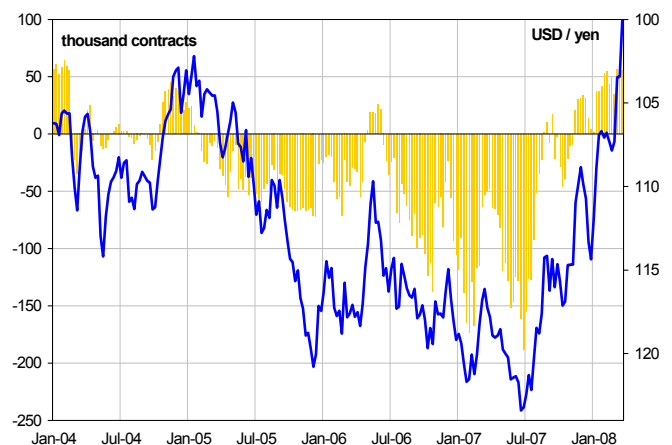


## The carry trade and recent yen movements

- The existence of a strong Japanese current account surplus against a background of relative yen weakness in recent years raises questions, and is contributing to the persistence of international balance of payments imbalances.
- Over and beyond the role played by macroeconomic policy in Japan (with very low key rates especially), a decline in Japanese households' preference for domestic securities (known as the "home bias") is one suggested explanation for the yen's weakness: they are thought to be buying greater quantities of foreign securities to rebalance their portfolios, previously overweight in Japanese assets. However, a closer look at the securities held by Japanese households does not bear out this hypothesis.
- We show here that the weakness of the yen until summer 2007 was partly due to speculative "carry trades" on the foreign exchange markets. It is hard to identify these trades—notably involving derivatives swaps—clearly. In addition, they may induce instability since they could potentially destabilise the financing of certain economies in the event of a shift in market operators' expectations.
- Indeed, periods of stronger market volatility have witnessed a rapid appreciation of the yen accompanied by a depreciation of other currencies (Iceland, Australia, United Kingdom, South Africa, etc.). From an estimation of an optimal portfolio, it is possible to determine which currencies are liable to experience sharp corrections.

This study was prepared under the authority of the Treasury and Economic Policy General Directorate and does not necessarily reflect the position of the Ministry of the Economy, Industry and Employment.

Net speculative positions on the yen (number of 12,500,000-yen contracts)



Source: Commodity Futures Trading Commission, DGTPE calculations.

Rising Asian current account surpluses and the persistent US current account deficit are a reflection of the imbalance in actual exchange rates between these two zones. An orderly resolution of these imbalances depends on an adjustment of supply and demand for goods in each of these zones, together with a depreciation of the dollar in actual terms and appreciation of the currencies of the countries with large current account surpluses<sup>1</sup>. That is because a depreciation of the dollar makes American products more competitive on world markets and therefore boosts US exports, while it curbs imports by making foreign goods dearer.

Since 2002, while certain currencies, including the euro, have already risen sharply, notably against the dollar, the major Asian currencies have scarcely begun to do so. The yen is no exception, and Japan's contribution to global macroeconomic imbalances may even have strengthened. The Japanese current account balance has been rising steadily since the beginning of the 2000s, growing to 4.8% of GDP in 2007. At the same time, the yen depreciated continuously, in effective terms, between the end of 2004 and mid-2007 (chart 1).

Until 2005, the macroeconomic policies pursued by the Japanese authorities would appear to account for a large proportion of these growing imbalances. Highly expansionary monetary policy aimed at lifting the economy out of its long period of deflation (by holding key rates at zero and through a policy of "quantitative easing"<sup>2</sup>), coupled with massive yen sales by the Bank of Japan on the foreign exchange markets until March 2004, helped keep the yen exchange rate low.

