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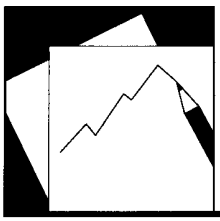

IMF Working Paper

Do Reserve Portfolios Respond to Exchange Rate Changes Using a Portfolio Rebalancing Strategy? An Econometric Study Using COFER Data

Ewe-Ghee Lim

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Abstract

This paper tests whether reserve portfolios respond to exchange rate changes with a portfolio rebalancing strategy, which requires the purchase of depreciating currencies and sale of appreciating ones. The paper finds empirical support for the strategy, in particular that dollar depreciation/appreciation results in rebalancing switches vis-a-vis the other major reserve currency, the euro; valuation changes in the minor currencies tend to result in switches among themselves. The finding implies that currency diversifications in response to exchange rate changes have thus far tended to be stabilizing for exchange markets; it also helps explain the relative stability of reserve currency shares.

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I. INTRODUCTION

In recent years, interest in data on the currency composition of foreign exchange reserves (COFER) has grown sharply. This interest reflects both the rapid growth of reserves and some concerns that large and abrupt shifts in reserve currency composition may pressure exchange rates and disrupt exchange markets. While there is no agreement on the extent of the risks for exchange markets (Truman and Wong, 2006), it may be useful to consider how different types of investment/diversification strategies may in fact affect such markets.

Truman and Wong (2006), in particular, have defined two types of investment/diversification strategies that affect exchange rates in different ways: [2] one strategy tends to follow market trends and sells a currency when the currency depreciates (or in anticipation of its depreciation) and purchases a currency when it appreciates (or in anticipation of its appreciation). This strategy tends to move a currency in the direction in which it is already trending in exchange markets. The second strategy does just the opposite; this strategy purchases a currency when it depreciates and sells the currency when it appreciates. By purchasing a falling currency and selling a rising currency, this strategy tends to offset the direction of movement of a currency. Such a strategy is often called portfolio rebalancing, which Truman and Wong (2006) has also called "stabilizing diversification" (p.9) because of its offsetting impact on currency movements. [3]

While the objective of the market trend strategy may be clear—capitalize on trends to make short-term profits or avoid short-term losses—that of portfolio rebalancing may not be as clear. In general, the objective of portfolio rebalancing is to return (rebalance) a portfolio back to or closer towards its originally chosen, optimal allocation—whenever changes in asset prices cause the portfolio's asset allocation to deviate beyond a certain threshold from the original allocation. Portfolio rebalancing is a dynamic (allocation) strategy in that it seeks to respond to the impact of price changes on a portfolio over time (Perold and Sharp, 1988). [4]

An example may make this strategy clearer. Suppose a reserve portfolio's optimally chosen allocation is one third each in dollars, euros, and yen. The one-third allocation is calculated using the portfolio's numeraire currency—normally the domestic currency. Assume now that the dollar depreciates while the euro and yen appreciate against the domestic currency. All

[2] Truman and Wong assume that "sterilized foreign exchange market intervention has at least some temporary influence on exchange rates in the expected direction (p. 8–9)."

[3] There is actually a third strategy—buy and hold—which does not react to valuation changes altogether. This strategy has no impact on exchange markets because it does not react to currency movements.

[4] Perold and Sharp (1988) also view trend following and buy and hold as dynamic allocation strategies for the same reason. For buy and hold, no response is a type of response.

other things equal, the domestic currency value of dollars in the portfolio will fall while those of the yen and euro rise. As a consequence, the shares of each currency (in terms of the numeraire) will deviate from the original one-third each allocation. If this deviation goes beyond a certain threshold, the rebalancing strategy kicks in and dollars (the depreciating currency) are purchased while yen and euros (the appreciating currencies) are sold to try to restore the original allocation under the new exchange rates. One implication of this strategy is that currency shares in terms of the numeraire would tend to remain relatively stable.

The question thus arises: Which type of dynamic investment/diversification strategy is normally favored by reserve managers? While both strategies may be variously employed at any point in time, the question remains interesting for this reason. A finding for portfolio rebalancing as the dominant strategy would allay some of the concerns that currency reserve diversifications may create pressure and disrupt exchange markets. Instead, the potential effects would be the reverse of what is feared. Once optimal portfolios have been determined, currency reserve diversifications over time would tend to offset trend currency movements and become "stabilizing diversification" (using Truman and Wong's language) instead of being potentially disruptive. In addition, this issue is testable. If portfolio rebalancing is the dominant strategy, its effects should show up in aggregate reserve data, where currency depreciations would tend to be associated with purchases of the depreciating currency, and appreciations with sales of the appreciating currency. [5]

This paper will test econometrically for the effects of portfolio rebalancing using the IMF's published aggregate COFER data for 1999–2005. [6] The paper will discuss briefly a few basic characteristics of the portfolio rebalancing strategy in Section II; describe the empirical model in Section III; and examine the econometric results in Section IV, before concluding.

Before proceeding, one further clarification on the paper's objective may be useful. The paper will not be testing for or assessing issues related to the construction of optimal reserve portfolios. As noted above, the focus is on how reserve portfolios respond to the impact of exchange rate changes, which by definition would tend to cause the currency allocations of a

[5] Truman and Wong (2006) examined COFER data for 1976–2004 to determine if the relationship between dollar depreciation/purchases and appreciation/sales exists. By breaking the period into various sub-periods, they observed that depreciation in the dollar's real trade-weighted index was associated with dollar purchases in 5 sub-periods, but the results for appreciation were not as clear-cut. Appreciation was associated with dollar purchases in 2 out of 4 sub-periods (contrary to expectations), with dollar sales only in 1 sub-period. It was not clear what the result was in the remaining sub-period (p. 18 and Table 2).

[6] Instead of the data used by Truman (2006), we are focusing on COFER data from 1999 onwards, which follow a new methodology and have been substantially revised, after an in-depth data review in 2005. The data used are those published on the IMF website at end-March 2007. That publication includes COFER data through 2006 but our study will use only the actual data available through 2005; the last four quarters of published COFER data are always provisional because they contain estimates.

portfolio to deviate from its prior optimally chosen allocation. The nature of this response speaks to the issue of whether the reaction to exchange rate changes might tend to be stabilizing in nature or trend-enhancing in exchange markets. The issue of whether or how the original optimal allocation has been derived, given risk-return, liquidity, or other characteristics is beyond the paper's scope. For a study of issues on optimal currency shares in reserve portfolios, see Papaioannou, Portes, and Siourounis (2006); for a study of the determinants of the currency composition of reserve portfolios, see Eichengreen et al (2001).

II. PORTFOLIO REBALANCING

Within the investing community, portfolio rebalancing is viewed as a common strategy for controlling risk (Tokat, 2005). The reason is as follows: To build an optimal, diversified portfolio, investors normally allocate their investments across different types of assets (stocks, bonds, cash, real estate investment trusts, etc) with varying risk and return characteristics. Optimal allocations, however, will differ across investors, who tend to have different risk tolerances and required/expected returns. Thus, for any one investor, a specific optimal allocation must be chosen containing that mix of assets consistent with the investor's required/expected return and risk tolerance. As an example, an investor with a higher risk tolerance may choose to allocate a larger share of his portfolio to stocks (the riskier asset) in order to generate a higher expected return, while an investor with a lower risk tolerance would allocate a lower share.

