	1.64 (0.99)	-2.16* (1.66)	-1.27** (2.97)	1.66** (2.88)	0.56* (1.77)	1.61	0.030
Dollar-yen	-1.20 (0.22)	2.01 (0.67)	-2.53 (1.51)	-1.57** (2.32)	1.82** (2.71)	—	1.77	0.035

*t*-statistics are in parentheses.

\*\* = significant at 5 per cent confidence level.

\* = significant at 10 per cent confidence level.

Only contemporaneous values have been tested as news variables; one month lagged values for all risk factors. The presented tables contain the following explanatory variables: the change in the interest differential  $\Delta(i_{us} - i_x)$ ; the change in the expected inflation differential,  $\Delta(\hat{p}_{us} - \hat{p}_x)$ ; the variance of the change in the short-term US interest rate,  $\text{var}(\Delta i_{us})$ ; the variance of the change in the expected US inflation,  $\text{var}(\Delta \hat{p}_{us})$ ; and a constant,  $c$ . In addition to these variables the equation for the dollar-pound exchange rate contains the cumulated current account term,  $(\text{var}(e) \cdot CCAB/W^*)$ . In the case of the dollar-DM and the dollar-yen exchange rate, neither the level nor the change in the current account term proved to be significant.

A few things stand out from Table 2. News about expected inflation enters the equation with the correct sign, but is only significant at the 0.10 level in the case of the dollar-pound exchange rate. In Table 2, the variance of the change in expected US inflation is always significant at the 0.05 level, while the variance of the change in the short-term US interest rate is significant in the case of the dollar-pound at the 0.05 level and in the case of the dollar-yen at the 0.10 level. The term for the current account term proves to be significant in the case of the dollar-pound exchange rate. A further interesting feature of the regressions reported in Table 2 is the presence of risk terms with both positive and negative signs suggesting an exchange risk premium which can change sign.<sup>16</sup>

The results in Tables 3 and 4 reveal a slightly different pattern. The constant term and the change in the interest differential change sign, being negative in the first subperiod and positive in the second subperiod, and thus reflecting the strong depreciation and the persistent appreciation in the subsequent subperiods. Another interesting feature is the significance of news about the inflation differential in the equation for the dollar-DM during the 1979-86 period. Taken together, news about the nominal interest rate differential and news about the inflation differential reflect news about the real interest rate differential between the United States and Germany.<sup>17</sup> The variance of the change in the short-term US interest rate is statistically insignificant during the 1976-79 period but statistically significant during the 1979-86 period, while the variance of change in expected US inflation

TABLE 5. *F*-test on joint significance of news and risk factors.  
January 1976 to March 1986.

Rate	News	Risk
Dollar-DM	2.53*	2.45*
Dollar-pound	1.75	3.07**
Dollar-yen	0.15	2.95*

\*\*=Significant at 5 per cent confidence level.\*

\* =Significant at 10 per cent confidence level.

only fails to be significant during the 1976-79 period in the case of the dollar-pound exchange rate. In order to test for the joint significance of the news factors and the risk factors over the full sample period, we used a standard *F*-test.<sup>18</sup>

We found the risk factors to be significant explanatory variables, for each of the reported currencies, causing the forward rate to deviate from the expected future spot rate.

#### IV. Summary and Concluding Remarks

This paper develops and empirically implements a model of the risk premium in the foreign exchange market. Previous portfolio balance models found very little direct empirical evidence for such a premium. However, most of these studies assumed constant conditional second moments and concentrated on variation in asset supplies as major sources of exchange risk. Recent work by Cumby and Obstfeld (1984) and by Giovannini and Jorion (1987) rejects the constancy of conditional covariances of exchange rate returns and argues that this restriction should be relaxed. In the present paper, we derive a model for the risk premium in which variation in covariances and variances is the major source of exchange risk. By specifying a real exchange rate framework we link changes in the risk premium to macroeconomic variables like interest rates and inflation rates. In empirically testing the model for the dollar-DM, dollar-pound and dollar-yen exchange rates for the period January 1976 to March 1986, we find that at least two variables that follow directly from our theoretical model as determinants of the risk premium — the variance of changes in the short-term US interest rate and the variance of changes in the expected US inflation rate — are significant explanatory variables in regressions for the difference between the spot rate and the lagged forward rate.

Furthermore, our analysis provides a theoretical framework to analyze the determinants of the exchange risk premium in *economic* terms. The economic interpretation of the model is straightforward and worth spelling out. If movements in the US interest rate are a major source of uncertainty and do affect real rates of return on domestic and foreign investments in the same direction, the required rate of return on these foreign holdings will be higher for US-based investors. The market provides the required rise in the real rates by pushing up the value of the dollar to a point where some further depreciation should be thought of as more likely than a further appreciation. Thus a strong dollar makes foreign investments more attractive to US-based investors, since they have the perspective

of some future appreciation of the value of their future holdings. According to our results this effect did play a role in the strong appreciation of the dollar since 1981. However, much more theoretical and empirical work is required before we can speak of risk premia in international investment with the same degree of confidence as in discussions of the risk-return relationship in national stock markets.