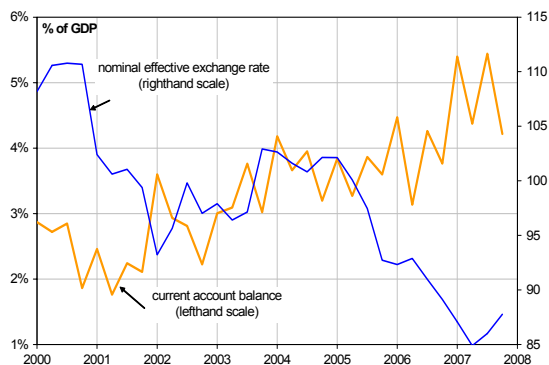
Conversely, Japan's economy picked up rapidly from 2004 onwards, and especially in 2005, and the Japanese authorities progressively wound down these exceptional measures. This policy stance ought to have been conducive to an appreciation of the yen. Yet the Japanese currency continued to slide until summer 2007. The pronounced appreciation that ensued, against a background of general reassessment of risk in the finan-

cial markets, has not been sufficient for an appreciation of the yen on average since 2005.

Do the depreciation between 2004 and 2007 and the appreciation in recent months reflect short-term market shifts? Do they reflect structural changes in the Japanese economy? The answer to these questions may help us to address the question as to whether an appreciation of the yen is still conceivable in the medium term.

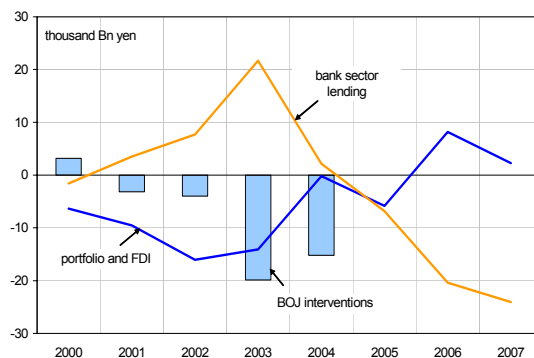
After rising moderately over the previous fifteen years or so, world prices for agricultural commodities accelerated in 2006.

Chart 1: current account and nominal effective exchange rate



Source: Datastream.

Chart 2: BOJ interventions and balance of financial flows



Source: Datastream.

## 1. Is the yen's weakness since 2004 linked to a possible decline in "home bias"?

The yen's depreciation since the early 2000s has gone hand in hand with a sharp increase in capital outflows from Japan. Initially, until the beginning of 2004, foreign exchange interventions accounted for the bulk of these flows. Subsequently, private capital took over.

It has been suggested that this second phase could reflect a growing desire on the part of Japanese investors to diversify their financial assets. By reducing demand for the yen, this diversification could thus explain why the effective

exchange rate has continued to decline since foreign exchange interventions ceased. According to this view, Japanese households' preference for securities issued by Japanese residents (i.e. their "home bias") has been dwindling progressively over the past few years after being particularly high relative to the other developed countries.

A look at the available data on the securities portfolios held by the Japanese on the one hand (FDI, equities and debt securities), and on interbank loans on the other

- (1) Carton (2005): "Interventions de change asiatiques et taux de change d'équilibre" (Asian exchange rate interventions and equilibrium exchange rates), *Diagnostics Prévisions et Analyses Economiques*, no. 72, DGTPE.
- (2) Quantitative easing consists in setting a high target for compulsory reserves for commercial banks in order to reduce the overnight money market rate to 0.

(under the "other investments" line in the balance of payments) does not support this assumption.

### 1.1 Trends in direct holdings of securities by households do not suggest any reduction in home bias

Home bias refers to national investors' preference for domestic securities over foreign securities, at a time when more open financial markets ought to induce them to look to other parts of the world offering better combinations of risks and returns<sup>3</sup>. To evaluate this bias and its change over time, we compare the proportion of domestic securities in a portfolio of financial assets held by domestic investors and the value of the stock of securities issued by the country in question, relative to the value of the stock of securities issued worldwide. The difference between these two magnitudes corresponds to what is known as home bias.