The problem, however, is that a portfolio's allocation is likely to drift over time away from the originally chosen, optimal allocation--because its assets are likely to experience different rates of return (a direct by-product of diversification). Assets experiencing faster rates of return will tend to increase their share relative to those experiencing slower rates, and may even begin to dominate the portfolio. At some threshold level, the portfolio's allocation changes to a point where its risk and return characteristics are no longer consistent with the investor's original goals and objectives. At that point, the need for portfolio rebalancing kicks in and the risk is controlled and reduced by returning the portfolio closer to the investor's original comfort zone—as long as no change in fundamentals has occurred to cause any reassessment. An example here could be a stock market boom that significantly increases the share of stocks (say, technology stocks) relative to that of the riskless assets (treasury bills and cash). At some point, a portfolio overly dominated by technology stocks may become too risky. The rebalancing strategy is normally formalized by guidelines on how frequently to rebalance, and the size of the deviation permitted before rebalancing needs to be implemented.

A. Critics of Portfolio Rebalancing

Portfolio rebalancing has its critics. Many find the strategy non-intuitive—how can it make sense to sell off the part of one's portfolio that is performing well in order to buy the part that

is not doing well? Famed mutual fund manager, Peter Lynch, sums up this criticism best by calling the practice, "cutting the flowers and watering the weeds." [7] However, defenders of the strategy argue that buying assets when their prices are low and selling assets whose prices have risen (buy low, sell high) is a useful contrarian strategy.

Perold and Sharpe (1988) have a more nuanced view. They point out that portfolio rebalancing is effective under certain market environments but not others. In general, the strategy performs best in volatile, mean-reverting, relatively trendless markets. Such markets do not move in one direction but instead often experience reversals. Assets that have performed well will tend to underperform later, while underperforming assets will later begin to turn around. Portfolio rebalancing excels in such markets because its trading strategy of buying low and selling high exploits the market reversals. On the other hand, the strategy will underperform the "market trend" and "buy and hold" strategies in long trending markets—bull or bear. In long trending markets, rebalancing underperforms because it continually sells assets that keep rising in price, thus losing out on price appreciation, or continually buys assets that keep falling in price, thus losing by hoarding depreciating assets.

B. What Type of Market are Exchange Markets?

What type of market environment are exchange markets? Exchange rates are notoriously volatile and may mean-revert, but at times have also appeared to have trended in one direction or another for long periods (for instance, the dollar in the eighties through the early nineties). However, on a year-to-year basis—the likely benchmark horizon for most official reserve managers—can exchange markets be characterized as volatile and relatively trendless, such that portfolio rebalancing would make a sensible strategy? We will now examine the empirical model and data.

III. EMPIRICAL MODEL

A. Disaggregating Changes in Currency Shares

Since the objective is to examine the impact of exchange rate (price) changes on purchases/sales (quantities) of currencies, it is useful first to disaggregate **changes** in currency shares into its two components: (1) those resulting purely from quantity changes (currency purchases/sales) and (2) those resulting purely from price changes (exchange rate changes). To derive these two components, we totally differentiate currency shares as defined below, using the SDR as the numeraire: [8]

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[7] Joshua Kennon, http://beginnersinvest.about.com/od/assetallocation1/a/aa102404_2.htm

[8] Individual domestic currencies cannot be numeraire because the COFER data are aggregate data from 120 countries (as of March 2007); to the extent that COFER data are dominated by the dollar, euro, pound, and yen, an international aggregate currency unit like the SDR seems an appropriate numeraire for this study.

Define $d = D*ds/ (D*ds + E*es + P*ps + Y*ys + F*fs) = D*ds/(T)$[9] Eqn 1

where: d = share of the dollar in total reserves
D = quantity of dollars in total reserves
ds = dollar's exchange rate versus the SDR= SDR/dollar
E = quantity of euros in total reserves
es = euro's exchange rate versus the SDR=SDR/euro
P = quantity of pounds in total reserves
ps = pound's exchange rate versus the SDR=SDR/pound
Y = quantity of yen in total reserves
ys = yen's exchange rate versus the SDR=SDR/yen
F = quantity of Swiss francs in total reserves
fs = Swiss franc's exchange rate versus the SDR=SDR/Swiss franc
T = (D*ds+E*es+P*ps+Y*ys+F*fs)=total reserves in SDRs

In terms of notation, note that capital letters are used to denote quantities of currencies and small letters denote exchange rates or currency shares.

Now, totally differentiating Eqn 1, we have:

$$\Delta d = (1/T)*\{(1-d)*ds*\Delta D - d*[es*\Delta E + ps*\Delta P + ys*\Delta Y + fs*\Delta F]\}$$
$$+ (1/T)*\{(1-d)*\Delta ds*D - d*[E*\Delta es + P*\Delta ps + Y*\Delta ys + F*\Delta fs]\}$$ [10] Eqn 2

where: Δd=change in the dollar's share in total reserves;
ΔD=change in the quantity of dollars in total reserves;
ΔE=change in the quantity of euros in total reserves;
ΔP=change in the quantity of pounds in total reserves;
ΔY=change in the quantity of yen in total reserves;
ΔF=change in the quantity of Swiss francs in total reserves;
Δds=change in the dollar's SDR exchange rate;
Δes=change in the euro's SDR exchange;
Δps=change in the pound's SDR exchange rate;
Δys=change in the yen's SDR exchange rate;

[9] COFER data has a category called "Other Currencies" which makes up a very small portion of total reserves. Since individual components of these "other currencies" are not identified in the data, there are no exchange rates for "other currencies." The data used in this paper thus exclude data for "other currencies."

[10] Note that the equations for the other currencies have the same structure. For example,

$$\Delta e=(1/T)*\{(1-e)*es*\Delta E - e*[ds*\Delta D + ps*\Delta P + ys*\Delta Y + fs*\Delta F]\}$$
$$+ (1/T)*\{(1-e)*\Delta es*E - e*[D*\Delta ds + P*\Delta ps + Y*\Delta ys + F*\Delta fs]\}$$

where Δe = change in the euro's share in total reserves, and e=the euro's share in total reserves.

Δfs=change in the Swiss franc's SDR exchange rate.

Observe that Δd (the change in the dollar's share) is made up of two components: (1) the top row of Eqn 2, which shows the change resulting purely from changes in the quantities of each currency (quantity changes); and (2) the lower row, which shows the change resulting purely from changes in each exchange rate (price changes). This can be shown as follows:

Assume that **price changes** are zero, i.e., let $\Delta ds=\Delta es=\Delta ps=\Delta ys=\Delta fs=0$. Eqn 2 then reduces to:

Δdqty (change in the dollar's real share, where dqty=dollar's real share) [11]

$$= (1/T)*\{(1-d)*ds*\Delta D - d*[es*\Delta E + ps*\Delta P + ys*\Delta Y + fs*\Delta F]\} \quad \text{Eqn 3}$$

Eqn 3 is the top row of Eqn 2. We call it Δdqty, the *change in the dollar's real share,* because it shows the change in the dollar's share resulting purely from changes in the *quantities* of each currency in the portfolio (ΔD, ΔE, ΔP, ΔY, ΔF). It shows that the dollar's real share will increase if dollars are purchased ($\Delta D>0$) or if the other currencies are sold ($\Delta E < 0$, $\Delta P < 0$, $\Delta Y< 0$, $\Delta F< 0$); and fall if dollars are sold ($\Delta D< 0$) or if the other currencies are purchased ($\Delta E> 0$, $\Delta P > 0$, $\Delta Y> 0$, $\Delta F> 0$).

