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The Currency Composition of Foreign Exchange Reserves 1/

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Abstract

This study examines the determinants of the currency composition of foreign exchange reserves for both industrial and developing countries. During the period from 1976-85, our empirical results indicate that the currency composition of reserves has been influenced by each country's exchange rate arrangements, its trade flows with reserve currency countries, and the currency of denomination of its debt-service payments. The evidence is consistent with the view that managing the currency composition of a country's net foreign asset position is done more cheaply by altering the currency of denomination of assets and liabilities that are not held as reserve assets.

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4310, 4314, 4320

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I. Introduction

While the currency composition of foreign exchange reserves was a key element in the discussions of the Substitution Account during the 1970s, the relative stability of the currency composition of aggregate reserve holdings since 1980 and the belief that official reserve portfolio practices have had little effect on exchange rates subsequently limited the attention focused on this topic. However, the sharp swings in exchange rates between the major industrial countries in the 1980s and the large scale exchange market intervention that has been undertaken by the authorities of those countries have lead to proposals for achieving greater exchange rate stability through the use of coordinated intervention, target zones, or a return to fixed parities. Reserve management practices could be important determinants of the stability of any such new arrangements. Moreover, even under current exchange rate arrangements, there is the issue of how countries have responded to the the greater variability of exchange rates by changing either the level of reserve holdings or by altering the currency composition of these reserves in order to attain a more stable value for their reserve portfolio.

One of the major shortcomings of most earlier analyses of the currency composition of foreign exchange reserves has been the use of data representing the portfolio of behavior of country groups (e.g., the industrial countries). This has made it difficult to distinguish between the changes in the currency composition of a group's foreign exchange reserves due to shifts in the portfolio preferences of the authorities in individual countries from those due to changes in the distribution of reserves across countries within the group. This study separates these effects through the use of a combined cross-country, time series regressions which are based on data from individual countries. For the period 1976-85, our empirical results are consistent with the view that, while risk and return considerations played a role in determining countries' net foreign asset (liability) positions in different currencies, their gross holdings of reserve assets were more strongly influenced by transaction needs and exchange rate arrangements.

II. Trends in the Currency Composition of Foreign Exchange Reserves

1. Aggregate Data

Between the end of 1976 and the end of 1986, the evolution of the currency composition of foreign exchange reserves reflected an ongoing diversification of official portfolios. As part of its collection of data on international reserves, the International Monetary Fund regularly surveys its members regarding the currency composition of their

Table 1. Share of National Currencies in Total Identified Official Holdings of Foreign Exchange, 1976-86 1/

(In percent)

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
All countries											
U.S. dollar	78.8	79.2	76.1	73.2	68.6	71.5	70.5	71.2	69.4	64.2	66.2
Pound sterling	2.2	2.1	1.8	2.0	2.9	2.2	2.5	2.6	3.0	3.1	2.8
Deutsche mark	8.2	8.4	11.0	12.1	15.0	13.0	12.5	11.7	12.5	15.2	15.0
French franc	2.0	1.3	1.1	1.3	1.7	1.5	1.4	1.1	1.1	1.3	1.2
Japanese yen	2.5	2.7	3.4	3.6	4.4	4.3	4.8	4.9	5.7	7.8	7.6
Unspecified currencies 2/	6.2	6.1	6.5	7.6	7.4	7.5	8.2	8.4	8.4	8.4	7.2
Industrial countries											
U.S. dollar	87.0	89.0	86.2	83.5	77.6	78.7	77.1	77.4	73.6	65.4	68.8
Pound sterling	1.8	1.7	0.7	0.8	0.8	0.7	0.8	0.9	1.6	2.1	1.6
Deutsche mark	4.4	4.6	7.9	9.5	14.4	13.0	12.5	13.1	15.2	19.8	17.8
French franc	0.5	0.3	0.4	0.6	0.5	0.5	0.4	0.3	0.4	0.5	0.6
Japanese yen	1.9	1.8	2.3	2.6	3.5	3.8	4.5	5.2	6.3	8.8	8.1
Unspecified currencies 2/	4.3	2.6	2.5	3.0	3.2	3.2	4.7	3.2	2.9	3.4	3.1
Developing countries											
U.S. dollar	71.9	69.5	62.7	62.9	59.8	64.1	63.8	64.8	64.9	62.8	62.3
Pound sterling	2.4	2.6	3.2	3.2	5.0	3.6	4.3	4.5	4.4	4.4	4.6
Deutsche mark	11.5	12.3	15.2	14.8	15.5	12.9	12.6	10.3	9.7	9.9	10.7
French franc	3.3	2.3	2.1	2.1	2.9	2.5	2.5	1.9	1.7	2.2	2.2
Japanese yen	3.0	3.6	4.8	4.6	5.3	4.9	5.1	4.7	5.0	6.7	6.8
Unspecified currencies 2/	7.9	9.6	12.0	12.3	11.5	12.0	11.7	13.9	14.2	14.1	13.5

Sources: International Monetary Fund, various publications, the Annual Report, and staff estimates.

1/ Starting with 1979, the SDR value of European currency units (ECUs) issued against U.S. dollars is added to the SDR value of U.S. dollars, but the SDR value of ECUs issued against gold is excluded from the total distributed here.

2/ This residual is equal to the difference between total identified reserves and the sum of the reserves held in the five currencies listed in the table.

foreign exchange reserves. This currency composition data are reported for the major country groups in the Fund's Annual Report and are summarized in Table 1. 1/

For all countries taken together, the most noticeable trend has been the decline in the proportion of the reserve assets denominated in U.S. dollars from nearly 80 percent at the end of 1976 to 66 percent at the end of 1986. This decline has been offset principally by a rise in the proportions held as deutsche marks (from 8 to 15 percent) and the Japanese yen (from 3 to nearly 8 percent). 2/

The trend changes in the aggregate currency composition of foreign exchange reserves have encompassed somewhat contrasting behavior on the part of industrial and developing countries. For the industrial countries, the erratic but significant decline in the share of reserves denominated in U.S. dollars from 87 percent at the end of 1976 to 69 percent at the end of 1986 was accompanied by sharp increases in the shares of the deutsche mark (from 4 to 18 percent) and the Japanese yen (from 2 to 8 percent). However, three distinct phases of the decline in the dollar share have been evident. Between the end of 1976 and the end of 1980, the dollar share fell by 9 percentage points during a period of a substantial depreciation of the U.S. dollar relative to other reserve currencies. The period from the end of 1980 to end of 1984, during which the U.S. dollar appreciated sharply, saw a much more limited decline in the U.S. dollar share (4 percentage points). However, this share declined by over 8 percentage points in 1985 before recovering somewhat in 1986. In contrast, while there has been a relatively steady increase in the share of the Japanese yen, much of the increase in the deutsche mark share was concentrated in the period between the end of 1976 and the end of 1980.

For the developing countries, the pattern of currency diversification has been much more uneven. After an initial sharp decline in the U.S. dollar share between the end of 1976 and the end of 1980 (by 12 percentage points), this share was relatively stable between the end of 1981 and the end of 1986. In contrast, while the share of reserves denominated in Japanese yen more than doubled over the period between

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1/ In Table 1, European Currency Units (ECUs) which have been issued by the European Monetary Cooperation Fund (EMCF) to the central banks of the members of the European Monetary System in exchange for the deposits of 20 percent of gold holdings and 20 percent of their U.S. dollar holdings have not been treated separately. Instead, the value of ECUs issued against U.S. dollars has been added to dollar holdings, and the value associated with gold holdings has been excluded. The discussions of Table I.2 of Appendix I of the IMF Annual Report, 1987 provide a more detailed information on these adjustments.

2/ The unspecified currencies consist principally of holdings of Netherlands guilders and Swiss francs.

1976 and 1986, the share of developing country reserves denominated in deutsche marks reached a peak of nearly 16 percent at the end of 1980 before declining to about 11 percent at the end of 1986.

2. Previous studies

Two general approaches have been used to explain the behavior of the currency composition of foreign exchange reserves. The mean-variance approach has stressed the influence of the risks and returns associated with holding reserve assets denominated in different currencies. The alternative "transaction" approach has argued that the proportion of foreign exchange reserves denominated in a particular currency should be related to currency composition of the authorities' exchange market activities. Under the mean-variance approach, the utility, or desirability, of a particular portfolio depends on both the expected value and the variability of the value of the financial assets in the portfolio measured in terms of some basket of goods. Thus, a rational government would not put all of its wealth in the one currency that has the highest expected yield, since this could imply a highly variable outcome for its wealth depending on future exchange rates changes. This theory also suggests that countries producing or consuming different goods and services would optimally hold different portfolios of financial assets. 1/

The alternative transaction approach postulates that the desired currency composition of reserve assets is largely independent of the optimal distribution of net wealth across currencies. Instead, the holdings of reserve assets denominated in a particular currency will be related to "vehicle" currency services associated with that currency.

An early study by Heller and Knight (1978) provided evidence in support of the view that transaction needs played a major role in determining the currency composition of reserves. This study used data on the currency composition of foreign exchange reserves obtained by the International Monetary Fund for the mid 1970s. In their regression analysis, they explained the proportions of a country's foreign exchange reserves held as assets denominated in U.S. dollars, pound sterling, deutsche marks, French francs, and other reserve currencies as a func-

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1/ A theoretical and empirical literature has developed relating international asset demand to principles of expected utility maximization. Theoretical papers include Kouri (1977), Kouri and Macedo (1978), Frankel (1979), Krugman (1981), and Dornbusch (1982). Empirical work includes Roll and Solnik (1977), Kouri and Macedo (1978), Macedo (1980), Dornbusch (1982), Healy (1981) and von Furstenberg (1981). Asset demand functions derivable from expected utility maximization have been employed to estimate the effects of changes in the relative supplies of assets on exchange rates and rates of return. See Branson, Halttunen and Masson (1977), Frankel (1982), and Dooley and Isard (1984).

tion of the country's exchange rate arrangement and the share of its trade with a particular reserve currency country. 1/ Their results indicated that in general countries increased the proportion of their foreign exchange reserves held as a given currency if they pegged their exchange rate to that currency; that countries tended to hold a high proportion of dollars whether they were dollar peggers or not; and that the Snake countries 2/ tended to hold U.S. dollars almost exclusively. Countries also held a higher percentage of the currencies of those reserve centers that were also their important trading partners. Moreover, as a country's trade share with a reserve center increased, it held less of the other reserve currencies. However, their regression analysis was based on individual country data at only one point in time (the end of 1975).