In 2002, Japan accounted for approximately 13% of the global financial economy, and the proportion of Japanese securities held by Japanese residents in their portfolio was approximately 83% (see table 1). The gap was therefore approximately 69%. The same estimation for 2006 shows no significant change in this gap: the stock of foreign securities held by the Japanese has admittedly grown, but in proportions equivalent to the change in the size of the stocks of securities issued worldwide (excluding Japan) and in Japan. Balance of payments data concerning financial flows for 2007 do not suggest any inflection in the home bias. Over this period Japanese households have bought foreign securities, but they have maintained constant their home bias in response to fluctuations in the prices of domestic and foreign securities and to movements in the foreign exchange markets (a depreciation of the yen raises the yen value of the foreign securities they hold).

Overall, this stability in the home bias suggests at first sight that the progressive depreciation of the yen since 2005 cannot be accounted for by an increase in Japanese households' preference for foreign securities.

### 1.2 The reduction in home bias appears to be heavily intermediated

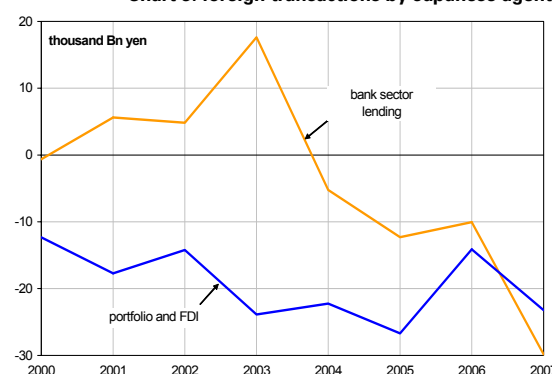
One reason why it is difficult to point to any reduction in home bias for securities held directly by Japanese economic agents could possibly be that there is a high degree of intermediation in holdings of foreign securities

in Japan. On this view, Japanese households are unwilling to take direct risks on foreign securities, preferring to buy complex financial products ultimately giving them exposure to these risks.

This thesis is partially confirmed by Japanese balance of payments data for interbank loans (under "other investments" in the balance of payments). Whereas between 2001 and 2003 Japanese banks borrowed abroad, they became lenders as from 2004, contributing in rising proportions to capital outflows (chart 3). After the end of foreign exchange interventions, capital outflows notably consisted of interbank loans (short-term loans and deposits).

Some of these transactions were no doubt carried out on behalf of private investors. For example, GAITAME, a company providing short-selling services to Japanese private investors, states that the number of accounts under management increased from fewer than 2,000 at the beginning of 2003 to nearly 120,000 in June 2007<sup>4</sup>.

Chart 3: foreign transactions by Japanese agents



Source: Datastream.

However, financial sector lending to the rest of the world as indicated in the Japanese balance of payments presumably does not concern Japanese households alone. There may be other motives for this type of transaction. In particular, Japanese banks may exploit persistent interest rate differentials unaccompanied by foreign exchange movements, either on their own behalf or on behalf of third parties. In general, these cross currency positions frequently take the form of carry positions, in other words leveraged strategies involving several currencies (*i.e.* carry trade transactions).

Table 1: change in home bias between 2002 and 2006

	2002	2006	2006/2002
Size of Japanese market in relation to world market	13%	11%	-2%
Proportion of domestic securities in Japanese portfolio	83%	80%	-3%

Source: IMF-Global Financial Stability Report (Sept. 2007), Datastream-market value, Datastream-External position of Japan. DGTPE calculations.

(3) See L. Eyraud, F. Jacquet-Saillard (2006): "Réduction du biais domestique et financement du déficit courant américain" (Reduction in home bias and funding the US current account deficit), *Diagnostics Prévisions et Analyses Économiques*, No. 115, DGTPE.

(4) G. Galati, A. Heath, P. McGuire (2007): "Evidence of carry trade activity", *BIS Quarterly Review*, September 2007.

## 2. Movements in the yen exchange rate since the end of 2004 appear to have been heavily influenced by the carry trade

A carry trade transaction consists in borrowing in a low yield currency (for example the yen), and lending in another, higher yielding currency. For this strategy to be profitable, one must be prepared to incur a certain "currency risk". After all, hedging a transaction like this would be tantamount to waiving all of the potential gains or losses from the carry trade. **In other words, engaging in a carry trade amounts to betting on the non-validity of the uncovered interest-rate parity (see box 1).**

The carry trade transaction is broken down into borrowing in yen, a spot conversion of yen into another foreign currency (here we use the pound sterling by way of illustration) and a loan in sterling; finally, at maturity, a spot conversion of sterling into the yen, allowing the operator to reimburse the yen loan with part payment of the loan in sterling, and to pocket a premium. This transaction is profitable if the yen interest rate is lower than for sterling and/or if the yen depreciates.