Now, assume that **quantity changes** are zero, i.e., let $\Delta D=\Delta E=\Delta P=\Delta Y=\Delta F=0$. Eqn 2 then reduces to:

Δdval (change in the dollar's valuation share, where dval=dollar's valuation share)

$$= (1/T)*\{(1-d)*\Delta ds*D - d*[E*\Delta es + P*\Delta ps + Y*\Delta ys + F*\Delta fs]\} \quad \text{Eqn 4}$$

Eqn 4 is the bottom row of Eqn 2. We call it Δdval, the *change in the dollar's valuation share,* because it shows the change in the dollar's share resulting purely from changes in the *valuation or exchange rate* of each currency ($\Delta ds, \Delta es, \Delta ps, \Delta ys, \Delta fs$). It shows that the dollar's valuation share will increase if its exchange rate appreciates ($\Delta ds>0$) or if the other exchange rates depreciate ($\Delta es< 0$; $\Delta ps< 0$; $\Delta ys< 0$; $\Delta fs< 0$); and fall if its exchange rate depreciates ($\Delta ds< 0$) or if the other exchange rates appreciate ($\Delta es>0$; $\Delta ps>0$; $\Delta ys>0$; $\Delta fs>0$).

To summarize, Eqn 2 can be written as: $\Delta d=\Delta dqty + \Delta dval$. A change in the dollar's share derives from two sources: (1) a change in its real share and (2) a change in its valuation share.

[11] The dollar's real share is calculated with currency stocks valued at the same base quarter exchange rates, in the same way that goods can be measured in real terms using their base year prices.

B. What Happens When Exchange Rates Change and Rebalancing Is Implemented?

Suppose the dollar appreciates (Δds>0) and rebalancing is implemented. How might rebalancing show up in the data? From Eqns 2–4, dollar appreciation first increases its valuation share (Eqn 4; Δdval>0) which then increases the dollar's share (Δd>0) (Eqn 2). Under rebalancing, this positive increase must be reversed so as to return the dollar's share back to or close to the original allocation. To achieve that, the dollar's real share must fall (Δdqty< 0) so as to offset the increase in its valuation share (Eqn 2). Thus, dollars are sold and the other currencies bought and its real share falls (Δdqty< 0; Eqn 3) (note that the real shares of the other currencies rise since they are bought). In the limit, if rebalancing is required to restore the original allocation fully each period, the dollar's real share must fall until Δd is reset to zero. [12] In any event—full or partial restoration—under portfolio rebalancing, the data must show a fall in the dollar's real share and increases in the real shares of the other bought currencies when the dollar appreciates.

The chain of events is the same with depreciation, just in reverse. Dollar depreciation (Δds< 0) causes its valuation share to decline (Δdval< 0) which makes Δd negative (the dollar's share falls). Under rebalancing, the decline in the dollar's share must be reversed by increasing the dollar's real share. Dollars are bought and the other currencies sold. Thus, under portfolio rebalancing, the data must show a rise in the dollar's real share and declines in the real shares of the other sold currencies when the dollar depreciates. The empirical model to test this hypothesis is stated below.

C. The Empirical Model

$$\Delta dqty = c1 + c2*\Delta ds + c3*\Delta es + c4*\Delta ps + c5*\Delta ys + c6*\Delta fs + e1 \quad \text{Eqn 5}$$

$$\Delta eqty = c7 + c8*\Delta ds + c9*\Delta es + c10*\Delta ps + c11*\Delta ys + c12*\Delta fs + e2$$

$$\Delta pqty = c13 + c14*\Delta ds + c15*\Delta es + c16*\Delta ps + c16*\Delta ys + c17*\Delta fs + e3$$

$$\Delta yqty = c18 + c19*\Delta ds + c20*\Delta es + c21*\Delta ps + c22*\Delta ys + c23*\Delta fs + e4$$

$$\Delta sqty = c24 + c25*\Delta ds + c26*\Delta es + c27*\Delta ps + c28*\Delta ys + c29*\Delta fs + e5$$

where: Δdqty = change in the dollar's real share
Δeqty=change in the euro's real share
Δpqty=change in the pound's real share
Δyqty=change in the yen's real share

[12] As noted, however, the concept of rebalancing does not require full restoration of the original allocation. There are cost benefit issues in how close or how quickly to get back to the original allocation. For an initial discussion of the cost-benefit issues, see Tokat, 2005.

Δsqty=change in the Swiss franc's real share;
and e1, e2, e3, e4, e5 are the error terms.

Since portfolio rebalancing requires real shares to be negatively related to own exchange rate appreciation, we expect c2< 0, c9< 0, c16< 0, c22< 0, c29< 0. Since it also requires real shares to be positively related to other currencies' appreciation, we expect all the other exchange rate coefficients to be positive. The data used for estimation are described below.

D. The Data

Table 1 shows COFER data for 1999Q1–2005Q4; these data were published at end-March 2007 on the IMF website in dollar terms. [13] Panel 1 shows the data in millions of SDRS and currency shares in percent, while Panel 2 shows data excluding "Other Currencies" and their currency shares in percent. (Panel 2 uses data from Panel 1 but excludes "Other Currencies.") The two panels show that the two dominant currencies are the dollar and the euro, with the yen and the pound, a distant third and fourth, respectively. Panel 3 shows *real* COFER data (where exchange rates are maintained at their 1999Q1 levels while quantities are allowed to change) plus their *real shares*; and Panel 4 shows end-period SDR exchange rates. In the estimation, changes in the real shares from Panel 3 are regressed against the SDR exchange rate changes.

The econometric tests use quarterly data, but it may be useful to inspect the data to spot trends and see if portfolio rebalancing is suggested by the data. On trends, Panel 2 suggests that the currency shares change very gradually from quarter to quarter. For instance, the dollar's share hovers around 72–73 percent in 1999Q1–2002Q1 before falling to 70 percent in 2002Q2 and 68 percent in 2005Q4. This relative stability of the dollar's share bodes well for portfolio rebalancing which by definition tends to create stability in currency shares.

To further emphasize the point, it is useful to compare portfolio rebalancing with the other two dynamic allocation strategies—trend following and buy and hold—both of which would likely generate less stable currency shares. Suppose we start with the same optimal allocation in all three strategies. During the investment horizon, trend following would purchase the currency whose share is already rising via appreciation, and vice versa, thus tending to generate less stable currency shares. "Buy and hold" fixes a portfolio's allocation in real terms (the same mix valued at the original exchange rates). Again, buy and hold and rebalancing have the same mix at the beginning. As exchange rates fluctuate over the investment horizon, currency shares change. Portfolio rebalancing seeks to restore the original currency shares, but buy and hold does not react to the exchange rate changes, allowing the currency shares to fluctuate. Thus, buy and hold would also tend to generate less

[13] In June 2007 and September 2007, updated COFER datasets through 2007Q2 will be published; these new data incorporate revisions since the March 2007 release.

stable currency shares.