In the late 1970s and early 1980s, a number of studies applied optimal portfolio theory to the selection of official reserve portfolios. For example, Ben-Bassat (1980, 1984) argued that a country's optimal reserve portfolio composition depends on three factors: (1) a country's motives for holding reserves; (2) the risk and return on the various reserve currencies; and (3) a country's interest in maintaining international stability. Establishing the optimal reserve portfolio would involve first identifying the combinations reserve positions that are on the efficiency frontier (i.e., those positions which yield the highest rate of return for a given level of risk as measured by the variance of yields) and then allowing the authorities to select their preferred risk-return combination. Using data from the 1970s, Ben-Bassat (1984) compared actual and optimal reserve portfolios for both industrial and developing countries in 1976 and 1980. For the developing countries, actual and optimal portfolios in 1976 were regarded as similar. Moreover, this group reduced the U.S. dollar share in its actual portfolio between 1976 and 1980 which further reduced the gap between the actual and optimal reserve portfolios. However, the gap between the actual and optimal reserve portfolios for the industrial countries increased between 1976 and 1980. In addition, the proportion of reserves denominated in the U.S. dollar held by industrial countries that were not part of the Snake arrangements increased although the calculated optimal portfolio implied that this proportion should decline. It was also noted that, in the case where the authorities preferred a low-risk portfolio, the shares of the various reserve

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1/ The sum of a country's exports plus imports to a particular reserve country divided by the sum of its total exports plus imports.

2/ The snake countries were the members of the European System of Narrower Exchange Rate Margins.

currencies in the optimal portfolio tended to be quite similar to the currency composition of the group's import basket. 1/

In examining the evolution of the currency composition of reserves of developing countries, Dooley (1983) stressed the differences between the determinants of net and gross currency positions. Many earlier studies of gross foreign exchange holdings had concluded both that the proportion of the foreign exchange reserves denominated in the U.S. dollar of developing countries had varied over a narrow range and that observed charges mainly reflected exchange rate changes. Dooley noted, however, that net currency positions had changed sharply as the share of net liabilities denominated in the U.S. dollar rose from 25 to 60 percent of their total net external liabilities between 1974 and 1979. Moreover, it was argued that there were a number of difficulties associated with applying the mean-variance optimal portfolio approach to explaining the level and currency composition of gross foreign exchange holdings. First, the optimal portfolio approach really applies to allocation of wealth to net holdings of particular assets; whereas foreign exchange data refers to gross holdings of particular assets. Second, in order for the optimal portfolio approach to be useful, it must encompass decisions regarding all of the financial positions; whereas reserve holdings constitute only a small subset of potential assets or liabilities. This means that both the yields on a variety of assets and liabilities other than reserve assets and the covariances of these yields with the returns on reserve assets would typically have to be included as determinants of optimal reserve positions. In addition, since reserve decisions are made by central banks which use their reserve instruments for transactions, it may be more efficient for the typical government to alter its net foreign currency position by changing the currency composition of its assets and liabilities not held as reserves. As a result, the currency composition and level of foreign exchange reserves would most likely reflect the authorities' transaction needs in the foreign exchange market. Finally, mean-variance portfolio considerations would be relevant for a single country; whereas the currency composition of foreign exchange reserves data considered in most studies referred to country groups rather than individual countries. Dooley's empirical analysis supported the view that reserve assets are held for transaction reasons, and the currency composition of

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1/ Macedo, Goldstein, and Meerschwan (1984) examined the optimal diversified portfolio for an agent (not necessarily a central bank) operating in international financial markets. Based on data from April 1973 to March 1981, they calculated the optimal portfolio for investors holding gold and short-term financial assets denominated in eight major currencies. The minimum variance portfolio was found to include long positions in four currencies (98 percent in duetsche marks) and gold, and short (net negative) positions four currencies (including the U.S. dollar). The net negative positions were interpreted as borrowing in the particular currency.

such assets was determined by the consideration that they could be easily liquidated and used to make payments.

Recently, Horii (1986) examined reserve currency diversification during the 1970s and 1980s. Although Horii noted that the currency composition of reserves should be studied on an individual country basis, he focused on country group data since individual country data were unavailable. After allowing for factors that altered the distribution of reserves across countries; he argued that there was no large scale diversification out of reserve assets denominated in the U.S. dollar for all countries during the 1970s and 1980s.

However, some diversification was evident when consideration was given to the subgroups of industrial countries, oil exporting countries, and the non-oil developing countries in the overall period 1972-84 as well as for the subperiods 1972-76, 1976-79, and 1980-84. Overall, there was some evidence of a movement out of reserves denominated in pounds sterling in 1972-76, a small shift from U.S. dollar to deutsche mark denominated instruments in 1976-79 (mainly due to passive exchange rate changes), and a slight diversification out of U.S. dollars denominated instruments in 1980-84. These results led Horii to conclude that the currency composition of reserve holdings could not be explained in terms of a transaction demand determined by trade flows alone since capital flows have become increasingly important. Moreover, the stability of the currency composition of reserves during a period of significant changes in exchange rate arrangements did not support the view that such arrangements were important determinant of the currency composition as suggested by Heller and Knight. Finally, Horii calculated the reserve portfolios that should have existed under efficient portfolio theory for 1979 (using data from 1974 to 1979) and 1984 (using data from 1979 to 1984). In general, optimal holdings for U.S. dollar denominated reserves were well below actual holdings in both years. In contrast, actual holdings of reserves denominated in deutsche marks, French francs, and pounds sterling were well below their calculated optimal levels.

III. Analysis of Currency Composition of Foreign Exchange Reserves Based on Country Data

As already noted, one of the principal shortcomings of most previous studies of the currency composition of foreign exchange reserves has been the use of data on the portfolio preferences of country groups rather than those for individual countries. The use of data for country groups makes it impossible to distinguish between changes in the currency preferences of individual countries and shifts in the distribution of reserves across countries that are members of the group. This study is designed to overcome these problems by employing a cross country-time series analysis of the International Monetary Fund's data on the currency composition of foreign exchange reserves for both industrial and developing countries for the period from 1976 to 1985.

Our analysis is designed to test the hypothesis that, while a country's net foreign currency position is influenced importantly by risk and return considerations, its gross holdings of foreign exchange reserves will be principally motivated by transaction concerns. However, in measuring these transactions needs, it is important to consider the scale of both trade and capital flows that the authorities are likely to encounter in the foreign exchange market. Our model is a direct complement to those models of the demand for reserves which relate holdings of reserves to the scale of a country's imports, its degree of openness and the variability of the country's balance of payments. 1/ While such models seek to explain the overall holdings of reserves and takes the currency composition of these reserves as exogenous, this study attempts to identify the determinants of the currency composition while taking overall holdings of foreign exchange reserves as exogenous. Our empirical results suggest that, both developed and developing countries take into account the currency composition of their foreign exchange market transactions as well as the nature of their exchange rate arrangements when selecting the currency denomination of their foreign exchange reserves. Moreover, for developing countries, the currency composition of debt-service flows has been as important as trade flows in determining the proportions of foreign exchange reserves held in each of the major reserve currencies.

1. Basic model

In this section, we consider a simple model which incorporates the role of the transactions costs into the traditional mean-variance approach to the determination of a country's optimal portfolio of external assets and liabilities. It is argued that, while the mean-variance approach provides a description of the authorities' net foreign asset (or liability) positions in each potential currency of denomination, the structure of transactions costs as well as the scale of a country's anticipated foreign exchange market transactions are the principal determinant of each county's gross asset positions including their holdings of foreign exchange reserves.

In the standard optimum international portfolio model, 2/ the optimum proportion of currency i in a country's net foreign asset portfolio is determined by the expected real returns on holding positions in different currencies as well as the covariances between the yields. If x_i represents the proportion of currency i in the authorities' portfolio and X is the vector of the x_i, then the mean (m) and variance (σ^2) the return on the net foreign asset position will be given by

$$(1) \quad m = X'R$$

1/ Lizondo and Mathieson (1987) provide a comparison of empirical estimates of alternative specifications of these models.

2/ For example, see Roll (1977), Macedo (1980), and Horii (1986).

$$(2) \quad \sigma^2 = X'VX$$

where:

R = vector of expected real returns on maintaining a position in the various currencies.

V = covariance matrix of expected real yields. 1/

Under the assumption that the authorities' utility is positively related to the expected return on their portfolio and negatively related to portfolio risk, 2/ the optimal vector of portfolio positions (X^*) will be given by (see Horii (1986)).

$$(3) \quad X^* = V^{-1}e/e'V^{-1}e + (1/b)\ V^{-1}\ (R-(R'V^{-1}e/e'\ V^{-1}e)e)$$

where e is the unit vector and b is the degree of relative risk aversion.

To illustrate the relationship between net and gross assets positions implied by the solution to (3), it is convenient to focus on the situation where there are only two currencies: dollars (currency 1) and deutsche marks (currency 2). Let A_i represent the holdings of assets in currency i; L_i be the issuance of liabilities in currency i; and N_i equal the net asset position in currency i($=A_i-L_i$). Moreover, let the country be a net debtor where W (< 0) represents the overall size of its net debt position (taken as exogenous). 3/ Assume that the solution to (3) indicates that the optimal net portfolio implies that half of the country's debtor position should be denominated in dollars and half in deutsche marks ($N_1 = N_2$). If the country had no gross assets, then the liabilities issued in each currency would have to be equal, $L_1 = L_2$ as shown in Figure I for A = 0. In the more general case, the debtor may hold A* in gross assets, but it can still maintain its desired net debt position in each currency ($N_1 = N_2$) by altering the currency denomination of its liabilities (L*). Suppose, for example, that to minimize transactions costs, the authorities chose to hold most of their gross assets in dollars so that $A_1^* > A_2^*$ (Figure I). In order to maintain their desired net positions in each currency, the country

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1/ The expected real yield on a position in currency i (r_i) is defined to equal the nominal yield adjusted for the anticipated changes in the exchange rate and the inflation rate for domestic prices.

2/ For example, $U = m - (b/2)\ \sigma^2$.

3/ Let total foreign assets be given by $A(= A_1 + A_2$ if the exchange is initially equal to 1) and total foreign liability are given by $L(= L_1 + L_2)$. Thus, $W = A_1 + A_2 - L_1 - L_2$.

would have to issue dollar and deutsche mark gross liabilities such that $L_1^* - A_1^* = L_2^* - A_2^*$. This implies that the theory of optimal net foreign exchange positions places no obvious theoretical restrictions on the currency denomination of a country's gross reserve position. 1/

In the content of this two currency model, the roles of transactions costs and risk-return considerations in determining a country's net and gross asset positions can be described more formally as follows. As noted earlier, let A_i be gross holdings of reserve assets denominated in denominated in currency i, and L_i be the gross external liabilities issued in that currency. The country can hold reserve assets in currency i that yield a random real world interest rate which has a mean of r_i and variance $\sigma^2_{r_i}$. Alternatively, the country can borrow in currency i and must pay $r_i + d_i$, where d_i is a positive constant that reflects the spread between the lending and borrowing rates. The net interest earned on a given net asset position is $r_i(A_i - L_i) - d_i L_i$.