In reality, the carry trade boils down to a forward sale of yen: selling a yen/foreign currency hedge (i.e. selling yen forward) is equivalent to capturing the potential gains of carry trades (*via* the claimed premiums) by bearing the foreign exchange risk. These last transactions are frequently carried out *via* derivative products.

### 2.1 The expectations of agents engaging in carry trades can be self-fulfilling and lead to volatility

Several factors may have led economic agents to see this type of transaction on the yen as profitable. From 2005 onwards, the probability of an appreciation of the yen cancelling out the gains on carry trade transactions may perhaps have been thought relatively small:

- On the one hand, the progressive and clearly expected rise in US key rates made the yen less and less attractive;
- On the other, there was still a possibility that the interventions halted in March 2004 to limit any pronounced yen appreciation could be resumed.

The strong preference of Japanese households for Japanese securities may have reinforced the incentive for other operators to engage in carry trades. That is because agents who are indifferent to nationality can make a profit on carry trades since Japanese households tend to accept lower yields on Japanese securities.

These transactions push the yen downwards since they are essentially forward yen sales against other higher-yielding currencies. In that sense they can trigger a self-fulfilling mechanism akin to a bubble as soon as a sufficient number of agents engage in these transactions.

In addition to exerting downward pressure on the yen even though the fundamentals would argue rather for its appreciation, these short-term transactions may also undermine global financial stability, notably because they are accompanied by rapid exchange rate variations. In step with agents' shifting expectations of yen movements, we see a rapid swelling or contraction in transaction volumes and sudden changes in yen/target currency parities, which are damaging to the real economy and destabilising for the financial sector (due to the sudden drying up of financial flows associated with carry trades in the target countries, as illustrated by the case of Iceland in 2006 for example, in box 2). Measuring and locating these transactions is therefore crucial to any attempt to monitor global financial stability.

### 2.2 It is hard to measure the precise scale of carry trade transactions

A variety of factors tend to show that investors seeking high returns have indeed financed foreign assets against yen denominated liabilities without necessarily hedging these transactions against currency variations. Available statistics are fragmentary, however. Japanese financial institutions lent approximately \$250 billion in 2007 (in the form of bank loans) to foreign debtors, which is three times more than in 2006. Part of this sum could have been used to finance the purchase of higher yielding foreign assets (in which case the carry trade is borne by a non-Japanese investor).

As we saw earlier, carry trade transactions can be carried out with the aid of spot currency transactions, and purchases and sales of securities. In that case, they can be measured *via* balance of payments statistics. They are not directly observable by means of official statistics when they are carried out by means of derivative products, on the other hand.

According to the IMF<sup>5</sup> and the Bank of Japan, Japanese banks are also thought to have financed carry trade positions via derivative swaps (frequently with offshore institutions). For the BIS<sup>6</sup>, these products (interest-rate swaps, structured bonds, securitised products, etc.), which are mainly traded over the counter, are indeed the main

(5) Global Financial Stability Review, p17, IMF, September 2006.

(6) G. Galati, A. Heath, P. McGuire (2007), op.cit.

vehicle for these transactions, hence the difficulty of assessing their scale. For the most part, these transactions are not visible in the balance of payment flows since, by construction, they balance out (because claims equal liabilities) from the Japanese operator's point of view. It is only possible to identify them through valuation effects on the occasion of exchange rate movements. Phases of yen depreciation apparently give rise to large valuation effects on the "derivative products" item in the Japanese balance of payments, reflecting short selling of the yen: in 2006, when the yen was declining, net inflows of derivative products totalled ¥283 billion (liabilities-assets), the net position rose by only ¥31 billion, reflecting the ¥252 billion increase in assets relative to liabilities. This is consistent with the fact that the Japanese, betting on a yen

depreciation, accumulated yen liabilities in order to purchase assets in foreign currencies, realising capital gains when the yen actually fell.