Returning to the data, portfolio rebalancing appears to be indicated if the period is divided into two sub-periods, but not over the whole period. Taking first the sub-periods, in 1999Q1–2002Q1, the dollar appreciates by 9 percent (Panel 4) but the appreciation is offset by a fall in its real share from 72 percent to 69 percent (Panel 3)—which rebalances its share to 72.5 percent in 2002Q1, very close to the initial value of 72.3 percent in 1999Q1. Rebalancing is clearly suggested in this sub-period. In the second sub-period, 2002Q2–2005Q4, the dollar depreciates by 7 percent but the depreciation is partially offset by a rise in its real share from 69 percent to 70 percent. Hence, rebalancing is also suggested but the offset is small, and the dollar's share falls from 70 percent to 68 percent in this sub-period.

Over the whole period, however, these indications of portfolio rebalancing disappear. In 1999Q1–2005Q4, the dollar depreciates by 5 percent but the depreciation is not offset by a rise in the dollar's real share; instead, the depreciation is accompanied by a fall in the dollar's real share from 72 percent to 70 percent. Thus the hypothesis of portfolio rebalancing appears to break down over the longer term. An alternative interpretation, however, could be that portfolio rebalancing was probably the underlying dynamic allocation strategy (as observed in the data at shorter intervals) but over the longer term, another factor might have come into play—changes in the desired optimal allocation. Changes in the desired optimal allocation could potentially cloud the effects of rebalancing in the data over long periods.

IV. Econometric Results

In the econometric work, changes (in percentage points) in the real share of each currency are regressed against the percentage changes in the SDR exchange rate of the five currencies. [14] In doing the estimations, several features of the empirical model must first be taken into account. For convenience, the empirical model is reproduced below.

$$\Delta dqty = c1 + c2*\Delta ds + c3*\Delta es + c4*\Delta ps + c5*\Delta ys + c6*\Delta fs + e1$$
$$\Delta eqty = c7 + c8*\Delta ds + c9*\Delta es + c10*\Delta ps + c11*\Delta ys + c12*\Delta fs + e2$$
$$\Delta pqty = c13 + c14*\Delta ds + c15*\Delta es + c16*\Delta ps + c16*\Delta ys + c17*\Delta fs + e3$$
$$\Delta yqty = c18 + c19*\Delta ds + c20*\Delta es + c21*\Delta ps + c22*\Delta ys + c23*\Delta fs + e4$$
$$\Delta sqty = c24 + c25*\Delta ds + c26*\Delta es + c27*\Delta ps + c28*\Delta ys + c29*\Delta fs + e5$$

First, the model requires that the sum of *changes* in the real shares of each currency (the endogenous variables) must be zero. That is: $\Delta dqty + \Delta eqty + \Delta pqty + \Delta yqty + \Delta sqty = 0$. This can be seen as follows: The real shares of each currency must add up to one since they all have the same denominator (see Table 1). That means: dqty+eqty+pqty+yqty+fqty =1. Taking the change in that equation gives $\Delta dqty + \Delta eqty + \Delta pqty + \Delta yqty + \Delta sqty = 0$.

[14] Since the exchange rate changes are changes in percent and the change in real shares are changes in percentage points, the units of the estimated coefficients are also percentage points.

Econometrically, this constraint implies that there will be contemporaneous correlations among the error terms--since a shock that changes the real share of one currency must also affect the real share of at least one other currency, given the constraint. To take the constraint into account, the regression technique chosen was Seemingly Unrelated Regressions (SUR).

Second, a corollary of the above is that the sum of the coefficients of each exchange rate change (across equations) must also be zero. Taking the dollar's exchange rate as an example, that means that c2+c8+c14+c19+c25=0. If a depreciation of the dollar causes the real share of the dollar to increase (c2>0) the sum of its impact on the real shares of all the other currencies must be equal in magnitude but negative in order to satisfy the constraint (i.e., c2= -c8-c14-c19-c25). All these mean is that a purchase of one currency must be offset by equal sales of one or more other currencies, and vice versa. This constraint was imposed by making the exchange rate coefficients in the Swiss franc equation the residuals (negative sum of the other exchange rate coefficients).

A dummy variable was added to account for the addition of several new reporters to the COFER reporting sample in 2003Q4. In addition, several autoregressive (AR) terms were added to certain equations to get rid of autocorrelation in the error terms. [15]

[15] The addition of the dummy variable and autoregressive terms to certain equations implies that the exogenous variables are not the same in all equations. If they had all been the same, the error terms across each equation would sum to zero (because the endogenous variables sum to zero) and have created problems for estimation because of singular matrices. In that case, one equation must be dropped. Estimation dropping the Swiss franc equation was also tried but the main results did not change.