### Appendix: Data Sources and Computation of Exogenous Variables

$e$	logarithm of the spot rate (end of period) price of one US dollar in DM, pounds and yen. Source: Federal Reserve Bank of St. Louis.
$f$	logarithm of the 1-month forward rate (end of period). Source: Federal Reserve Bank of St. Louis.
$y$	real gross national product. Source: Federal Reserve Bank of St. Louis.
$p$	consumer price index. Source: Federal Reserve Bank of St. Louis.
$i$	short-term interest rate (representative money market rates end of month). Source: World Financial Markets (Morgan Guaranty).
$CA$	current account balance. Source: International Financial Statistics.
$W$	wealth approximated by gross national product. Source: International Financial Statistics.

The data for the current account are available on a quarterly basis only. Monthly data were obtained by linear interpolation. These data were then cumulated from the beginning of 1974 onwards.

Monthly data for the wealth term were also obtained by linear interpolation.

A circumflex  $\hat{\phantom{x}}$  indicates a rate of growth, the superscript  $e$  an expected value. First differences are indicated by  $\Delta$ . All expectations were derived with a Multi-State Kalman Filter, as explained in Kool (1982).

The expressions for the variances were obtained by calculating the product of the first differences.

### Notes

1. See for instance Frankel (1986a, 1986b).
2. During the past few years an extensive literature on risk premia in foreign exchange markets has appeared. We refer to Hansen and Hodrick (1983), Cosset (1984), Fama (1984), Hodrick and Srivastava (1984), Domowitz and Hakkio (1985), Korajczyk (1985), Levich (1985), and Mark (1985) for theoretical and empirical contributions to the literature.
3. The model is inspired by Conroy and Rendleman (1983).
4. This does not imply that investors are not faced with inflation uncertainty. Rates of return may vary due to changing perceptions of future inflation and covariances between asset returns and exchange rate movements may deviate systematically from zero because of the effect of changes in inflationary expectations on the domestic financial markets and on the exchange rate.
5. See, for example, the survey article by Branson and Henderson (1985) in the *Handbook of International Economics*. On the other hand, our model has no wealth effects of changes in the exchange rate on the domestic part of the portfolio. We refer to Frankel (1979b) for further discussions of the wealth effects, albeit in a context of purchasing power parity.
6. See Frankel (1979a) and Edwards (1982) for models of exchange rate determination that are also based on real interest rate differentials.
7. It follows that the real exchange rate must exhibit mean reversion. This proposition has recently obtained some empirical support. See, for instance, Frankel (1986b) and Huizinga (1987). Earlier studies that concentrated on shorter-term behavior of the real exchange rate were unable to reject

- the hypothesis that exchange rates follow random walks. See, for instance, Roll (1979), Darby (1980), and Hakkio (1984).
8. For descriptions of the Multi-State Kalman filter, we refer to Bomhoff (1982), Bomhoff and Korteweg (1983), and Kool (1982).
  9. The empirical literature has taken only limited steps to endogenize the long-run real exchange rate. Examples are Hooper and Morton (1982), Lothian (1987), and Wolff (1987).
  10. Adler and Dumas (1983) provide an extensive discussion about the validity of assuming purchasing power parity.
  11. See Fama and Schwert (1977) and the references therein for evidence regarding the relationship between stock returns and unexpected inflation. Solnik (1983) and Gultekin (1983) provide further international evidence.
  12. With this derivation we must assume that unexpected movements in return on the market portfolio and unexpected movements in the risk premium in the foreign exchange market are uncorrelated.
  13. Evidence of heteroskedasticity was found for each of the reported currencies using a seventh-order autoregressive conditional heteroskedasticity (ARCH) specification.
  14. Little is known about the stochastic behavior of second moments of macroeconomic variables. For example, are observed increases in volatility temporary or permanent? We measure the expected variances by substituting last period's observed variance. Ideally, constrained estimation of time series models for all variances in the model should lead to appropriate expressions for the expected variances. See Pagan and Ullah (1986) for an econometric discussion of these and other issues arising in the econometrics of second moments.
  15. See Frenkel (1986) for further discussion of the evidence regarding a structural shift not only in US monetary policy but also in relations between interest rates and exchange rates.
  16. The evidence for the hypothesis that forward exchange rates incorporate time-varying risk premia implies that risk premia are highly volatile and that their sign changes often. In a recent article Stulz (1987) convincingly argues that existing models of asset pricing are unlikely to yield risk premia whose sign changes often.
  17. The result that value of the dollar was driven up by real interest rate differentials confirms work by Engel and Frankel (1984).
  18. One should be careful with the interpretation of the  $F$ -test in case of heteroskedasticity.