The expected return on the country's foreign asset and liability positions will be given by:

$$(4) \quad m = r_1 A_1 + r_2 A_2 - (r_1+d_1)L_1 - (r_2+d_2)L_2$$

$$= (r_1+d_1)N_1 + (r_2+d_2)N_2 - d_1 A_1 - d_2 A_2$$

$$\text{with } N_i = A_i - L_i$$

The variance of this return will therefore equal

$$(5) \quad \sigma^2 = N_1^2 \sigma^2_{r_1} + N_2^2 \sigma^2_{r_2} + 2N_1 N_2 \sigma_{r_1 r_2}$$

where $\sigma^2_{r_i}$ = variance of yield r_i

$\sigma_{r_i r_j}$ = covariance of yields r_i and r_j.

In addition to earning net interest income, the authorities also incur transactions costs associated with their exchange market

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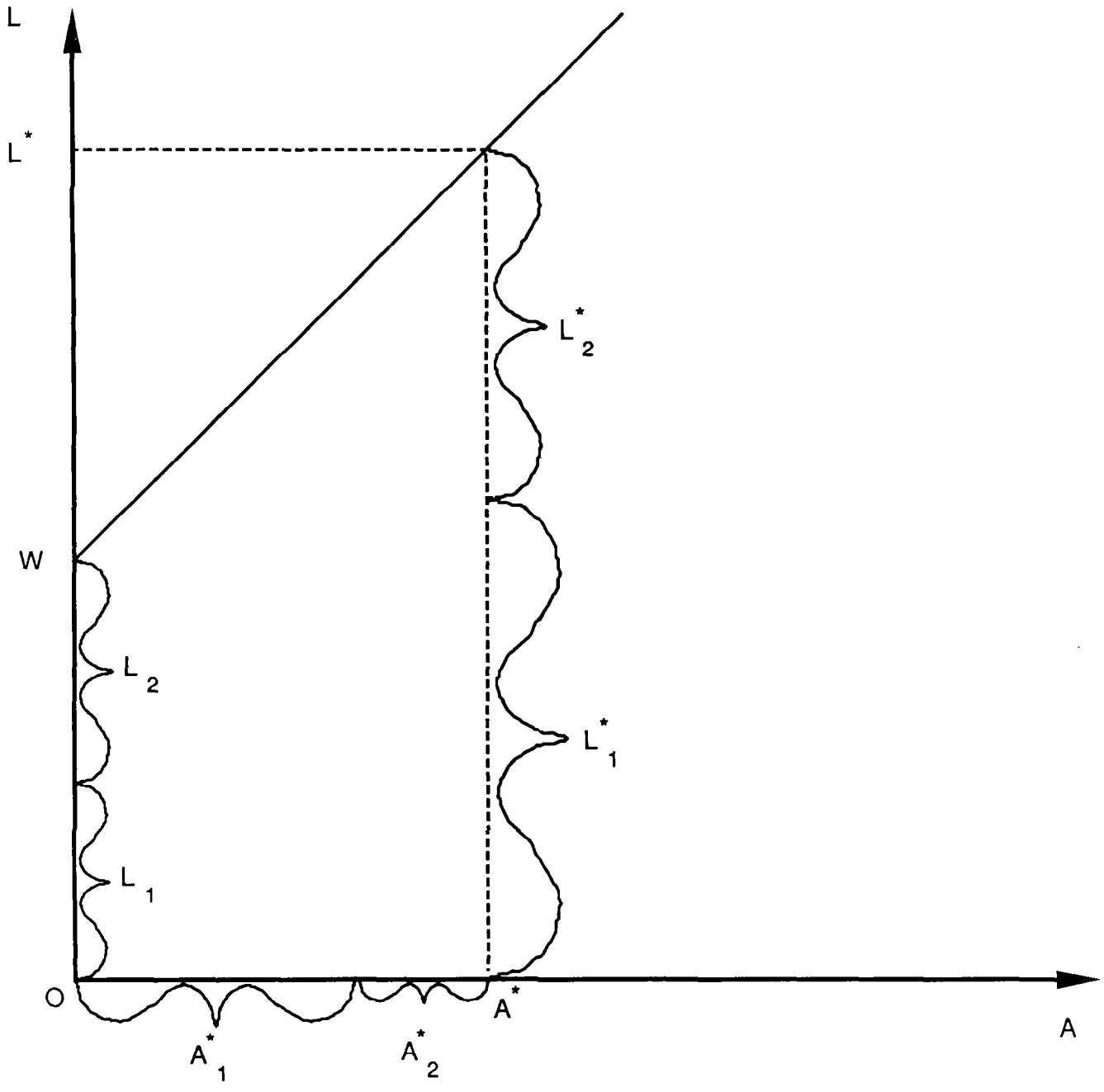
1/ If the desired position could not be met by manipulation of gross assets and liabilities, the same results could be attained by utilizing forward exchange contracts.

Figure I

Gross and Net Foreign Asset and Liability Position



transactions. 1/ To simplify our analysis, it is assumed that the amount of transactions the country must undertake in each currency in each period of time can be described by three possible states of nature (Figure II).

(t_1, t_2) occurs with probability π_1 (point B in Figure II)

$(t_1, T-t_1)$ occurs with probability π_2 (point C in Figure II)

$(T-t_2, t_2)$ occurs with probability π_3 (point D in Figure II)

with $T > t_1 + t_2$ and $\pi_1 + \pi_2 + \pi_3 = 1$.

Given this transaction structure, the country faces transaction costs that are influenced by two factors. First, there is the cost of converting one currency into another. If the authorities hold sufficient reserves denominated in a given currency (A_i) to meet the exchange market transactions in that currency, then it is assumed that the authorities do not incur any transaction cost. For example, assume that the authorities' holdings of reserves are represented by point A in Figure II, with A_1 of currency 1 and A_2 of currency 2. If actual transactions were t_1 and t_2, point B in Figure II, the country would not incur any transactions costs since its reserve holdings in each currency would be sufficient to meet all transactions in the respective currencies. However, when the transactions are such that the authorities exhaust their holdings of reserves denominated in one currency, they must convert the holdings of reserves denominated in the other currencies into the first currency, and this results in transactions costs. In Figure II, for example, if actual transactions were represented by either point C or D, the authorities would incur the costs of converting reserves from one currency to another currency since the amount of reserves in one of the currencies will be lower than the level of transactions in that currency.

The second type of cost is associated with the possiblity that the authorities may exhaust their reserve holdings. As Figure II is drawn, points C and D represent situations where the country's total reserves are inadequate. Such an outcome could force the authorities to engage in "emergency" borrowing which is assumed to be relatively costly.

The costs of converting currencies or engaging in emergency borrowing to offset reserve shortages are taken as being represented by

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1/ These could include transactions such as exchange market intervention designed to sustain an exchange rate policy or official purchases of foreign goods and services.

quadratic functions of the amounts involved. In terms of Figure II, if the outcome of transactions is B, there is no transactions cost since the level of reserves held in each currency is higher than the level of transactions in the respective currency, $A_1 > t_1$ and $A_2 > t_2$. If the outcome is C, holdings of currency 1 are higher than transactions in that currency, $A_1 > t_1$, but holdings of currency 2 are lower than transactions in that currency $A_2 < T-t_1$. In addition, total holdings of reserves $A_1 + A_2$ are lower than total transactions T. Therefore, there is a cost associated with the conversion of the excess of currency 1 into currency 2, $A_1 - t_1$, and a cost associated with the overall shortage of reserves $T - A_1 - A_2$. The same type of reasoning applies to outcome D. As a result, the expected conversion and reserve shortages costs for holdings of reserves A_1 and A_2 are given by: 1/

$$(6) \quad E(tc) = \pi_2 c\,(A_1-t_1)^2 + \pi_3 c\,(A_2-t_2)^2 + (\pi_2+\pi_3)\,p\,(T-A_1-A_2)^2$$

where c and p are parameters associated with the conversion of reserves from one currency to another and reserve shortages, respectively.

In determining their holdings of foreign assets and issuance of foreign liabilities, the authorities are assumed to maximize a utility function which is a positive function of the expected return (m) on their net foreign asset portfolio (net of expected transactions and emergency borrowing costs) and negatively related to the variance (σ^2) of the yield on its portfolio. In particular, the authorities select A_1, A_2, L_1, and L_2 subject to the constraint imposed by the size of their overall net foreign asset position 2/ $W = A_1 + A_2 - L_1 - L_2 = N_1 + N_2$. Thus,

$$(7) \quad U = m - b\sigma^2 - E(tc)$$

$$\text{where } m = (r_1+d_1)N_1 + (r_2+d_2)(W-N_1) - d_1A_1 - d_2A_2$$

$$= (r_2+d_2)W + (r_1+d_1-r_2-d_2)N_1 - d_1A_1 - d_2A_2$$

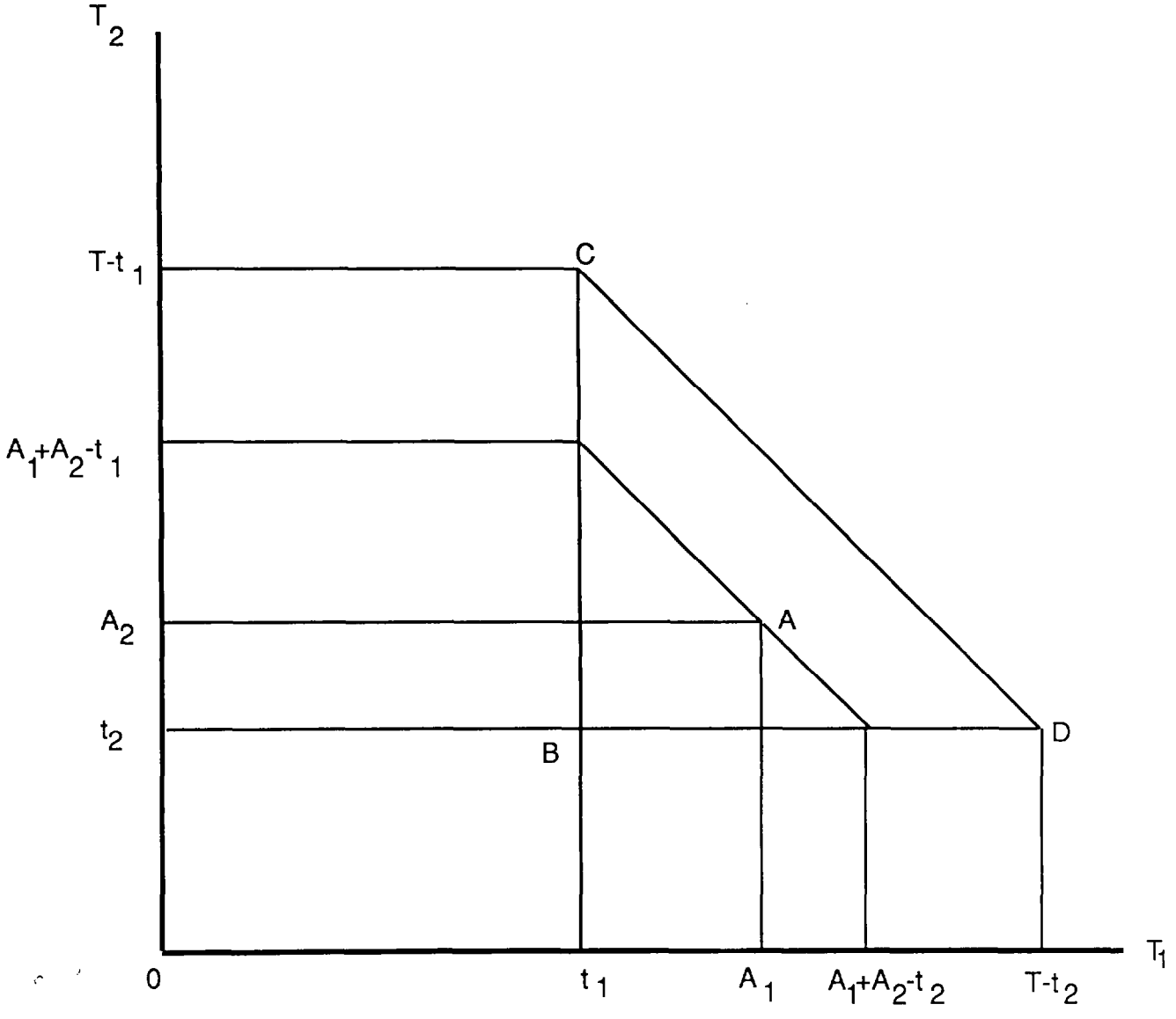
$$\sigma^2 = N_1^2\,\sigma_{r_1}^2 + (W-N_1)^2\,\sigma_{r_2}^2 + 2N_1(W-N_1)\,\sigma_{r_1r_2}$$