Table 1. COFER Data and Real Shares, 1999-2005

ALL COUNTRIES	1999Q1	1999Q2	1999Q3	1999Q4	2000Q1	2000Q2	2000Q3	2000Q4	2001Q1	2001Q2	2001Q3	2001Q4	2002Q1	2002Q2	2002Q3	2002Q4
PANEL 1					**In millions of SDRs**											
At Current Exchange Rates																
Total Foreign Exchange Reserves	1,183,214	1,232,736	1,234,476	1,297,950	1,342,631	1,385,622	1,444,295	1,486,313	1,532,688	1,552,973	1,573,439	1,631,028	1,669,882	1,681,729	1,744,825	1,771,521
Allocated Reserves	913,288	953,864	954,089	1,004,451	1,039,332	1,077,768	1,128,840	1,163,799	1,194,274	1,210,752	1,225,284	1,246,844	1,262,327	1,268,753	1,314,991	1,319,431
Claims in US dollars	649,343	687,243	674,082	712,973	742,257	775,635	815,615	827,410	863,147	879,740	874,361	891,182	903,498	876,240	894,494	884,577
Claims in Pound Sterling	25,050	26,630	26,684	29,018	30,384	29,754	30,819	32,078	33,194	32,118	32,264	33,737	33,788	34,677	36,785	37,169
Claims in Yen	55,068	53,654	59,615	64,072	65,901	64,659	72,564	70,670	65,924	64,952	66,286	63,012	55,436	60,013	60,096	57,479
Claims in Swiss Francs	2,630	2,315	2,301	2,311	2,665	2,187	2,527	3,137	3,277	3,185	3,219	3,479	4,300	4,226	4,534	5,380
Claims in Euros	165,657	167,572	174,897	179,926	182,032	188,853	191,663	213,065	211,714	213,768	231,906	239,486	248,645	273,765	297,137	314,307
Claims in Other Currencies	15,540	16,451	16,510	16,152	16,094	16,680	15,653	17,438	17,019	16,989	17,248	15,949	16,660	19,831	21,944	20,519
Unallocated Reserves	269,926	278,872	280,387	293,498	303,298	307,854	315,455	322,514	338,414	342,220	348,155	384,184	407,556	412,976	429,834	452,090
Shares (In Percent)																
Claims in US dollars	71.1	72.0	70.7	71.0	71.4	72.0	72.3	71.1	72.3	72.7	71.4	71.5	71.6	69.1	68.0	67.0
Claims in Pound Sterling	2.7	2.8	2.8	2.9	2.9	2.8	2.7	2.8	2.8	2.7	2.6	2.7	2.7	2.7	2.8	2.8
Claims in Yen	6.0	5.6	6.2	6.4	6.3	6.0	6.4	6.1	5.5	5.4	5.4	5.1	4.4	4.7	4.6	4.4
Claims in Swiss Francs	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Claims in Euros	18.1	17.6	18.3	17.9	17.5	17.5	17.0	18.3	17.7	17.7	18.9	19.2	19.7	21.6	22.6	23.8
Claims in Other Currencies	1.7	1.7	1.7	1.6	1.5	1.5	1.4	1.5	1.4	1.4	1.4	1.3	1.3	1.6	1.7	1.6
Allocated	77.2	77.4	77.3	77.4	77.4	77.8	78.2	78.3	77.9	78.0	77.9	76.4	75.6	75.4	75.4	74.5
Unallocated	22.8	22.6	22.7	22.6	22.6	22.2	21.8	21.7	22.1	22.0	22.1	23.6	24.4	24.6	24.6	25.5
PANEL 2																
At Current Exchange Rates Excl. Other Currencies																
Allocated Reserves (Excl. Oth. Curr.)	897,748	937,413	937,579	988,300	1,023,238	1,061,088	1,113,187	1,146,360	1,177,256	1,193,763	1,208,036	1,230,895	1,245,667	1,248,922	1,293,047	1,298,913
Shares (In Percent)																
Claims in US dollars	72.3	73.3	71.9	72.1	72.5	73.1	73.3	72.2	73.3	73.7	72.4	72.4	72.5	70.2	69.2	68.1
Claims in Pound Sterling	2.8	2.8	2.8	2.9	3.0	2.8	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.9
Claims in Yen	6.1	5.7	6.4	6.5	6.4	6.1	6.5	6.2	5.6	5.4	5.5	5.1	4.5	4.8	4.6	4.4
Claims in Swiss Francs	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Claims in Euros	18.5	17.9	18.7	18.2	17.8	17.8	17.2	18.6	18.0	17.9	19.2	19.5	20.0	21.9	23.0	24.2
PANEL 3 (Real Values; In terms of 1999Q1 Exch. Rates)																
Allocated Reserves	897,748	929,869	952,060	1,001,875	1,030,178	1,062,297	1,101,368	1,131,224	1,142,156	1,154,204	1,188,266	1,197,155	1,206,754	1,245,514	1,287,108	1,307,562
Claims in US dollars	649,343	676,123	688,901	720,676	736,260	763,891	779,605	793,938	801,365	807,053	830,039	824,821	829,686	858,571	871,339	885,672
Claims in Pound Sterling	25,050	26,808	26,691	29,243	30,448	31,228	32,291	33,241	34,839	33,817	33,572	34,693	35,133	35,625	36,928	37,208
Claims in Yen	55,068	53,092	54,068	54,974	57,469	55,746	62,131	64,714	63,340	61,392	62,351	63,842	56,319	58,339	59,100	57,311
Claims in Swiss Francs	2,630	2,378	2,368	2,513	2,967	2,356	2,819	3,312	3,543	3,527	3,312	3,631	4,468	4,107	4,405	5,023
Claims in Euros	165,657	171,469	180,032	194,470	203,034	209,077	224,523	236,019	239,069	248,416	258,992	270,169	281,148	288,871	315,336	322,348
Real Shares (In Percent)																
Claims in US dollars	72.3	72.7	72.4	71.9	71.5	71.9	70.8	70.2	70.2	69.9	69.9	68.9	68.8	68.9	67.7	67.7
Claims in Pound Sterling	2.8	2.9	2.8	2.9	3.0	2.9	2.9	2.9	3.1	2.9	2.8	2.9	2.9	2.9	2.9	2.8
Claims in Yen	6.1	5.7	5.7	5.5	5.6	5.2	5.6	5.7	5.5	5.3	5.2	5.3	4.7	4.7	4.6	4.4
Claims in Swiss Francs	0.3	0.3	0.2	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.4
Claims in Euros	18.5	18.4	18.9	19.4	19.7	19.7	20.4	20.9	20.9	21.5	21.8	22.6	23.3	23.2	24.5	24.7
PANEL 4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Exchange Rates																
SDR/$	0.74	0.75	0.72	0.73	0.74	0.75	0.77	0.77	0.79	0.80	0.78	0.80	0.80	0.75	0.76	0.74
SDR/Pound	1.19	1.18	1.19	1.18	1.18	1.13	1.13	1.15	1.13	1.13	1.14	1.15	1.14	1.16	1.18	1.19
SDR/Yen	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SDR/SFr	0.50	0.48	0.48	0.46	0.44	0.46	0.44	0.47	0.46	0.45	0.48	0.47	0.48	0.51	0.51	0.53
SDR/Euro	0.79	0.77	0.77	0.73	0.71	0.71	0.68	0.71	0.70	0.68	0.71	0.70	0.70	0.75	0.75	0.77
Percentage Change																
SDR/$		1.64	-3.73	1.11	1.90	0.72	3.03	-0.39	3.35	1.20	-3.36	2.57	0.79	-6.28	0.59	-2.71
SDR/Pound		-0.66	0.64	-0.74	0.56	-4.52	0.17	1.11	-1.27	-0.32	1.19	1.19	-1.10	1.21	2.33	0.28
SDR/Yen		1.06	9.10	5.71	-1.61	1.15	0.69	-6.50	-4.69	1.65	0.48	-7.16	-0.27	4.51	-1.15	-1.37
SDR/SFr		-2.63	-0.20	-5.35	-2.32	3.35	-3.47	5.67	-2.33	-2.39	7.65	-1.44	0.45	6.92	0.04	4.05
SDR/Euro		-2.27	-0.59	-4.76	-3.10	0.75	-5.49	5.75	-1.90	-2.83	4.05	-1.00	-0.23	7.16	-0.57	3.48

Table 1. COFER Data and Real Shares, 1999-2005 (Contd)