While it is difficult to assess the total value of positions taken, it is possible to form some idea of the variation in this value by observing the positions taken by the speculative segment of the market on futures contracts on the main currencies<sup>7</sup>. This shows that short positions on the yen expanded from the end of 2004 onwards, culminating in summer 2007 at the same time as the yen depreciated. This tendency to short the yen was nevertheless punctuated by a series of reverse currents producing sharp appreciations of the yen.

### Box 1: the carry trade and uncovered interest-rate parity (UIP)

Borrowing in one currency to lend in another is a risky operation that exposes its practitioner to currency risk. To overcome the currency risk one needs, at the moment of initiating the transaction, to be able to buy a hedge guaranteeing a specified exchange rate at maturity (on the foreign exchange futures or forward<sup>a</sup> markets). However, this transaction, which allows one to realise an instant profit with no currency risk, is directly arbitrated by the markets (and hence unprofitable). The "covered interest-rate parity" is always verified.

If the investor does not hedge his currency risk by borrowing at interest rate  $i_t$ , and lending at interest rate  $i_t^f$ , and as a function of the hoped-for exchange rate, he obtains a return  $R$ :

$$R = i_t^f - i_t + e_t - E_t[e_{t+1}]$$

Economic theory forecasts that the return obtained on this transaction is nil in the medium term (*i.e.* that the UIP is verified), if agents are neutral to risk and in the absence of transaction costs<sup>b</sup>. However, there are several reasons why economic agents may consider that the UIP is not verified and that there is a premium for "carrying" yen in other currencies.

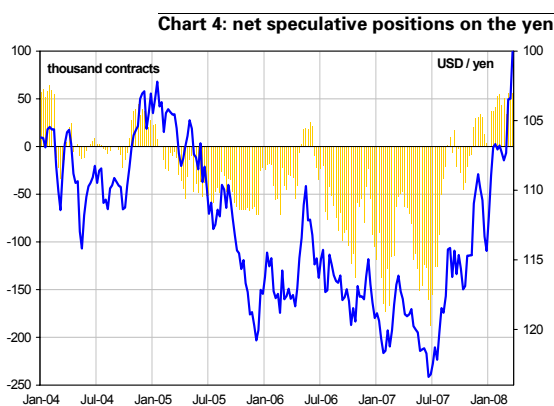
- These may be "informational" reasons: the agent may consider he has an expectation of one of the financial variables underlying his transaction that will enable him to realise a gain (this could concern a currency or an interest-rate movement). In the case of Japan for example, and from 2005 onwards, the probability of a yen appreciation cancelling out gains on carry trade transactions may have seemed relatively low. There may also be symmetrical effects, with potential buyers demanding a premium knowing that agents have privileged information regarding the assets they are selling.
- They may depend on differences of taste (utility functions) among agents. If the agent is not very risk averse, agents that are more so will be willing to pay him a premium to shoulder a risk in their place. Similarly, if certain agents have a pronounced taste for Japanese securities (on account of the home bias for example), these latter will be inclined to accept lower returns on Japanese securities, remunerating agents who are indifferent to the nationality of the assets used in carry trades.
- Mimeticism between agents may contribute to the formation of bubbles on the foreign exchange markets. It may also sometimes be rational to invest in carry trades during the bubble's formation phase<sup>c</sup>.

a. Futures are contracts traded on regulated markets such as the Chicago Mercantile Exchange, whereas forward contracts are traded over the counter (OTC).

b. See: S. Hisler (2007): "Do interest rates help predict exchange rates?", *Trésor Economics No. 15*, DGTPE.

c. B. Diba, H. Grossman (1988): "The Theory of Rational Bubbles in Stock Prices", *The Economic Journal*, Sept. 1988.