1/ This formula strictly applies only for points within the triangle BCD in Figure I. However, it can be shown that with appropriate restrictions on the parameters of the model, only those points are relevent. Analyzing points outside the triangle ABC would lengthen the discussion without adding new insights.

2/ W can be either positive or negative.

Figure II

Reserve Holdings and Transaction Structure



and with E(tc) as defined in equation (6).

As shown in Appendix II, the first order conditions yield

$$(8) \quad N_1 = \frac{(r_1+d_1-r_2-d_2)}{2bD} + W\frac{(\sigma_{r_2}^2-\sigma_{r_1r_2})}{D}$$

$$(9) \quad N_2 = \frac{(r_2+d_2-r_1-d_1)}{2bD} + W\frac{(\sigma_{r_1}^2-\sigma_{r_1r_2})}{D}$$

$$\text{with } D = \sigma_{r_1}^2 + \sigma_{r_2}^2 - 2\sigma_{r_1r_2}$$

and A_1 and A_2 are given by

$$(10) \quad A_1 = \frac{\pi_3 A + \pi_2 t_1 - \pi_3 t_2}{(\pi_2 + \pi_3)} + \frac{d_2 - d_1}{2c(\pi_2+\pi_3)}$$

$$(11) \quad A_2 = \frac{\pi_2 A + \pi_3 t_2 - \pi_2 t_1}{(\pi_2+\pi_3)} + \frac{d_1 - d_2}{2c(\pi_2 + \pi_3)}$$

$$(12) \quad A = \frac{2p(\pi_2+\pi_3)^2 T + 2c\,\pi_2\,\pi_3\,(t_1+t_2) - (\pi_3 d_1 + \pi_2 d_2)}{2p(\pi_2+\pi_3)^2 + 2\pi_2\pi_3 c}$$

Equations (8) and (9) imply that the country's net foreign asset position in each currency are determined by the expected yields (or borrowing costs), the variances and covariances of these yields, and the degree of relative risk aversion; but these positions are independent of the structure of transactions costs or the likely volume of exchange market transactions. In contrast, equations (10)-(13) imply that gross holdings of reserve assets will be influenced by transactions costs associated with currency conversion and reserve shortages, and by the minimum and maximum level of potential exchange market transactions. As a result, the currency composition of foreign exchange reserves will also reflect these transaction considerations.

2. Empirical model

The hypothesis that transactions needs are the principal determinants of the currency composition of foreign exchange reserves can be examined in terms of the behavior of the proportion of reserves denominated in each of the major reserve currencies. In particular, equations (10) and (11) imply that the currency composition of reserves (as represented by A_i/A) would be sensitive to the scale of transactions in a given currency relative to total transactions (as well as other variables). However, the scale of exchange market transactions undertaken by the authorities would also be influenced by the nature of its exchange rate arrangements they select. For example, maintaining a fixed exchange rate might require a higher level of exchange market intervention in a particular currency than maintaining a floating exchange rate. This relationship between the currency composition of reserves, the relative scale of exchange market transactions in different currencies, and exchange rate arrangements can be represented empirically by

$$(13)\quad \frac{A_{i,k,t}}{\bar{A}_{i,t}} = \beta_0 + \sum_{\substack{v=1 \\ v\neq i}}^{5} \beta_{1,v} \left[TR_{i,v,t}/TT_{i,t}\right] + \sum_{\substack{v=1 \\ v\neq i}}^{5} \beta_{2,v} \left[D_{i,v,t}/TT_{i,t}\right] + \sum_{s=1}^{5} \beta_{3,s} E_{i,s,t} + \mu_{i,t}$$

where $t=1,\ldots,T$ (number of periods)

$i=1,\ldots,n$ (number of countries)

$k=1,\ldots,5$ (number of reserve currency countries)

$s=1,\ldots,5$ (number of exchange rate arrangements)

$A_{i,k,t}$ = reserves of country i held as assets denominated in the currency of reserve country k at time t (converted to U.S. dollars at the end of the period).

$D_{i,v,t}$ = debt service payments of country i denominated in the currency of reserve currency country v at time t.

$E_{i,s,t}$ = exchange rate arrangement of type s adopted by country i at time t.

$\bar{A}_{i,t}$ = total end of period foreign exchange reserves for country i at time t (measured in U.S. dollars)

$TT_{i,t}$ = sum of exports, imports, and (in the case of developing countries) debt-servicing payments

$TR_{i,v,t}$ = trade flows (exports plus imports between country i and reserve currency country v) at time t.

In this formulation, the proportion of a country's reserves held in assets denominated in a particular currency is assumed to be influenced by the currency composition of both its trade flows and debt-servicing payments as well as the nature of its exchange rate arrangements. Trade transaction denominated in a particular reserve currency are represented by the sum of imports and exports between country i and reserve currency country v. The reserve currency countries in this study are taken as France, the Federal Republic of Germany, Japan, the United Kingdom, and the United States. Since the currency composition of a country's import and export contracts need not correspond to the country pattern of its trade flows (e.g., contracts for oil imports from a Middle East oil producer could be denominated in U.S. dollars), this measure can only be taken as an approximation to the true proportion of trade flows denominated in particular currency. Despite these shortcomings, earlier studies (e.g., by Heller and Knight (1978)) of the currency composition of foreign exchange reserves have found that this measure of the distribution of trade flows to be a useful explanatory variable. However, the signs of the $\beta_{i,v}$ s are subject to some ambiguity. While an increase in trade flows to a given reserve currency v would be likely to lead to increase holding of reserve denominated in that reserve currency ($\beta_{i,v} > 0$), the signs of the other $\beta_{i,v}$ $(i \neq v)$ could be either negative or positive. For example, larger imports from reserve currency country A could imply the need for larger holdings of reserve country B's currency if some of the these imports were priced in terms of B's currency.

Since data on financial flows are not available for most countries, the scale of financial flows was proxied by the level of interest payments associated with the country external debt denominated in the different currencies. A country's external debt was measured in terms of its public and public guaranteed debt as reported in the World Debt Tables published by the World Bank. Since this data is reported by currency of denomination, the interest payments in the different currencies were approximated by multiplying the stock of debt denominated in each currency by six-month Eurocurrency deposit rate for that currency. Obviously this measure captures only one component of financial flows; but, for many of the developing countries in our sample, interest payments on external debts account for a significant portion of total financial flows.

The effects of a country's exchange rate arrangements on the currency composition of its foreign exchange reserves were represented by a series of dummy variables corresponding to the type of arrangements employed by a country during each year being considered. The arrangements were classified into categories similar to those used in the Fund's Annual Report on Exchange Rate Arrangements and Trade Restrictions. The categories include pegged to the U.S. dollar, pegged to the French franc, pegged to a composite or other currency, member of a cooperative arrangement, and flexible exchange rate. 1/ While the placement of countries within this spectrum of arrangements is to some degree arbitrary, these categories do reflect the employment of greater or lesser degrees of exchange rate flexibility. In the regressions, a country's exchange rate arrangement is represented by a series of zero-one dummy variables one for each type of arrangement. Since there is a general intercept term in the each regression (β_0 s) and the set of exchange rate arrangements is exhaustive, one of the exchange rate arrangement dummies was excluded in each regression to avoid creating a linear dependency. The β_0 s in each regression therefore reflect the effects of both the excluded exchange rate arrangement and other factors not represented by trade and capital flows.

Since earlier analysis found that the behavior of the currency composition of reserves of the industrial and developing countries differed, our study examines separate regressions for these groups. Moreover, although the World Bank debt reporting system contains extensive information on the currency composition of the external debt of the developing countries, no such comparable reporting system exists for industrial countries. While some industrial countries do not appear to have any external debt denominated in foreign currencies (e.g., the Federal Republic of Germany and Japan), many others (e.g., certain Scandinavian countries) have significant amounts of such debts. The absence of comprehensive information the currency composition of external debt for the industrial countries means, however, that the interest payments variable has been excluded from the industrial country regressions.

This specification was estimated using data on the currency composition of foreign exchange reserves supplied to the International Monetary Fund on a regular basis by a large number of central monetary institution. A series of five cross-section time series regressions for each of the groups of industrial and developing countries were estimated. In these regressions, the dependent variables were the proportion of foreign exchange reserves held as instruments denominated in the U.S. dollar, pounds sterling, the deutsche mark, French francs, and the Japanese yen. The explanatory variables were the exchange rate regime, the five variables representation trade with the reserve centers (as a

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1/ This last category includes independent floaters, those countries with managed floating, and those countries with other flexible arrangements.

proportion of total trade plus interest payments) and, in the case of developing countries, five variables reflecting the interest payments on external debt (as a proportion of total trade plus interest payments). Data from a total of 19 industrial countries and 39 developing countries were included. 1/ The data consist of annual observations for each country's variables for the period from 1976 to 1985. It should be noted that, in this formulation, the marginal effects of exchange rate arrangements, trade flows, and interest payments are assumed to be uniform across countries (i.e., there are no country specific parameters). 2/

3. Estimation methods

Estimation of equation (13) using ordinary least squares (OLS) techniques would in general be inappropriate since the dependent variable can only take values in the interval (0,1). To illustrate the nature of the problems involved, let the standard regression model be represented by:

$$(14) \quad y_i = \beta' x_i + u_i$$

where β is a k x 1 vector of unknown parameters; x_i is a k x 1 vector of known independent variables, and the u_i's are residuals independently and normally distributed with mean zero and a common variance σ^2. Since u_i are assumed to be normally distributed, this model implies that y_i may take any positive or negative value, which is inconsistent with the particular dependent variable in our problem.