ALL COUNTRIES	2003Q1	2003Q2	2003Q3	2003Q4	2004Q1	2004Q2	2004Q3	2004Q4	2005Q1	2005Q2	2005Q3	2005Q4
PANEL 1					**In millions of SDRs**							
At Current Exchange Rates												
Total Foreign Exchange Reserves	1,821,186	1,905,484	1,981,002	2,035,833	2,226,346	2,279,062	2,341,641	2,413,616	2,553,304	2,710,608	2,797,832	2,920,686
Allocated Reserves	1,341,957	1,400,077	1,439,713	1,494,356	1,637,055	1,652,697	1,682,085	1,700,967	1,773,236	1,862,475	1,893,685	1,974,685
Claims in US dollars	898,764	934,442	966,548	984,765	1,104,996	1,120,843	1,131,908	1,119,331	1,158,790	1,230,456	1,255,709	1,318,021
Claims in Pound Sterling	33,974	35,486	34,935	41,458	44,229	45,120	51,679	57,565	63,332	64,995	68,184	71,525
Claims in Yen	52,391	50,387	55,258	58,955	65,549	63,804	60,497	65,540	69,407	70,368	72,072	71,202
Claims in Swiss Francs	3,230	2,913	3,265	3,375	3,690	3,895	2,844	2,845	3,031	2,494	2,749	2,899
Claims in Euros	331,351	351,782	354,123	376,320	386,629	387,977	402,876	423,731	446,759	462,907	462,123	478,057
Claims in Other Currencies	22,248	25,066	25,583	29,483	31,962	31,059	32,280	31,955	31,918	31,255	32,848	32,980
Unallocated Reserves	479,228	505,407	541,289	541,477	589,291	626,365	659,556	712,648	780,068	848,133	904,147	946,001
Shares (In Percent)												
Claims in US dollars	67.0	66.7	67.1	65.9	67.5	67.8	67.3	65.8	65.3	66.1	66.3	66.7
Claims in Pound Sterling	2.5	2.5	2.4	2.8	2.7	2.7	3.1	3.4	3.6	3.5	3.6	3.6
Claims in Yen	3.9	3.6	3.8	3.9	4.0	3.9	3.6	3.9	3.9	3.8	3.8	3.6
Claims in Swiss Francs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Claims in Euros	24.7	25.1	24.6	25.2	23.6	23.5	24.0	24.9	25.2	24.9	24.4	24.2
Claims in Other Currencies	1.7	1.8	1.8	2.0	2.0	1.9	1.9	1.9	1.8	1.7	1.7	1.7
Allocated	73.7	73.5	72.7	73.4	73.5	72.5	71.8	70.5	69.4	68.7	67.7	67.6
Unallocated	26.3	26.5	27.3	26.6	26.5	27.5	28.2	29.5	30.6	31.3	32.3	32.4
PANEL 2												
At Current Exchange Rates Excl. Other Currencies												
Allocated Reserves (Excl. Oth. Curr.)	1,319,710	1,375,011	1,414,129	1,464,873	1,605,093	1,621,638	1,649,805	1,669,012	1,741,318	1,831,220	1,860,837	1,941,705
Shares (In Percent)												
Claims in US dollars	68.1	68.0	68.3	67.2	68.8	69.1	68.6	67.1	66.5	67.2	67.5	67.9
Claims in Pound Sterling	2.6	2.6	2.5	2.8	2.8	2.8	3.1	3.4	3.6	3.5	3.7	3.7
Claims in Yen	4.0	3.7	3.9	4.0	4.1	3.9	3.7	3.9	4.0	3.8	3.9	3.7
Claims in Swiss Francs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Claims in Euros	25.1	25.6	25.0	25.7	24.1	23.9	24.4	25.4	25.7	25.3	24.8	24.6
PANEL 3 (Real Values; In terms of 1999Q1 Exch. Rates)												
Allocated Reserves	1,330,793	1,395,464	1,453,732	1,529,389	1,683,003	1,689,450	1,714,900	1,784,655	1,833,133	1,895,275	1,921,741	1,992,153
Claims in US dollars	909,321	964,048	1,017,764	1,077,691	1,204,823	1,210,306	1,224,564	1,280,218	1,289,353	1,319,960	1,340,438	1,387,357
Claims in Pound Sterling	35,065	35,754	35,421	40,967	42,365	43,337	50,088	54,935	60,320	62,648	66,406	70,461
Claims in Yen	52,896	51,746	53,740	57,391	61,914	62,019	60,340	64,824	68,856	69,217	72,302	73,435
Claims in Swiss Francs	2,975	2,744	3,042	3,072	3,452	3,546	2,606	2,476	2,710	2,311	2,546	2,697
Claims in Euros	330,536	341,171	343,766	350,268	370,449	370,242	377,303	382,202	411,895	441,139	440,049	458,204
Real Shares (In Percent)												
Claims in US dollars	68.3	69.1	70.0	70.5	71.6	71.6	71.4	71.7	70.3	69.6	69.8	69.6
Claims in Pound Sterling	2.6	2.6	2.4	2.7	2.5	2.6	2.9	3.1	3.3	3.3	3.5	3.5
Claims in Yen	4.0	3.7	3.7	3.8	3.7	3.7	3.5	3.6	3.8	3.7	3.8	3.7
Claims in Swiss Francs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Claims in Euros	24.8	24.4	23.6	22.9	22.0	21.9	22.0	21.4	22.5	23.3	22.9	23.0
PANEL 4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Exchange Rates												
SDR/$	0.73	0.71	0.70	0.67	0.68	0.68	0.68	0.64	0.66	0.69	0.69	0.70
SDR/Pound	1.15	1.18	1.17	1.20	1.24	1.24	1.22	1.24	1.25	1.23	1.22	1.20
SDR/Yen	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SDR/SFr	0.54	0.53	0.53	0.54	0.53	0.54	0.54	0.57	0.55	0.53	0.53	0.53
SDR/Euro	0.79	0.82	0.81	0.85	0.83	0.83	0.84	0.88	0.86	0.83	0.83	0.83
Percentage Change												
SDR/$	-1.04	-1.93	-2.02	-3.78	0.37	0.97	-0.19	-5.41	2.79	3.72	0.49	1.41
SDR/Pound	-3.01	2.44	-0.63	2.61	3.16	-0.27	-0.90	1.56	0.19	-1.19	-1.03	-1.14
SDR/Yen	-1.24	-1.69	5.60	-0.10	3.06	-2.83	-2.54	0.84	-0.30	0.86	-1.95	-2.73
SDR/SFr	1.38	-2.25	1.15	2.33	-2.70	2.75	-0.64	5.28	-2.68	-3.52	0.08	-0.45
SDR/Euro	2.81	2.86	-0.09	4.30	-2.86	0.40	1.90	3.83	-2.17	-3.25	0.08	-0.65

Source: COFER Database; International Financial Statistics

A. Regression Results

Table 2 shows the regression results. Six exchange rate coefficients are significant at the five percent level (probability value<0.05)—these six represent the impact of the dollar on the real shares of the dollar and the euro; the impact of the pound on the real shares of the yen and the Swiss franc; and the impact of the Swiss franc on the real shares of the yen and the Swiss franc. All of the significant coefficients have the right signs save one. For instance, an appreciation of the dollar leads to sales of the dollar (decline of 0.27 percentage points in the dollar's real share) [16] and purchases of other currencies, here, the euro (increase of .24 points in the euro's real share) as predicted by portfolio rebalancing. In addition, an appreciation of the pound leads to purchases of other currencies, here, the yen (increase of 0.05 points) and the Swiss franc (increase of 0.02 points; the impact on the pound's own real share has the right sign (-0.02 points) but is not statistically significant). The one anomaly contradicting portfolio rebalancing occurs with the impact of the Swiss franc exchange rate; while franc appreciation leads to purchases of the yen (increase of 0.03 points) in line with portfolio rebalancing, it also results in purchases of the franc (increase of 0.01 point) contrary to portfolio rebalancing.

All the other exchange rate coefficients are insignificant, although many have the right signs. The dummy variable is highly significant while the AR terms are mostly significant.