## References

- ADLER, M., AND B. DUMAS, 'International Portfolio Choice and Corporation Finance: A Synthesis,' *The Journal of Finance*, June 1983, **38**: 925-984.
- BOMHOFF, E.J., 'Predicting the Price Level in a World that Changes all the Time,' in: K. Brunner and A.H. Meltzer, eds, *Economic Policy in a World of Change, Carnegie-Rochester Conference Series on Public Policy*, Autumn 1982, **17**: 7-38.
- BOMHOFF, E.J., *Monetary Uncertainty*, Amsterdam: North-Holland, 1983.
- BOMHOFF, E.J., AND P. KORTEWEG, 'Exchange Rate Variability and Monetary Policy under Rational Expectations: Some Euro-American Experience 1973-1979,' *Journal of Monetary Economics*, March 1983, **11**: 169-206.
- BRANSON, W.H., AND D.W. HENDERSON, 'The Specification and Influence of Asset Markets,' in R.W. Jones and P.B. Kenen, eds, *Handbook of International Economics*, Vol. II, Amsterdam: Elsevier Science Publishers, 1985.
- CONROY, R.M., AND R.J. RENDLEMAN, 'Pricing Commodities when both Price and Output are Uncertain,' *The Journal of Futures Markets*, Winter 1983, **3**: 439-451.
- COSSET, J.C., 'On the Presence of Risk Premiums in Foreign Exchange Markets,' *Journal of International Economics*, February 1984, **16**: 139-154.
- CUMBY, R., AND M. OBSTFELD, 'International Interest Rate and Price Level Linkages under Flexible Exchange Rates: A Review of Recent Evidence,' in J. Bilson and R. Marston, eds, *Exchange Rate Theory and Practice*, Chicago: University of Chicago Press, 1984.
- DARBY, M.R., 'Does Purchasing Power Parity Work?,' NBER Working Paper Series, December 1980, No. 607.
- DOMOWITZ, I., AND C.S. HAKKIO, 'Conditional Variance and the Risk Premium in the Foreign Exchange Market,' *Journal of International Economics*, August 1985, **19**: 47-66.