More appropriate for our purposes is the censored regression model, also known as the tobit model. 3/ In our particular case, this model can be represented by:

$$(15) \quad y_i = \beta' x_i + u_i \qquad \text{if } 0 < RHS < 1$$

$$(16) \quad y_i = 0 \qquad \text{if } RHS \leq 0$$

1/ Other countries were excluded because of incomplete information on either reserve holdings, trade flows, or external debt.

2/ While it might be useful to allow for country specific parameters, they would provide information about individual holdings which would violate the confidentiality of the data file.

3/ Tobin (1958) was the first to discuss the estimation of the parameters of the truncated normal distribution in the regression context, and to relate it to the literature on probit analysis.

(17) $y_i = 1$ if RHS ≥ 1

where the β and u_i are defined as above. This model implies that the authorities decide on the share of a particular currency in their foreign exchange reserves according to the linear function in (15), but they hold a share of either zero or one when that linear function indicates a negative share or a share higher than one, respectively.

Estimation of a censored regression model by OLS results in biased and inconsistent estimators. Maximum likelihood (ML) estimators, on the other hand, are consistent and asymptotically normal. 1/ Among the various procedures available to obtain ML estimates, we used an iteration method suggested by Fair (1977). 2/ Although the problem we examine in this paper is strictly described by the two-limit censored regression model in (15), (16), and (17), we estimated a one-limit model because there were virtually no observations on the upper limit 3/ and observations on both limits are needed to estimate a two-limit model. 4/ Therefore, the estimated model was:

(18) $y_i = \beta' x_i + u_i$ if RHS > 0

(19) $y_i = 0$ otherwise

As indicated by Dhrymes (1986), it is convenient to have separate goodness of fit statistics for observations with $y_i > 0$ from those for observations with $y_i = 0$. For the set of observations with $y_i > 0$, we have therefore used the square of the simple correlation coefficient between the predicted and actual values of the dependent variable (R^2_{T1}). 5/ For the set of observations with $y_i = 0$, we calculated the

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1/ See Amemiya (1973).

2/ For a description of other procedures, see Maddala (1983).

3/ There were some countries that held only French francs or U.S. dollars during some time periods.

4/ For a discussion of the estimation of two-limit models see Rosett and Nelson (1975).

5/ There are three types of predictions of y_i given x_i. One is the unconditional prediction of y_i. Another is the prediction of y_i given the information that $y_i > 0$. The third type of prediction requires a slight reinterpretation of the model. In this reinterpretation $y_i^* = \beta' x_i + u_i$, where y_i^* is a latent variable; then we have $y_i = y_i^*$ if $y_i^* > 0$ and $y_i = 0$ otherwise. The third type of prediction is the prediction of the latent variable y_i^*. Each one of these predictions is useful for a particular purpose. For a discussion see Maddala (1983). For the statistic suggested by Dhrymes, we used the conditional prediction of y_i.

proportion of observations correctly predicted to be zero by the model (R^2_{T2}) and the mean error ($\bar{E}_T$) for the observations for which the model incorrectly predicted as being $y_i > 0$. 1/ In order to give an idea of the overall goodness of fit, we also calculated the square of the simple correlation coefficient between predicted and actual values of the dependent variable for the complete sample (R^2_{T3}). 2/

One difficulty with the tobit maximum likelihood estimator is that it is sensitive to violations of the assumptions that its error terms have a normal distribution and are homoskedastic. The presence of either nonnormality (see Goldberger (1983)) or heteroskedasticity (see Hurd (1979)) can result in inconsistent tobit estimates. However, Powell (1986) has recently developed estimators that are robust to a wide set of nonnormal or heteroskedasticic disturbance distributions. As noted by Newey (1987), Powell's symmetrically censored least squares (SCLS) estimator not only provides estimates of the regression parameters that are robust to failure in the normality assumption but also make feasible Hausman (1978) tests for the presence heteroskedasticity or nonnormality based on the differences between the tobit estimates and the SCLS estimators.

If the normality or homoskedasticity assumptions are violated, then the use of SCLS estimator involves symmetrically censoring the dependent variable so that symmetry of its distribution about the regression ($\beta' x_i$) is restored, and least squares techniques will yield consistent estimators. The nature of the SCLS procedures can be illustrated using Figure III. 3/ As given in equations (18) and (19), $y_i = \max \{0, \beta' x_i + u_i\}$ $(i=1,....T)$. In a censored sample, for data points with $u_i < -\beta' x_i$, the value of y_i is taken to be zero. However, in contrast to the sided (lower bound) censoring of the tobit model, the SCLS procedures set y_i equal to $2\beta' x_i$ when $u_i > \beta' x_i$. Then the observations would have terms in the interval $(0, 2\beta' x_i)$. Since this approach assumes that the original errors where distributed symmetrically, the residuals of the "symmetrically censored" regressions will also be symmetrically distributed about zero, and the dependent variable would take on values between zero and $2\beta' x$ and would be symmetrically distributed about $\beta' x$ (Figure III). For such a symmetric sample, Powell (1986) derived a series of "normal" equations that allowed for the estimation of the SCLC parameter (β_s) as well as their standard errors (see Appendix III for the normal equations).

1/ In this case, the prediction of the latent variable is the appropriate one.

2/ The unconditional prediction of y_i must be used in this case.

3/ This is taken from Powell (1986).

In addition, Newey (1987) has shown that one can use the tobit and SCLC estimates (and their variance-covariance matrices) to derive a Hausman test statistic (h) which tests to see if the normality and homoskedasticity assumptions of the tobit analysis are violated. If $\hat{\beta}_t$ and $\hat{\beta}_s$ are the vectors of tobit and SCLC estimated parameters, then $h = T(\hat{\beta}_s - \hat{\beta}_t)' [V(\hat{\beta}_s - \hat{\beta}_t)]^{-1} (\hat{\beta}_s - \hat{\beta}_t)$; where T = number of observations; $V(\hat{\beta}_s - \hat{\beta}_t)$ = estimates of the asympotitic covariance matrix for $T(\hat{\beta}_s - \hat{\beta}_t)$; h will be distributed as chi-squared with k (number of exogenous variables) degrees of freedom. 1/ In our empirical analysis, we will examine the SCLC and tobit estimates to see if the normality and homoskedasticity assumptions have been violated.

4. Empirical results

Our empirical results indicate that transaction variables and exchange rate arrangements have played important roles in determining the currency composition of foreign exchange reserves throughout the period 1976-85. The estimation results for both the developing and industrial countries for the period 1976-85 are reported in Tables 2 through 11.

a. Developing countries

The estimation results support the view that for developing countries, the proportions of foreign exchange reserves held as U.S. dollars, French francs, and Japanese yen were most strongly influenced by exchange rate arrangements, especially when the country was pegged to a particular currency. For example, developing countries whose exchange rates were pegged to the U.S. dollar held significantly larger proportions of their foreign exchange reserves as dollars. In addition, French franc peggers tended to hold much lower proportion of dollar and higher proportion of French francs. In contrast, countries pegged to other currencies or composite indicators tended to hold significantly higher proportions of reserves denominated in the yen which were offset by lower holdings of U.S. dollars and French francs.

These results also imply that an increase in the proportion of trade between a given developing country and a particular reserve currency country (relative to the developing country's total external payments) resulted in a significant higher share of the country's foreign exchange reserves being held in the currency of that reserve currency country. However, the cross effects of trade flows (e.g., the influence of increased trade with France on holdings of U.S. dollars)

1/ See Appendix III for the estimate of $V(\hat{\beta}_s - \hat{\beta}_t)$.

Figure III

Symmetrically Censored Least Squares

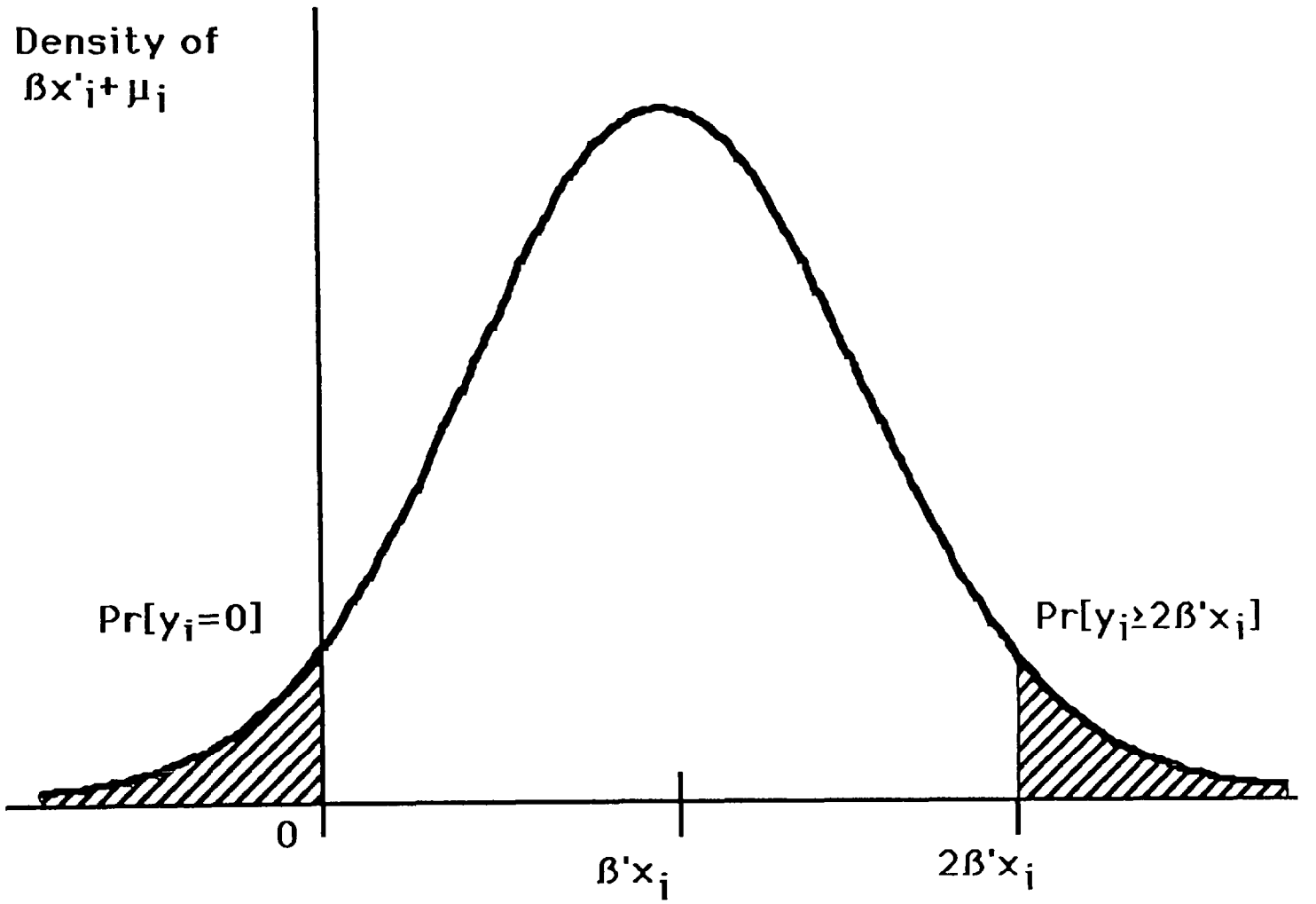

Table 2. Determinants of Central Bank Holdings of Reserve Currencies: Developing Countries, 1/ 1976-85