Impact of Changes in the Dollar Exchange Rate

To assess the results, we use the criterion that the sum of the coefficients for each exchange rate (across equations) must equal zero. From that perspective, the strongest and most interesting finding in favor of portfolio rebalancing is the impact of the dollar exchange rate on the dollar and the euro's real shares. These coefficients are significant at the 1 percent level, quite close to each other in terms of magnitude but with opposite signs (- 0.27 and 0.24 points, implying almost an equal swap), and their size dwarfs those of all the other coefficients. These attributes suggest that reserve managers respond to changes in the dollar's exchange rate by rebalancing almost exclusively via the dollar and the euro (sales of 0.27 points of the total portfolio of dollars and purchases of 0.24 points of euros). This result is in line with the dominance of the dollar and the euro in reserve portfolios. The econometric

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[16] A decline of 0.27 percentage points in the real share of the dollar implies a sale of 0.0027*T SDRs of dollars, where T is the total portfolio in SDRs. This can be seen from Equation 3:

Δ dqty = (1/T)*[(1-d)*ds* Δ D – d*(es* Δ E +ps* Δ P+ ys* Δ Y+ fs* Δ F)]; by construction, being a weighted average with weights that sum to 1, Δ dqty represents a sale/purchase of dollars and an equivalent purchase/sale of the other currencies. For instance, Δ dqty= - 0.0027 implies a sale of 0.0027*T of dollars and a purchase of 0.0027*T in total of all the other currencies. That is:

- 0.0027*T = (1-d)*ds* Δ D – d*(es* Δ E+ ps* Δ P+ ys* Δ Y+ fs* Δ F) where the right hand side is a weighted average of a change in dollars in SDRs (ds* Δ D) and the sum of changes in the other currencies in SDRs. How much of each of the other currencies is purchased depends on the change in their real shares in response to the dollar appreciation. See Appendix I for an example with a 3-currency system.

results suggest that the yen may also be part of the mix (purchases of 0.04 points of yen—which helps to close the gap between the 0.27 points of dollar sales and 0.24 points of euro purchases) but the coefficient is not statistically significant (probability value of 0.179).

Impact of Changes in the Other Exchange Rates

Using the same criterion, the significant coefficients for the pound and Swiss franc exchange rates appear less interesting. While pound appreciation leads to purchases of the yen and franc, there is no offsetting sale of the pound or any other currency that is statistically significant; all the other coefficients are insignificant. Similarly, franc appreciation leads to purchases of the yen and franc but there are no offsetting sales that are statistically significant; all the other coefficients are insignificant. The coefficients are also much smaller, in line with the currencies' lesser importance in reserve portfolios. However, one interesting aspect of these results may be that changes in the exchange rates of the minor currencies appear to result in rebalancing via these minor currencies. Thus rebalancing decisions appear demarcated in that valuation changes in the major currencies result primarily in switches between the major currencies, while changes in the minor currencies result in switches among the minor currencies.

The most disappointing result is the statistical insignificance of the euro exchange rate coefficient in all the equations. These coefficients mostly also have the wrong signs. A possible explanation could be the high correlation between the euro, dollar, and Swiss franc exchange rates, such that multicollinearity problems might have distorted the results for the euro's exchange rate. [17] The impact of the yen's exchange rate is also insignificant.

Other Issues

As expected, the constants in the euro (0.30 percentage points) and yen (-0.17 points) equations are significantly positive and negative, respectively—suggesting that reserve portfolios have trended in favor of the euro at the yen's expense. The euro's general uptrend and yen's general downtrend are also readily apparent from inspection of the data. The constant in the dollar equation is large and negative (-0.09) but surprisingly statistically insignificant (probability value of 0.216)—even though data inspection also suggests some downtrend in preference for the dollar. The constants in the pound and franc equations are very small, negative, and insignificant. Overall, the results suggest that independent of exchange rate effects, optimal portfolios during the period have trended in favor of the euro at the expense of the yen and probably also the dollar.

[17] The correlation between the changes in the euro's rate and the dollar's rate was -0.79; between the euro's rate and the franc's rate, 0.86; and between the dollar's rate and the franc's rate, -0.73.

Table 2. Regression Results: 1999Q1-2005Q4 1/

Dependent Variable is Change in Real Share of Each Currency

	Endogenous Variables				
	Change in Real Share of:				
Explanatory Variable	**U.S. Dollar**	**Euro**	**Japanese Yen**	**Pound Sterling**	**Swiss Franc**
Constant	-0.094	0.300	-0.170	-0.021	-0.007
standard error	0.069	0.061	0.022	0.021	0.005
probability value	0.179	0.000	0.000	0.336	
Percent Change in:					
SDR/dollar	-0.269	0.243	0.037	-0.019	0.008
standard error	0.088	0.079	0.028	0.026	0.124
probability value	0.003	0.003	0.179	0.465	0.423
SDR/euro	-0.075	0.079	0.008	-0.001	-0.011
standard error	0.070	0.063	0.023	0.020	0.099
probability value	0.287	0.215	0.730	0.949	0.130
SDR/yen	-0.045	0.051	0.010	-0.014	-0.002
standard error	0.039	0.035	0.012	0.011	0.055
probability value	0.251	0.155	0.440	0.208	0.810
SDR/pound	-0.066	0.012	0.054	-0.018	0.018
standard error	0.047	0.042	0.015	0.014	0.066
probability value	0.159	0.758	0.001	0.198	0.003
SDR/swiss franc	-0.038	0.017	0.025	-0.014	0.010
standard error	0.039	0.036	0.012	0.011	0.056
probability value	0.332	0.638	0.048	0.212	0.004
Dummy Variable	…	-0.358	0.160	0.168	…
standard error	…	0.093	0.039	0.035	…
probability value	…	0.000	0.000	0.000	…
AR (1)	0.195	0.214	…	…	…
standard error	0.110	0.115	…	…	…
probability value	0.082	0.068	…	…	…
AR (2)	…	…	…	…	-0.282
standard error	…	…	…	…	0.200
probability value	…	…	…	…	0.163
AR (6)	-0.418	-0.533	-0.433	…	…
standard error	0.121	0.125	0.089	…	…
probability value	0.001	0.000	0.000	…	…
R-Squared	0.615	0.714	0.656	0.373	0.516
Total Observations	27	27	27	27	27

Source: IMF COFER Database; International Financial Statistics

1/ Coefficients for the exchange rates are constrained to sum to zero in each equation.

Note: AR terms are auto-regressive terms introduced to eliminate auto-correlation in the individual equations.

V. CONCLUSIONS

The econometric results suggest that portfolio rebalancing is likely the dominant dynamic allocation strategy in the management of reserve portfolios. Once the optimal mix of currencies has been determined, the investment strategy in response to exchange rate changes appears to be rebalancing portfolios closer towards their original allocation. Such a strategy requires reserve managers to purchase depreciating currencies and to sell appreciating currencies. This strategy has two major implications. One is that the rebalancing transactions of reserve managers would tend to be "stabilizing" in exchange markets—in that they would tend to offset market trend movements in currency exchange rates. From that perspective, fears that reserve currency diversifications would create pressure and disrupt exchange markets would not be well-founded. Instead, these results support Truman and Wong (2006)'s notion that there could be "stabilizing diversification" from currency diversifications.

The second implication is that this strategy helps to explain the observed relative stability of currency shares over long periods. If optimal portfolios are not volatile and do not change frequently and substantially, the discipline of rebalancing towards their original optimal allocation by definition would tend to lead to relatively more stable and smoother currency shares. We have shown in Section III how rebalancing is likely superior to the market trend following and buy and hold strategies in terms of the relative stability of currency shares. Considering now even scenarios where optimal portfolios may change abruptly and significantly every few years, the consequences are that currency shares may gap up or down at the moments of change, but implementation of the rebalancing strategy would still tend to generate significant periods of relative stability in currency shares thereafter.