(7) This analysis is made possible by the publication, for the sake of transparency, of traders' liabilities by the Commodity Futures Trading Commission (CFTC), which regulates the CME, one of the leading markets (with the International Money Market) for futures contracts, particularly for financial products. This is highly partial, nevertheless, most carry trade transactions presumably being conducted outside of the organised markets.



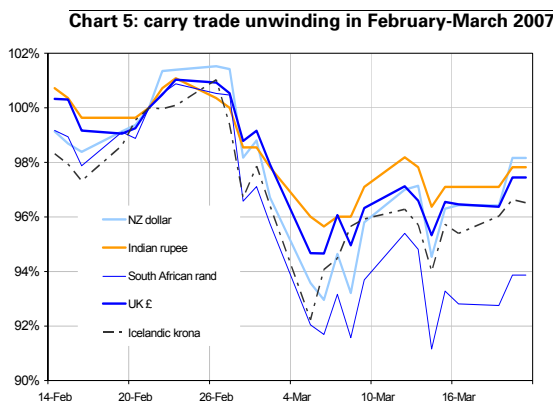
Source: Commodity Futures Trading Commission.

### 2.3 The target currencies of carry trades are not directly observable either

Identifying the currencies targeted by carry trades is also difficult, notably because many financial flows travel through offshore centres (a net \$45 billion denominated in yen transited between Japan and the offshore centres in the Caribbean between 2002 and 2007). The increase in the share of yen liabilities observed in a number of countries, including the United Kingdom, tends to show that part of these flows in transit correspond to carry trade transactions. Two approaches are used to identify target currencies: the first, known as *ex-post*, is confined to noting the impact on the foreign exchange market of the presumed unwinding of carry trades (notably in periods of sudden appreciation of the yen); the second, *ex-ante* approach, seeks to identify the most profitable carry trades and helps detect the currencies potentially most affected.

For the past three years, based on yen-dollar exchange rate variations, we have identified five periods of carry trade unwinding (chart 4), including for example March 2007, when the **Icelandic krona** and the **South African rand** both fell sharply, along with the New Zealand dollar, sterling and the Australian dollar (chart 5). Based on

these observations, we can identify the main target currencies of the carry trades, namely Australia, New Zealand, Indonesia, South Korea, India, the Philippines, Brazil, South Africa, Turkey and Iceland<sup>8</sup> (box 2).



Interpretation: bilateral parity with the yen, index base 100% at 21 February 2007.

### 2.4 Identifying *ex-ante* the most profitable and the least risky currencies

It would be preferable, nevertheless, from the point of view of financial stability, to have access to indicators allowing us to identify the target currencies before they are affected by sudden movements.

These indicators are heavily inspired by the tools market participants use to detect carry trade opportunities. In addition to unquantifiable factors, the key factors determining the target currencies of carry trades are:

- **The hoped-for gain**, *i.e.* the difference in the return on a yen investment and on an investment in another currency, including the requisite currency conversion transaction at initiation of the position and at the moment of its unwinding;
- **The risk incurred**, which can be represented by the volatility of the hoped-for gain in the foregoing transaction.

#### Box 2: the case of Iceland

The case of Iceland illustrates rather well the consequences for a local currency of the financial system's vulnerability in the face of the risk of a rapid unwinding of carry trades. The IMF identified the vulnerability of the Icelandic financial system in 2005. At that time the country had a very large current account deficit, equivalent to -16% of GDP at the end of 2005 (compared with +1.4% in 2002), reflecting rapid growth in household and company debt. Because the Icelandic economy is primarily financed by banks, their net external position had deteriorated considerably (98% of GDP in 2003, 122% in 2004). Fears over the sustainability of Iceland's imbalances had been expressed by Fitch<sup>a</sup> in February 2006, when it issued a negative outlook on Icelandic debt, triggering a sudden withdrawal of capital. Between 9 February and 24 April 2006, the Icelandic krona lost 21% against the yen, sentiment regarding the sustainability of Iceland's imbalances having deteriorated throughout the month of March.

a. A financial rating agency.

(8) See also IMF, Regional Economic Outlook: Asia and Pacific - April 2007.

An increase in perceptions of currency risk ought therefore to reduce the propensity to engage in a carry trade transaction, whereas an increase in the expected return ought, on the contrary, to increase the propensity to engage in one.