(Portion of foreign exchange reserves denominated in U.S. dollars) 2/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	47.78 (9.53)	47.78 (9.53)	49.00 (8.83)
Exchange rate regime			
a. Pegged to the U.S. dollar	7.69 (3.53)	7.69 (3.53)	7.53 (3.39)
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	-7.06 (2.39)	-7.06 (2.39)	-7.46 (2.46)
d. Cooperative agreement	—	—	—
e. Flexible exchange rate	—	—	—
Proportion of trade with each country relative to external payments to all countries 3/			
a. United States	0.58 (5.89)	0.58 (5.89)	0.57 (5.27)
b. France	0.07 (0.23)	0.07 (0.23)	0.07 (0.24)
c. Federal Republic of Germany	-0.48 (1.69)	-0.48 (1.69)	-0.58 (1.93)
d. United Kingdom	-0.29 (1.36)	-0.29 (1.36)	-0.32 (1.49)
e. Japan	0.14 (0.85)	0.14 (0.85)	0.13 (0.84)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	2.28 (6.29)	2.28 (6.29)	2.20 (6.70)
b. French franc	16.34 (3.14)	16.34 (3.14)	16.73 (3.83)
c. German deutsche mark	-21.82 (4.36)	-21.82 (4.36)	-21.86 (3.97)
d. British pound	0.98 (0.82)	0.98 (0.82)	1.08 (0.43)
e. Japanese yen	-3.10 (0.82)	-3.10 (0.82)	-3.37 (0.85)
R^2	0.55		
$\bar{R}^2$	0.53		
R^2_{T1}		0.55	
R^2_{T2}		--	
$\bar{E}_t$		--	
R^2_{T3}		0.55	
h 4/			0.24
Sample size	340	340	340

1/ Excludes developing countries pegged to the French franc.

2/ t ratios in parentheses.

3/ External payments is defined to equal the sum of exports and imports plus debt-service payments.

4/ One percent of the time, a χ^2 with 13 degrees of freedom will exceed the value of 27.7.

Table 3. Determinants of Central Bank Holdings of Reserve Currencies: Developing Countries, 1976-85

(Portion of foreign exchange reserves denominated in French francs) 1/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	3.67	0.63	-0.83
	(2.68)	(0.51)	(0.63)
Exchange rate regime			
a. Pegged to the U.S. dollar	-1.37	-1.48	-3.76
	(2.01)	(2.47)	(3.20)
b. Pegged to the French franc	84.34	82.75	83.90
	(47.7)	(46.81)	(34.56)
c. Pegged to a composite or other currency	-2.36	-2.21	-8.76
	(2.90)	(2.90)	(4.92)
d. Cooperative agreement	—	—	—
e. Flexible exchange rate	—	—	—
Proportion of trade with each country relative to external payments to all countries 2/			
a. United States	-0.03	-0.01	-0.12
	(1.17)	(0.21)	(2.24)
b. France	0.18	0.25	0.23
	(4.52)	(6.39)	(4.22)
c. Federal Republic of Germany	-0.02	0.17	0.24
	(0.23)	(2.39)	(2.51)
d. United Kingdom	0.05	-0.03	0.28
	(0.82)	(0.54)	(2.71)
e. Japan	-0.09	-0.10	0.17
	(2.05)	(2.19)	(1.88)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	-0.19	-0.37	0.03
	(1.73)	(3.81)	(0.14)
b. French franc	1.36	1.79	1.51
	(4.17)	(5.45)	(3.62)
c. German deutsche mark	1.27	1.79	1.07
	(1.35)	(1.92)	(0.90)
d. British pound	-0.84	0.27	-1.17
	(1.29)	(0.42)	(0.59)
e. Japanese yen	1.20	0.84	-8.16
	(1.12)	(0.81)	(1.67)
R^2	0.99		
$\bar{R}^2$	0.99		
R^2_{T1}		0.99	
R^2_{T2}		0.88	
$\bar{E}_t$		1.35	
R^2_{T3}		0.99	
h 3/			89.95
Number of observations	258	390	390

1/ t ratios in parentheses.

2/ External payments is defined to equal the sum of exports and imports plus debt-service payments.

3/ One percent of the time, a χ^2 with 14 degrees of freedom will exceed 29.1.

Table 4. Determinants of Central Bank Holdings of Reserve Currencies: Developing Countries 1/ 1976-85

(Portion of foreign exchange reserves denominated in Pounds sterling) 2/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	-1.64	-2.64	-93.14
	0.71	(1.17)	(9.44)
Exchange rate regime			
a. Pegged to the U.S. dollar	-1.44	-2.12	17.61
	(1.40)	(2.12)	(2.78)
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	-1.50	-1.94	8.64
	(1.10)	(1.46)	(0.83)
d. Cooperative agreement	—	—	—
e. Flexible exchange rate	—	—	—
Proportion of trade with each country relative to external payments to all countries 3/			
a. United States	0.04	0.01	-1.03
	(0.89)	(0.16)	(1.47)
b. France	0.28	0.34	-1.71
	(2.05)	(2.51)	(0.24)
c. Federal Republic of Germany	0.02	0.04	0.22
	(0.13)	(0.32)	(0.17)
d. United Kingdom	0.56	0.62	2.52
	(5.88)	(6.57)	(3.27)
e. Japan	0.02	0.04	2.32
	(0.23)	(0.55)	(3.11)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	0.17	0.09	4.16
	(0.99)	(0.53)	(2.32)
b. French franc	-4.56	-6.01	41.74
	(1.80)	(2.53)	(3.65)
c. German deutsche mark	-0.50	1.26	-51.94
	(0.22)	(0.57)	(6.49)
d. British pound	9.69	9.79	43.13
	(8.86)	(9.03)	(10.76)
d. Japanese yen	1.77	2.48	-23.29
	(1.04)	(1.49)	(2.83)
R^2	0.52		
$\bar{R}^2$	0.50		
R^2_{T1}		0.52	
R^2_{T2}		0.71	
$\bar{F}_t$		1.74	
R^2_{T3}		0.55	
h 4/			738.91
Number of observations	288	340	340

1/ Excludes developing countries pegged to the French franc.

2/ t ratios in parentheses.

3/ External payments is defined to equal the sum of exports and imports plus debt-service payments.

4/ One percent of the time, a χ^2 with 13 degrees of freedom will exceed the value of 27.7.

Table 5. Determinants of Central Bank Holdings of Reserve Currencies: Developing Countries, 1/ 1976-85

(Portion of foreign exchange reserves denominated in deutsche marks) 2/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	34.14 (9.87)	36.36 (10.53)	47.49 (10.47)
Exchange rate regime			
a. Pegged to the U.S. dollar	1.06 (0.68)	0.42 (0.27)	2.30 (1.22)
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	1.59 (0.78)	0.33 (0.16)	-0.18 (0.10)
d. Cooperative agreement	—	—	—
e. Flexible exchange rate	—	—	—
Proportion of trade with each country relative to external payments to all countries 3/			
a. United States	-0.53 (7.06)	-0.69 (9.79)	-1.18 (9.58)
b. France	-0.38 (1.87)	-0.32 (1.58)	-1.93 (6.41)
c. Federal Republic of Germany	0.52 (2.66)	0.41 (2.14)	0.86 (1.92)
d. United Kingdom	-0.50 (3.39)	-0.43 (2.91)	-0.46 (3.30)
e. Japan	-0.21 (1.82)	-0.19 (1.63)	-0.16 (1.36)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	-1.78 (6.63)	-1.85 (7.07)	-2.60 (6.85)
b. French franc	-5.98 (1.69)	-6.68 (1.86)	-0.28 (0.08)
c. German deutsche mark	9.38 (2.73)	10.51 (3.04)	14.77 (3.08)
d. British pound	-3.75 (2.22)	-4.42 (2.58)	-13.72 (6.88)
e. Japanese yen	-1.48 (0.57)	0.16 (10.06)	-2.47 (0.77)
R^2	0.40		
$\bar{R}^2$	0.38		
R^2_{T1}		0.42	
R^2_{T2}		0.68	
$\bar{\varepsilon}_t$		5.91	
R^2_{T3}		0.47	
h 4/			209.81
Number of observations	312	340	340

1/ Excludes developing countries pegged to the French franc.

2/ t-ratios in parentheses.

3/ External payments are defined to equal the sum of exports and imports plus debt-service payments.

4/ One percent of the time, a χ^2 with 13 degrees of freedom will exceed the value of 27.7.

Table 6. Determinants of Central Bank Holdings of Reserve Currencies: Developing Countries, 1/ 1976-85

(Portion of foreign exchange reserves denominated in Japanese yen) 2/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	7.07 (3.20)	8.15 (3.81)	6.95 (1.96)
Exchange rate regime			
a. Pegged to the U.S. dollar	-2.00 (2.04)	-3.29 (3.47)	-12.45 (7.60)
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	4.64 (3.77)	5.05 (4.03)	11.51 (5.28)
d. Cooperative agreement	—	—	—
e. Flexible exchange rate	—	—	—
Proportion of trade with each country relative to external payments to all countries 3/			
a. United States	-0.04 (0.87)	-0.08 (1.77)	-0.10 (1.13)
b. France	-0.12 (0.68)	-0.28 (2.06)	-2.61 (2.21)
c. Federal Republic of Germany	-0.03 (0.24)	-0.14 (1.15)	0.40 (2.07)
d. United Kingdom	-0.07 (0.79)	-0.08 (0.84)	-0.24 (1.91)
e. Japan	0.24 (3.36)	0.27 (3.96)	0.22 (1.67)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	-0.38) (2.40)	-0.36 (2.29)	-0.71 (0.87)
b. French franc	-4.04 (1.41)	-3.34 (1.41)	4.48 (0.76)
c. German deutsche mark	4.15 (1.54)	-0.76 (0.34)	5.98 (1.12)
d. British pound	-2.70 (2.69)	-2.55 (2.42)	-8.62 (3.89)
e. Japanese yen	3.54 (2.34)	3.29 (2.08)	6.63 (1.53)
R^2	0.32		
$\bar{R}^2$	0.29		
R^2_{T1}		0.32	
R^2_{T2}		0.42	
$\bar{E}_t$		2.16	
R^2_{T3}		0.39	
h 4/			535.44
Number of observations	273	340	340

1/ Excludes developing countries pegged to the French franc.