In this regard, abrupt and substantial shifts in currency shares have not been observed in COFER data in our study period. For instance, the largest one quarter shift is a two percentage point decline in the dollar's share in 2002Q2 (Table 1) and there is only one such shift in the dollar's share during the period. All other shifts are generally smaller. These data thus suggest that while desired optimal reserve portfolios may have changed over time, reserve managers have on average implemented the change very gradually, or that the determinants of optimal currency portfolios have not changed abruptly, significantly, or frequently during the period of this study (see also Eichengreen et al (2000)). [18] This combination of a gradual approach to revising optimal reserve portfolios and a dynamic strategy of portfolio rebalancing over time further underscores that currency diversifications

[18] Reserve managers who change their optimal allocations frequently and substantially cannot by definition be viewed as following a portfolio rebalancing strategy. Frequent and significant portfolio adjustments suggest optimal allocations that are subject to fluctuations in short-term factors and the currency transactions are being undertaken to reach new optimal allocations, not rebalancing objectives.

of reserve portfolios are unlikely to add pressure to exchange markets. [19]

On the specific aspects of rebalancing, the study finds that the rebalancing of reserve portfolios is dominated by switches between the dollar and the euro, in line with their dominance in reserve portfolios. The size of the coefficients for dollar/euro switches in response to dollar exchange rate changes is considerably larger than the size of the coefficients showing switches among the minor currencies. Another interesting result is that the rebalancing decisions appear to be demarcated in that valuation changes in the major currencies result primarily in switches between the major currencies, while changes in the minor currencies result in switches among the minor currencies. As expected, the constant term is significant and positive in the euro equation but significant and negative in the yen equation, suggesting trend shifts during the period into euros at the expense of the yen. The constant term for the dollar is large and negative suggesting also a long-term move out of dollars but happens surprisingly to be statistically insignificant.

APPENDIX I

This appendix explains the nature of the coefficients in the empirical model. To simplify, assume there are only 3 currencies—dollar, euro, and the yen. The empirical model thus consists of three equations:

Empirical Model

$$\Delta dqty = c1 + c2*\Delta ds + c3*\Delta es + c5*\Delta ys + e1 \quad \text{(dollar equation)}$$
$$\Delta eqty = c7 + c8*\Delta ds + c9*\Delta es + c11*\Delta ys + e2 \quad \text{(euro equation)}$$
$$\Delta yqty = c18 + c19*\Delta ds + c20*\Delta es + c22*\Delta ys + e4 \quad \text{(yen equation)}$$

We take as example the coefficients for the dollar. Suppose the estimated coefficients for the dollar exchange rate are c2= -0.27, c8=0.24, and c19=0.03. That means that a one percentage point appreciation in the dollar's exchange rate implies a 0.27 percentage point decline in the dollar's real share, and 0.24 and 0.03 percentage point increases in the euro's and yen's real shares, respectively. What does this mean in terms of the amounts of each currency purchased and sold? To see this we reproduce the equations for the change in real shares. The change in the dollar's real share is shown as Eqn 3 in the main text (excluding terms for the pound and franc); the changes in the euro and the yen's real shares have the same structure.

[19] However, a caveat is in order here. All investment strategies are subject to change. Just because strategies followed in the past have tended not to be disruptive does not mean that new strategies may turn out the same way. What we are saying is that the data and econometric results for our period of study reveal an underlying reserve investment strategy that if continued in the future (or if the determinants of that investment strategy do not change significantly in the future) would also likely tend not to be disruptive in nature.

Changes in real shares

$\Delta dqty = (1/T)*\{(1-d)*ds*\Delta D - d*[es*\Delta E + ys*\Delta Y]\}$ (change in dollar's real share) Eqn 6
$\Delta eqty = (1/T)*\{(1-e)*es*\Delta E - e*[ds*\Delta D + ys*\Delta Y]\}$ (change in euro's real share) Eqn 7
$\Delta yqty = (1/T)*\{(1-y)*ys*\Delta Y - y*[ds*\Delta D + es*\Delta E]\}$ (change in yen's real share) Eqn 8

where d=share of the dollar in total reserves
e=share of the euro in total reserves
y=share of the yen in total reserves
T=total reserves in SDRs
d+e+y=1 since there are only 3 currencies involved.

The estimated coefficients (from the empirical model) indicate that the dollar's real share falls and the real shares of the euro and yen rise, suggesting that dollars are sold in exchange for euros and yen. Such an exchange is governed by the constraint below.

$-ds*\Delta D = es*\Delta E + ys*\Delta Y$ Eqn 9

Now substitute the estimated coefficients, c2=Δdqty= -0.0027, c8=Δeqty=0.0024, and c19=Δyqty=0.0003 into Eqns 6-8 and bring T to the other side, we have:

$-0.0027*T = (1-d)*ds*\Delta D - d*[es*\Delta E + ys*\Delta Y]$ (change in dollar's real share)
$0.0024*T = (1-e)*es*\Delta E - e*[ds*\Delta D + ys*\Delta Y]$ (change in euro's real share)
$0.0003*T = (1-y)*ys*\Delta Y - y*[ds*\Delta D + es*\Delta E]$ (change in yen's real share)

Since the equations are all weighted averages on the right hand side, one might guess that the solution is: $ds*\Delta D = -0.0027*T$; $es*\Delta E = 0.0024*T$; and $ys*\Delta Y = 0.0003*T$

That guess would be correct and can be seen by substituting the constraint (Eqn 9) into the 3 equations. Substituting $ys*\Delta Y = -ds*\Delta D - es*\Delta E$ into the dollar and euro's real share equations, we get:

$-0.0027*T = (1-d)*ds*\Delta D - d*(es*\Delta E - ds*\Delta D - es*\Delta E)$
$= (1-d)*ds*\Delta D + d*(ds*\Delta D)$
$= ds*\Delta D$

$0.0024*T = (1-e)*es*\Delta E - e*(ds*\Delta D - ds*\Delta D - es*\Delta E)$
$= (1-e)*es*\Delta E + e*(es*\Delta E)$
$= es*\Delta E$

Substituting $ds*\Delta D = -0.0027*T$ and $es*\Delta E = 0.0024*T$ into the constraint (Eqn 9), we get:

$ys^* \Delta Y = 0.0027^*T - 0.0024^*T$
$= 0.0003^*T$

By moving T over, we get:

$-0.0027 = c1 = (ds^* \Delta D)/T$; $0.0024 = c8 = (es^* \Delta E)/T$; and $0.0003 = c19 = (ys^* \Delta Y)/T$

Therefore, the coefficients for the dollar exchange rate in the dollar, euro, and yen equations tell us the amounts of dollars, euros, and yen, respectively, in percent of the total SDR reserves, that are bought or sold, given a one percentage point change in the dollar's exchange rate. The interpretation for the other exchange rate coefficients is the same.

To get own units, we divide by the SDR exchange rates to get the amount of dollars sold in exchange for euros and yen, given a one percentage point appreciation.

$\Delta D = -0.0027^*T/ds$; $\Delta E = 0.0024^*T/es$; and $\Delta Y = 0.0003^*T/ys$

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