To synthesise these two factors, the BIS observes<sup>9</sup> for example the carry-to-risk ratio defined as the relationship between the interest rate differential between two currencies and the exchange rate volatility. Using this method,

### 3. Carry trades as a simple portfolio asset

To determine *ex-ante* the target of carry trades, we study the optimal portfolio of the risk-averse agent. This agent will favour the highest risk-free returns: he is therefore inclined to invest in currencies with a high carry-to-risk ratio, but not only.

#### 3.1 The currencies in an optimal portfolio as defined by Markovitz

The higher the return on the currency, the greater the reason to think it will be the target of carry trades, unless the exchange rate with this currency is very volatile. However, when there are more than two risky assets, a **low-return, high-risk asset can have its place in the portfolio**, provided it allows the investor to diversify the portfolio's risks.

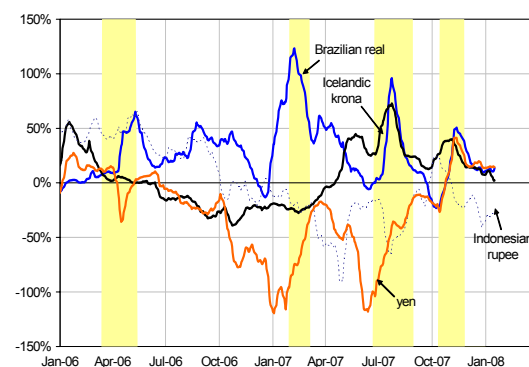
Markovitz<sup>10</sup> formalised these effects in his optimal portfolio theory. In a Markovitz portfolio, a currency with a low carry-to-risk ratio can nevertheless be the target of carry trades if the currency risk is highly uncorrelated—or even negatively correlated—with the risks associated with the holding of other available assets. The composition of the Markovitz portfolio allows for these parameters. The composition of the optimal portfolio gives a qualitative idea of the most "rational" target for carry trades.

We apply this theory to the Japanese currency. Before each unwinding phase (in yellow in chart 6), we find a sharply negative share of yen in the "optimal" portfolio. This means that, within the framework of the Markovitz portfolio model, it is "rational" to sell the yen (or to engage in carry trade transactions).

We find, moreover, that before each unwinding phase the Brazilian real, the Indian rupee and the Turkish pound are highly attractive. They could have been priority targets of carry trades. Before May 2006, the South African rand and the Indonesian rupee could have been affected; before March 2007, sterling would have been a shrewd target of carry trades.

the BIS estimates that yen outflows in 2007 were invested mainly in Brazil and Turkey, rather than in the United Kingdom, Australia or New Zealand, as previously. However, this method overlooks the possibility of correlation between risks, which can modify investment opportunities. In reality, carry trades can be seen as a financial service like any other and, in that sense, can be viewed as a possible choice in investors' portfolios.

Chart 6: composition of an optimal portfolio for an American investor



Interpretation: Each line represents the share of the currency in an optimal currency portfolio over time. For the sake of legibility, only a small sample is represented here (the portfolio studied contains 12 currencies whose value is stated in dollars, considered to be the benchmark currency). The negative shares represent forward sales of a currency. The yen is relatively unattractive prior to actual unwinding periods.

#### 3.2 The financial turbulence appears to have discouraged carry trades on the yen

Finally, we find that the yen, which was formerly conducive to carry trades, appears to be less and less well suited to them (its share in the optimal portfolio becomes positive, chart 6).

It would now appear to be rational, rather, to expect a rise in the yen when determining portfolio choices. Moreover, we note a return of interest in a broad array of currencies, notably the Turkish pound. This change has occurred mainly at the expense of the benchmark asset (here the dollar), which was sold against all currencies. This finding is consistent with the fall in the dollar observed since summer 2007, which has gained momentum since the beginning of 2008.

Nicolas GRISLAIN  
Françoise JACQUET-SAILLARD

(9) BIS Quarterly Review, March 2007.

(10) Winner of the 1952 Nobel Prize for Economics for his work on optimal portfolio theory.