- EDWARDS, S., 'Exchange Rates and "News", a Multicurrency Approach,' *Journal of International Money and Finance*, December 1982, 1: 211-234.
- EDWARDS, S., 'Comment on Isard,' in J.A. Frenkel, ed., *Exchange Rates and International Macroeconomics*, Chicago: University of Chicago Press, 1983.
- ENGEL, C., AND J.A. FRANKEL, 'Why Interest Rates React to Money Announcements, An Explanation from the Foreign Exchange Market,' *Journal of Monetary Economics*, January 1984, 13: 31-39.
- FAMA, E.F., 'Forward and Spot Exchange Rates,' *Journal of Monetary Economics*, November 1984, 14: 319-338.
- FAMA, E.F., AND M.R. GIBBONS, 'Inflation, Real Returns and Capital Investment,' *Journal of Monetary Economics*, May 1982, 9: 297-325.
- FAMA, E.F., AND G.W. SCHWERT, 'Asset Returns and Inflation,' *Journal of Financial Economics*, November 1977, 5: 115-146.
- FRANKEL, J.A., 'On the Mark,' *American Economic Review*, September 1979, 69: 610-622 (1979a).
- FRANKEL, J.A., 'The Diversifiability of Exchange Risk,' *Journal of International Economics*, August 1979, 9: 379-393 (1979b).
- FRANKEL, J.A., 'In Search of the Exchange-Risk Premium: A Six-Currency Test Assuming Mean-Variance Optimization,' *Journal of International Money and Finance*, August 1982, 1: 255-274.
- FRANKEL, J.A., 'The Implications of Mean-Variance Optimization for Four Questions in International Macroeconomics,' *Journal of International Money and Finance* (supplement), March 1986, 5: 53-75 (1986a).
- FRANKEL, J.A., 'International Capital Mobility and Crowding out in the U.S. Economy: Imperfect Integration of Financial Markets or of Goods Markets,' in R. Hafer, ed., *How Open is the U.S. Economy*, Lexington Books, 1986 (1986b).
- FRANKEL, J.A., AND K. FROOT, 'Using Survey Data to Test Some Standard Propositions Regarding Exchange Rate Expectations,' NBER Working Paper Series, No. 1672, 1985.
- FRENKEL, J.A., 'Comments on Hodrick and Srivastava,' *Journal of International Money and Finance*, March 1986, 5: 23-30.
- GIOVANNINI, A., AND P. JORION, 'Interest Rates and Risk Premia in the Stock Market and in the Foreign Exchange Market,' *Journal of International Money and Finance*, March 1987, 6: 107-123.
- GULTEKIN, N.B., 'Stock Market Returns and Inflation: Evidence from Other Countries,' *The Journal of Finance*, March 1983, 38: 49-66.
- HAKKIO, C.S., 'A Re-examination of Purchasing Power Parity,' *Journal of International Economics*, November 1984, 17: 265-277.
- HANSEN, L.P., AND R.J. HODRICK, 'Risk Averse Speculation in the Foreign Exchange Market: An Econometric Analysis of Linear Models,' in J.A. Frenkel, ed., *Exchange Rates and International Macroeconomics*, Chicago: University of Chicago Press, 1983.
- HODRICK, R.J., AND S. SRIVASTAVA, 'An Investigation of Risk and Return in Forward Foreign Exchange,' *Journal of International Money and Finance*, April 1984, 3: 5-24.
- HODRICK, R.J., AND S. SRIVASTAVA, 'The Covariation of Risk Premiums and Expected Future Spot Exchange Rates,' *Journal of International Money and Finance*, March 1986, 5: 5-21.
- HOOVER, P., AND J. MORTON, 'Fluctuations in the Dollar: A Model of Nominal and Real Exchange Rate Determination,' *Journal of International Money and Finance*, April 1982, 1: 39-56.
- HUIZINGA, J., 'An Empirical Investigation of the Long Run Behavior of Real Exchange Rates,' in K. Brunner and A.H. Meltzer, eds, *Carnegie-Rochester Conference Series on Public Policy*, 27: 1987, forthcoming.
- ISARD, P., 'An Accounting Framework and some Issues for Modeling How Exchange Rates Respond to the News,' in J.A. Frenkel, ed., *Exchange Rates and International Macroeconomics*, Chicago: University of Chicago Press, 1983.
- KOOL, C.J.M., 'The Multi-State Kalman Filter Method,' in K. Brunner and A.H. Meltzer, eds, *Economic Policy in a World of Change*, *Carnegie-Rochester Conference Series on Public Policy*, Autumn 1982, 17: 39-46.
- KORAJCZYK, R.A., 'The Pricing of Forward Contracts for Foreign Exchange,' *Journal of Political Economy*, April 1985, 93: 346-368.
- LEVICH, R.M., 'Empirical Studies of Exchange Rates: Price Behavior Rate Determination and Market Efficiency,' in R.W. Jones and P.B. Kenen, eds, *Handbook of International Economics*, Vol. II, 979-1035, Amsterdam: Elsevier Science Publishers, 1985.
- LOTHIAN, J.R., 'The Behavior of Real Exchange Rates,' *International Journal of Forecasting*, March 1987, 3: 17-42.

- MARK, N.C., 'On Time Varying Risk Premia in the Foreign Exchange Market, An Econometric Analysis,' *Journal of Monetary Economics*, July 1985, 16: 3-18.
- MEESE, R.A., AND K. ROGOFF, 'Empirical Exchange Rate Models of the Seventies: Do they fit out of sample?,' *Journal of International Economics*, February 1983, 14: 3-25.
- MEESE, R.A., AND K. ROGOFF, 'Was It Real? The Exchange Rate-Interest Differential, 1973-1984,' International Finance Discussion Paper No. 268, Federal Reserve Board, Washington DC, 1985.
- MUSSA, M., 'Empirical Regularities in the Behavior of Exchange Rates and Theories of the Foreign Exchange Market,' in K. Brunner and A.H. Meltzer, eds, *Policies for Employment, Prices and Exchange Rates, Carnegie-Rochester Conference Series on Public Policy*, 1979, 11: 9-57.
- PAGAN, A., AND A. ULLAH, 'The Econometric Analysis of Models with Risk Terms,' unpublished paper, Australian National University. 1986.
- ROLL, R., 'Violations of Purchasing Power Parity and their Implications for Efficient International Commodity Markets,' in M. Sarnat and G.P. Szego, eds, *International Finance and Trade*, Vol. 1, Cambridge, Mass.: Ballinger, 1979.
- SOLNIK, B., 'The Relation between Stock Returns and Inflationary Expectations: The International Evidence,' *The Journal of Finance*, March 1983, 38: 35-48.
- STULZ, R.M., 'Time-Varying Risk Premia, Imperfect Information, and the Forward Exchange Rate,' *International Journal of Forecasting*, March 1987, 3: 171-178.
- WHITE, H., 'A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity,' *Econometrica*, May 1980, 48: 817-838.
- WOLFF, C.P., 'Time-Varying Parameters and the Out-of-Sample Forecasting Performance of Structural Exchange Rate Models,' *Journal of Business and Economic Statistics*, January 1987, 5: 87-97.