2/ t ratios in parentheses.

3/ External payments is defined to equal the sum of exports and imports plus debt-service payments.

4/ One percent of the time, a χ^2 with 13 degrees of freedom will exceed the value of 27.7.

Table 7. Determinants of Central Bank Holdings of Reserve Currencies: Industrial Countries, 1976-85

(Portion of foreign exchange reserves denominated in U.S. dollars) 1/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	80.63 (13.19)	80.63 (13.19)	80.63 (18.58)
Exchange rate regime			
a. Pegged to the U.S. dollar	—	—	—
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	—	—	—
d. Cooperative agreement	14.30 (3.50)	14.30 (3.50)	14.30 (3.18)
e. Flexible exchange rate	12.54 (2.55)	12.54 (2.55)	12.54 (2.64)
Proportion of trade with each country relative to total trade with all countries 2/			
a. United States	0.16 (1.31)	0.16 (1.31)	0.16 (2.35)
b. France	0.41 (1.37)	0.41 (1.37)	0.41 (1.68)
c. Federal Republic of Germany	-0.64 (3.24)	-0.64 (3.24)	-0.64 (3.57)
d. United Kingdom	-0.81 (4.98)	-0.81 (4.98)	-0.81 (4.62)
e. Japan	-1.62 (5.53)	-1.62 (5.53)	-1.62 (6.47)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	—	—	—
b. French franc	—	—	—
c. German deutsche mark	—	—	—
d. British pound	—	—	—
e. Japanese yen	—	—	—
R^2	0.41		
$\bar{R}^2$	0.38		
R^2_{T1}		0.41	
R^2_{T2}		—	
$\bar{E}_t$		—	
R^2_{T3}		0.41	
h 3/			0.0
Number of observations	180	180	180

1/ t-ratios in parentheses.
2/ Total trade is measured as the sum of exports and imports.
3/ One percent of the time, a χ^2 with 8 degrees of freedom will exceed the value of 20.1.

Table 8. Determinants of Central Bank Holdings of Reserve Currencies: Industrial Countries, 1976-85

(Portion of foreign exchange reserves denominated in French francs) 1/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	-2.39 (5.34)	-1.28 (2.24)	3.85 (1.09)
Exchange rate regime			
a. Pegged to the U.S. dollar	—	—	—
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	—	—	—
d. Cooperative agreement	-1.61 (4.07)	-1.92 (4.00)	-15.02 (2.55)
e. Flexible exchange rate	-0.06 (0.13)	0.17 (0.36)	-5.93 (3.03)
Proportion of trade with each country relative to trade with all countries 2/			
a. United States	0.05 (2.74)	0.01 (1.20)	0.05 (0.16)
b. France	0.25 (8.26)	0.32 (9.13)	0.93 (2.56)
c. Federal Republic of Germany	0.03 (1.45)	-0.09 (3.83)	-0.57 (2.11)
d. United Kingdom	0.05 (5.07)	0.06 (4.35)	-0.09 (2.04)
e. Japan	0.17 (1.30)	-0.17 (2.51)	-0.17 (0.24)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	—	—	—
b. French franc	—	—	—
c. German deutsche mark	—	—	—
d. British pound	—	—	—
e. Japanese yen	—	—	—
R^2	0.74		
$\bar{R}^2$	0.72		
R^2_{T1}		0.75	
R^2_{T2}		0.84	
$\bar{E}_t$		0.51	
R^2_{T3}		0.72	
h 3/			130,928.91
Number of observations	81	180	180

1/ t ratios in parentheses.

2/ Total trade is measured as the sum of exports and imports.

3/ One percent of the time, a χ^2 with 8 degrees of freedom will exceed the value of 20.1.

Table 9. Determinants of Central Bank Holdings of Reserve Currencies: Industrial Countries, 1976-85

(Portion of foreign exchange reserves denominated in pounds sterling) 1/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	0.97 (0.77)	0.91 (0.69)	-10.72 (1.10)
Exchange rate regime			
a. Pegged to the U.S. dollar	—	—	—
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	—	—	—
d. Cooperative agreement	-1.30 (1.58)	-1.42 (1.65)	1.03 (0.54)
e. Flexible exchange rate	-0.85 (0.78)	-2.02 (1.87)	-23.09 (4.40)
Proportion of trade with each country relative to trade with all countries 2/			
a. United States	-0.02 (0.80)	-0.00 3/ (0.02)	0.37 (2.50)
b. France	-0.01 (0.21)	-0.03 (0.48)	-0.08 (0.10)
c. Federal Republic of Germany	-0.08 (2.03)	-0.10 (2.34)	-0.58 (0.94)
d. United Kingdom	0.30 (8.92)	0.28 (8.41)	0.52 (10.78)
e. Japan	0.24 (3.95)	0.28 (4.39)	1.25 (4.00)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	—	—	—
b. French franc	—	—	—
c. German deutsche mark	—	—	—
d. British pound	—	—	—
e. Japanese yen	—	—	—
R^2	0.51		
$\bar{R}^2$	0.48		
R^2_{T1}		0.52	
R^2_{T2}		0.86	
F^*_t		5.97	
R^2_{T3}		0.51	
h 4/			489.82
Number of observations	152	180	180

1/ t-ratios in parentheses.
2/ Total trade is measured as the sum of exports and imports.
3/ Less than 0.01.
4/ One percent of the time, a χ^2 with 8 degrees of freedom will exceed the value of 20.1.

Table 10. Determinants of Central Bank Holdings of Reserve Currencies: Industrial Countries, 1976-85

(Portion of foreign exchange reserves denominated in deutsche marks) 1/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	12.54 (2.92)	7.10 (1.88)	-7.05 (1.20)
Exchange rate regime			
a. Pegged to the U.S. dollar	—	—	—
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	—	—	—
d. Cooperative agreement	-10.41 (4.24)	-10.80 (4.47)	-7.21 (2.76)
e. Flexible exchange rate	-9.45 (3.05)	-7.07 (2.40)	-19.31 (5.80)
Proportion of trade with each country relative to trade with all countries 2/			
a. United States	-0.04 (0.52)	0.01 (0.01)	0.27 (3.44)
b. France	-0.20 (1.03)	-0.36 (1.98)	-2.51 (4.24)
c. Federal Republic of Germany	0.53 (3.46)	0.77 (6.18)	1.47 (6.32)
d. United Kingdom	0.22 (2.90)	0.33 (3.32)	0.69 (5.13)
e. Japan	0.47 (2.63)	0.51 (2.87)	1.33 (6.66)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	—	—	—
b. French franc	—	—	—
c. German deutsche mark	—	—	—
d. British pound	—	—	—
e. Japanese yen	—	—	—
R^2	0.30		
$\bar{R}^2$	0.27		
R^2_{T1}		0.32	
R^2_{T2}		1.00	
$\bar{E}_t$		0.00	
R^2_{T3}		0.35	
h 3/			81.21
Number of observations	170	180	180

1/ t-ratios in parentheses.

2/ Total trade is measured as the sum of exports and imports.

3/ One percent of the time, a χ^2 with 8 degrees of freedom will exceed the value of 20.1.

Table 11. Determinants of Central Bank Holdings of Reserve Currencies: Industrial Countries, 1976-85

(Portion of foreign exchange reserves denominated in Japanese yen) 1/

Independent Variables	Ordinary Least Squares	Tobit	Symmetrically Censored Least Squares
Constant	5.94	5.00	11.59
	(2.20)	(1.95)	(2.70)
Exchange rate regime			
a. Pegged to the U.S. dollar	—	—	—
b. Pegged to the French franc	—	—	—
c. Pegged to a composite or other currency	—	—	—
d. Cooperative agreement	0.56	-1.27	-4.90
	(0.34)	(0.76)	(2.55)
e. Flexible exchange rate	-1.09	-1.64	-3.85
	(0.55)	(0.81)	(2.39)
Proportion of trade with each country relative to trade with all countries 2/			
a. United States	-0.03	-0.20	-0.23
	(0.38)	(3.17)	(0.64)
b. France	-0.33	-0.24	-0.31
	(2.42)	(1.91)	(2.07)
c. Federal Republic of Germany	0.06	0.06	-0.04
	(0.73)	(0.70)	(0.46)
d. United Kingdom	0.03	0.02	-0.28
	(0.49)	(0.23)	(3.33)
e. Japan	0.67	0.90	0.79
	(5.01)	(7.51)	(3.31)
Proportion of interest payments on external debt in given currency relative to external payments to all countries			
a. U.S. dollar	—	—	—
b. French franc	—	—	—
c. German deutsche mark	—	—	—
d. British pound	—	—	—
e. Japanese yen	—	—	—
R^2	0.33		
$\bar{R}^2$	0.29		
R^2_{T1}		0.28	
R^2_{T2}		0.42	
$\bar{E}_t$		3.08	
R^2_{T3}		0.35	
h 3/			142.61
Number of observations	137	180	180

1/ t-ratios in parentheses.
2/ Total trade is measured as the sum of exports and imports.
3/ One percent of the time, a χ^2 with 8 degrees of freedom will exceed the value of 20.1.

showed a more mixed pattern with some significant and positive coefficients (implying that the currencies were complements) and some negative and significant coefficients (implying that currencies tended to be substitutes).

The proportions of interest payments on the external debt denominated in particular reserve currencies (relative to total external payments) were also a key variables in the developing country regressions. In all cases, the proportions of foreign exchange reserves denominated in a given reserve currency (except for the yen) were positively and significantly related to the proportion of interest payments denominated in that currency. Moreover, eight of the cross effect parameters were significantly negative. These parameter estimates imply that a rise in the share of a country's external debt denominated in a given currency (e.g., the deutsche mark) resulted not only in a higher share of foreign exchange reserves held in that currency but also reduced shares of reserve held in other reserve currencies that are included in our study (e.g., the dollar). 1/

The correlation measures for both the OLS and tobit estimators suggest that the explanatory power of these equations varies considerably for the different currencies. 2/ While the regressions explained 99 percent of the observed variation in the share of foreign exchange reserve held as French francs, only 55 percent of the variation in the U.S. dollar share could be explained. The explanatory power declined to about 50, 40, and 30 percent for the pound sterling, the deutsche mark, and the yen, respectively.

b. Industrial countries

For the industrial countries, the absence of complete information about the currency composition of their external debt means that the regression analysis considers only the role of trade flows and exchange rate arrangements. First, the explanatory power of the regressions for the industrial countries varied considerably. While over 70 percent of the variability in the French franc share was accounted by its regression (measured in terms of R^2_{T3}), the proportions of variability

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1/ Holdings of certain unspecified currencies have been excluded from our study.