### Box 3: how to calculate a Markovitz optimal portfolio

The Markovitz optimal portfolio is defined as one that maximises the hoped-for return while minimising the volatility of its value. The relative weight of each of the criteria depends on the manager's risk aversion. The investor thus introduces into his portfolio a certain quantity of safe assets and risky assets among the  $n$  existing assets. The portfolio at the moment  $t$  is thus represented by the vector  $\pi_t$  giving the proportion of total wealth invested in each asset.

This proportion may be negative, since the investor can sell the asset forward.

$R_t$  is the (risk-free) rate of remuneration on a sight deposit and  $P_t$  the vector giving the price of each risky asset. This vector follows a stochastic process verifying:  $dP_t = \text{diag}(P_t) \cdot [\mu_t + \sigma_t dz_t]$ ;  $z_t$  is a standard multivariate Brownian motion of dimension  $n$  and  $\sigma_t \sigma_t'$  is the variance-covariance matrix of returns on risky assets at moment  $t$ .

It is shown that wealth follows the process:

$$dW_t = W_t \cdot [r_t + \pi_t' (\mu_t - r_t \mathbf{1})] \cdot dt + W_t \cdot \pi_t' \sigma_t dz_t$$

And that, according to Markowitz's assumptions, the optimal portfolio is given by the formula:

$$\pi_t^* = \frac{1}{\alpha} \cdot (\sigma_t \sigma_t')^{-1} \cdot (\mu_t - r_t \mathbf{1})$$

Where  $\alpha$  is a coefficient that depends on the agent's risk aversion; the greater the risk aversion, the smaller the portion of wealth invested in risky assets.

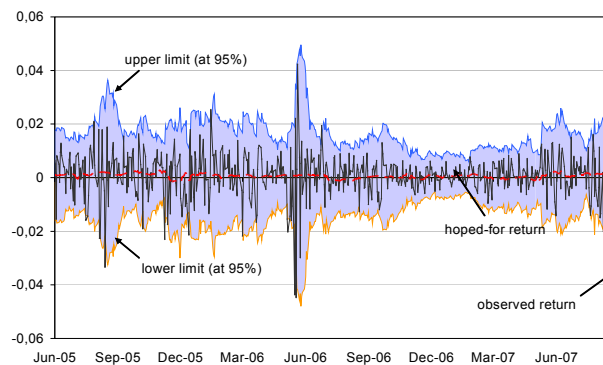
The optimal portfolio in the Markovitz sense thus depends on the hoped-for return on assets relative to a risk-free asset; on the variance in their change (i.e. the risk associated with each asset); on the covariance of assets among themselves (i.e. on the capacity of an asset to cover the risk associated with another asset).

To estimate these parameters, we assume that at each moment in time there exist: observable variables (i.e. the history of returns on each currency); and unobserved latent variables (i.e. the hoped-for return and instantaneous variances and covariances in returns). Consequently, the distribution of observable variables is a function of latent variables. We further assume that latent variables change slowly (like low volatility random markets), which allows us to identify the model. Latent variables are estimated over time in two ways:

- The Extended Kalman Filter (EKF) method, where a linear approximation is made of the link between latent variables and the distribution of observed variables, and where we estimate the trajectory of latent variables maximising likelihood.
- A more modern Bayesian method: the particle filter method (the sequential equivalent of the Markov Chain Monte-Carlo methods<sup>a</sup>), which produces a sample having the latent variables distribution, from which we extract their means.

We thus obtain an estimation of latent variables (chart 7).

Chart 7: estimation of hoped-for return and exchange rate volatility: Brazilian real /US dollar



a. M. K. Pitt; N. Shephard, "Filtering via Simulation: Auxiliary Particle Filters", *Journal of the American Statistical Association*, Vol. 94, No. 446. (June 1999), pp. 590-599.

#### Publisher:

Ministère de l'Économie,  
de l'Industrie et de l'Emploi  
Direction Générale du Trésor  
et de la Politique économique  
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#### Layout:

Maryse Dos Santos  
ISSN 1777-8050

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