2/ As noted earlier, four measures of goodness of fit are supplied for each of the tobit regressions. The R^2_{T1} measures the square of the simple correlation coefficient between the predicted and actual values of the dependent variable for those observations in which the actual values were positive; R^2_{T2} measures the proportion of the zero observations correctly predicted by the model; $\bar{E}_T$ is the mean error for the observations which were predicted to be positive but whose actual value was zero; and R^2_{T3} is the square of the simple correlation coefficient between actual and predicted values of the dependent variable for the complete sample.

explained for the pound sterling (51 percent), U.S. dollars (41 percent), deutsche mark (35 percent), and yen (35 percent) were lower.

In addition, these regressions suggest that for the industrial countries exchange rate arrangements most strongly affected the proportions of reserves held as U.S. dollars, French francs, and deutsche marks. For example, the adoption of a flexible exchange rate was accompanied by a significantly higher proportion of reserves held as U.S. dollar instruments partly offset by a significantly lower share for deutsche marks. This may reflect the option that countries with flexible exchange rates have of always intervening in U.S. dollars rather than in other currencies as could occur under certain pegging arrangements. Similarly, participation in a cooperative agreement (e.g., the European Monetary System or some of its earlier variants) resulted in a significantly higher proportion of foreign exchange reserves being held as U.S. dollars that was offset by significantly lower proportions for the French franc and deutsche marks. The results for the cooperative agreements dummy are consistent with those obtained by Heller and Knight (1978). As they noted, the results reflect the fact that at times the countries that have been members of such arrangements as the European Monetary System (or European System of Narrower Exchange Rate Margins) have committed themselves to intervene in the U.S. dollar and to limit their holdings of other members' currencies. As a result, a higher proportion of foreign exchange reserves was held as U.S. dollars.

A higher level of trade between a industrial country and a particular reserve currency country generally led the country to hold a significantly (except in the case of trade with the United States) higher proportion of its reserves in that reserve currency. The effects of an increase in trade with one reserve currency country on holdings of other reserve currencies were more mixed with eight negative and significant cross-effect coefficients and four positive and significant coefficients.

c. A comparison of the OLS, tobit, and SCLS estimates

Tables 2 through 11 also allow for a comparison of the estimation results for ordinary least squares (OLS) based solely on the observations for which the proportions of reserves held in a given currency are nonzero, the tobit estimator, and the symmetrical censored least squares estimator. First, as noted earlier, the tobit estimates were derived under the assumptions that the error terms in the regression were normally distributed and homosketastic. However, the test of the residuals from the tobit estimates indicates that they were generally not normally distributed and homoskedastic. This means that both the OLS and tobit estimates were inconsistent. It is only in the case of the U.S. dollar that the hypothesis of normality and homoskedasticity could not be rejected. In part, this reflects the fact that virtually all countries held some U.S. dollar denominated reserve assets during each period. In this case, the OLS regression on the U.S. dollar share were

identical with the tobit estimates. Moreover, the point estimates of the SCLS estimator were also similar to those of the OLS and tobit estimators, although the standard errors were smaller due to the censoring technique.

A second difference between the estimators is that the SCLS estimates often implied larger effects for trade flows and debt-service payments. To the extent that the OLS or tobit estimators are biased and inefficient, then the SCLS estimates suggest that earlier studies based on OLS results have tended to understate the influence of trade and capital flows on the currency composition of foreign exchange reserves.

Finally, the SCLS estimates also often suggested larger effects of exchange rate arrangements on the currency composition of foreign exchange reserves. These exchange rate effects were most noticeable for the developing countries that pegged to a composite indicator or some currency other than the U.S. dollar or French francs, and for industrial countries in the case where a flexible exchange rate has been employed.

IV. Conclusion

This study has considered the determinants of the currency composition of foreign exchange reserves for both industrial and developing countries. Our empirical results indicate that for countries in these groups the currency composition has been influenced by each country's exchange rate arrangements, its trade flows with reserve currency countries, and the currency of denomination of its debt-service payments. During the period from 1976 to 1985, a developing country tended to hold a greater proportion of its foreign exchange reserves in assets denominated in a particular reserve currency if its exchange rate was pegged to that currency, if a large share of its exports and imports was with the country issuing the reserve currency, and if a higher proportion of the interest payments on its external debt was denominated in this reserve currency. The currency composition of foreign exchange reserves for industrial countries was also influenced by exchange rate arrangements, although the effects were strongest for those countries that participated in cooperate agreements (e.g., the European Monetary System) which tended to hold relatively higher shares of U.S. dollars. In addition, the shares of an industrial country's exports and imports to the reserve currency countries had significant influences on the proportion of reserves held in different currencies.

The evidence is consistent with the view that managing the currency composition of a country's net foreign asset position is done more cheaply by altering the currency denomination of assets and liabilities that are not held as reserve assets. While transactions costs in currency markets are low, it appears that they are high enough so that central banks find it optimal to avoid holding reserve assets in one reserve currency that must be converted into another reserve currency

before being used to make payment. This, in turn, suggests that inferences about the stability of preferences for net currency positions on the part of governments cannot be drawn from an analysis of reserve holdings in isolation from the rest of the government's financial portfolio.

Data Sources

Foreign exchange reserves--this data was obtained from the International Monetary Fund's survey of the currency composition of members' foreign exchange reserves. In order to maintain the confidentiality of the data file, all regressions were run "blind" without any country specific parameters.

Exchange rate arrangements--these arrangements were classified according to the system used in the Fund's Annual Report on Exchange Arrangements and Exchange Restrictions. The classifications prevailing at the end of 1985 were extended back through the period beginning in 1976.

Exports and imports--these variables were taken from the Fund's Direction of Trade Statistics data file.

External debt--the currency denomination of public and publically guaranteed debt was taken from the World Debt Tables issued by the World Bank.

Eurodollar six-month deposit rate--this was taken from the International Financial Statistics.

First Order Conditions for Optimal Net and Gross Foreign Asset Portfolio

Selecting N_1, N_2, A_1, and A_2 so as to maximize (7) yields:

$$(20)\quad \frac{\partial U}{\partial N_1} = r_1 + d_1 - r_2 - d_2 - 2bN_1\sigma_{r_1}^2 + 2b(W-N_1)\sigma_{r_2}^2$$

$$- 2b(W-N_1)\sigma_{r_1r_2} + 2bN_1\sigma_{r_1r_2} = 0$$

$$(21)\quad N_2 = W - N_1$$

$$(22)\quad \frac{\partial U}{\partial A_1} = - d_1 - 2\pi_2 c\,(A_1-t_1) + 2(\pi_2+\pi_3)\,p(T-A_1-A_2) = 0$$

$$(23)\quad \frac{\partial U}{\partial A_2} = - d_2 - 2\pi_3 c\,(A_2-A_2) + 2(\pi_2+\pi_3)\,p(T-A_2-A_2) = 0$$

Equation (20) and (21) imply equations (8) and (9) in the text. Equations (22) and (23) imply that:

$$(24)\quad A_1 - t_1 = \frac{\pi_3}{\pi_2}(A_2-t_2) + \frac{d_2 + d_1}{2\pi_2 c}$$

or using $A = A_1 + A_2$

$$(25)\quad A_1 = \frac{\pi_3 A + \pi_2 t_1 - \pi_3 t_2}{(\pi_2+\pi_3)} + \frac{d_2 - d_1}{2c(\pi_2+\pi_3)}$$

$$(26)\quad A_2 = \frac{\pi_2 A + \pi_3 t_2 - \pi_2 t_1}{(\pi_2+\pi_3)} + \frac{d_1 - d_2}{2c(\pi_2+\pi_3)}$$

Thus, for a given total level of reserves, the holdings of a particular currency depend on the expected amount of transactions in that currency in comparison with the expected amount of transactions in other currencies, the cost of converting from one currency to another, and the differential net costs of borrowing reserves in the different currencies. Notice that, from the assumed distribution of transactions,

$$(27) \quad E(T_1) = (\pi_1+\pi_2)t_1 + \pi_3(T-t_2)$$

$$(28) \quad E(T_2) = (\pi_1+\pi_3)t_2 + \pi_2 (T-t_1)$$

so that $E(T_1)$ increases with t_1 and declines with t_2, while the opposite occurs with $E(T_2)$.

Replacing (25) and (26) in either (22) or (23), it is possible to solve for the total level of reserves A. Thus

$$(29) \quad A = \frac{2p(\pi_2+\pi_3)^2 T + 2c\pi_2\pi_3 (t_1+t_2) - (\pi_3 d_1+\pi_2 d_2)}{2p (\pi_2+\pi_3)^2 + 2\pi_2\pi_3 c}$$

Calculation of Symmetrically Censored Least Squares Estimates

As shown in Powell (1986), the symmetrically censored least squares estimates must satisfy:

$$(30)\quad \hat{\beta}_s = \left[\sum_{t=1}^{T} 1(\hat{\beta}_s' x_t > 0) \cdot x_t x_t'\right]^{-1} \sum_{t=1}^{T} 1(\hat{\beta}_s' x_t > 0) \cdot \min\{y_t, 2\hat{\beta}_S' x_t\} x_t$$

where x_t = vector of independent variables at t.

$1(A) = 1$ if A is true

$= 0$ otherwise

The procedure starts with the tobit estimates of the β's and uses them to calculate the right hand side (r.h.s.) of equation (30). This implies an initial vector of $\hat{\beta}_s^0$. The r.h.s. of equation (30) was then recalculated using this value of $\hat{\beta}_s^0$. The interations were continued until the largest difference between any element in the old and new values of $\hat{\beta}_s$ was less than 10^{-6}. Between 12 and 60 iterations were required to calculate the $\hat{\beta}_s$ for the different currencies.

The variance-covariance matrix for the SCLS estimates was calculated as:

$$(31)\quad V(\hat{\beta}_s) = \frac{1}{T} \hat{C}_T^{-1} \hat{D}_T \hat{C}_T^{-1}$$

where T = sample size

$$\hat{C}_T = \frac{1}{T} \sum_{t=1}^{T} 1(0 < y_t < 2\hat{\beta}_s' x_t) x_t x_t'$$

$$\hat{D}_T = \frac{1}{T} \sum_{t=1}^{T} 1(\hat{\beta}_s' x_t > 0) \min(\hat{u}_t^2, (\hat{\beta}_s' x_t)^2) x_t x_t'$$

$$\hat{u}_t = y_t - \hat{\beta}_s' x_t.$$

The test statistic (h) for the test of normality and homoskedasticity of the error terms was calculated (see Newey (1987)) as:

$$(32) \quad h = T(\hat{\beta}_s - \hat{\beta}_t)' [V(\hat{\beta}_s - \hat{\beta}_t)]^{-1} (\hat{\beta}_s - \hat{\beta}_t)$$

where $\hat{\beta}_s$ = SCLS estimates

$\hat{\beta}_t$ = tobit estimates.

The $V(\hat{\beta}_s - \hat{\beta}_t)$ matrix was calculated following the procedures described in Newey (1987, pp. 129-30, equation (3.6)).

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