SWEDISH ECONOMIC POLICY REVIEW 6 (1999) 87-116

Portfolio choice and currency risk inside and outside the EMU

Giorgio De Santis, Bruno Gerard, Pierre Hillion*

Summary

■ We investigate the impact of EMU and non-EMU currency risk on asset returns and international portfolio choices. We estimate a conditional version of the *International Capital Asset-Pricing Model* and find that the premium for bearing currency risk is significant, time-varying, and often represents a significant fraction of the total premium. While EMU and non-EMU currency premiums are statistically significant over the entire sample period, we find that the premium for non-EMU risk has significantly increased in the 1990s and now accounts for most of the aggregate currency premium. We also implement out-of-sample dynamic asset-allocation strategies that take advantage of the predictability and time-varying nature of equity and currency risk premiums and of risk exposures. We find that strategies that include equities and currencies significantly outperform strategies that exclude currencies, and that most of the benefits accrue from managing non-EMU currency exposures. We conclude that the adoption of the euro is unlikely to drastically alter the portfolio trade-offs for international investors. ■

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On January 1, 1999, financial markets witnessed one of the most significant currency regime changes since the breakdown of the Bretton-Woods system in the early 1970s. On that date, a single common currency, the euro, replaced 11 existing currencies to start the final stage of the implementation of the EMU, which the Maastricht Treaty initiated in 1991. How will this currency changeover affect the risk-return trade-offs and optimal portfolio strategies in international markets? The issue greatly concerns international investors and is the topic of this paper.

Given the well-documented low level of correlation among national equity markets, modern portfolio theory suggests that investors should hold internationally diversified portfolios to improve the reward-to-risk ratio of their asset holdings. It is often argued that investors are reluctant to diversify across borders because international investments are exposed to currency risk in addition to market risk. The presence of this additional source of risk raises two related issues:

1. It is important to determine whether currency risk is a priced factor in international financial markets.
2. If currency risk is priced, it becomes important to measure both the exposure to non-diversifiable currency risk and the compensation that investors can expect from bearing such risk.

The answers to these questions have direct implications for hedging strategies, since any source of risk not compensated in terms of expected returns should be diversified or hedged. Conversely, if currency risk is priced, currency investments become an important asset class to include and manage for every international investor. This

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suggests that adoption of the single currency could have a significant impact on the risk and return of international portfolio strategies.

In this paper, we use the parametric approach developed in De Santis and Gerard (1997, 1998) to evaluate the possible impact of the adoption of the euro on the risk and return trade-offs for international investors, and we investigate the performance of alternative dynamic currency hedging strategies. In De Santis, Gerard, and Hillion (1998), we estimate and test the conditional version of the international CAPM and assess whether exchange risk premiums significantly affect international asset returns from the perspective of German investors. We find that both EMU and non-EMU components of the currency risk command a statistically and economically significant premium over the 1974-1990 sample period. After 1990, however, the non-EMU component increases significantly and accounts for most of the aggregate currency premium. We conclude that the adoption of the single currency and the subsequent elimination of the intra-EMU currency risk are likely to have a limited impact on the risk-return trade-off available to international investors.

This paper extends the analysis of the impact of the EMU and non-EMU currency risk in a realistic portfolio-management setting. We investigate simultaneously the equity markets and one-month, euro-currency deposits of six countries: France, Japan, the Netherlands, US, UK, and Germany, which we treat as the reference country. We explicitly parameterise the conditional measures of market and currency risk as well as their prices, and allow them to vary over time. We use our empirical model to recover the time series of the conditional expected returns and of the conditional expected covariances among assets to generate one-month-ahead forecasts of currency risk premiums, market risk premiums, and risk exposures. We use these estimates to implement optimal dynamic asset-allocation strategies that exploit the predictability of risk premiums and risk exposures. We evaluate several easily implementable strategies out-of-sample.

We find that although overlay currency-management strategies can yield significant benefits, the largest gains accrue to strategies that jointly optimise equity and currency positions. Most benefits of currency risk management accrue from managing the non-EMU currency risk. Little or no additional benefits arise from managing the EMU currency risk. This provides further evidence that the adoption of the single currency is unlikely to drastically affect the portfolio trade-offs for international investors.

The paper is organised as follows: Section 2 describes the model, and Section 3 presents the portfolio strategies. Section 4 describes the data, while Section 5 discusses the empirical evidence. Section 6 concludes.

1. Currency risk and asset returns

We analyse the conditional version of an intertemporal asset-pricing model that incorporates currency and market risk. This section briefly reviews the model that was originally derived by Solnik (1974), Sercu (1980), and Adler and Dumas (1983).

The model is derived under the assumption that relative purchasing power parity (PPP) does not hold[1]. This implies that investors from different countries have a different appreciation for the real return on any given asset. Deviations from PPP have two important implications:

1. Optimal portfolios differ across countries.
2. In equilibrium, the expected return on any asset is equal to the return on the risk-free asset, denominated in the reference currency, plus a premium for exposure to market risk and a premium for exposure to currency risk.

Market risk is captured by the covariance of the asset return with the return on the worldwide portfolio of all traded assets. Exchange risk for a particular currency is measured by the covariance of the asset return with the relative change in the corresponding exchange rate.

To illustrate the source and the exact definition of currency risk, consider the following example:

Assume there exists only two countries, the US and Germany. Suppose that investors hold well-diversified portfolios, such as country funds, in both countries. Consider a German investor taking a position in the US fund. Let the German mark (DEM) be the measurement currency and, accordingly, the DEM denominated bill be the risk-free asset. Then, in equilibrium, the international asset-pricing model requires that the expected return in the US fund satisfies the following restriction:

[1] Although the debate on whether PPP holds in terms of expectations is still open, the empirical evidence against PPP is quite strong in the short term.

$$E(R_{US}^{DM}) - R_f^{DM} = \gamma \operatorname{cov}(R_{US}^{DM}, R_M^{DM}) + \delta \operatorname{cov}(R_{US}^{DM}, v_\$^{DM}) \tag{1}$$

where:
1. R_{US}^{DM} : DEM return on the US fund,
2. R_f^{DM} : DEM denominated risk free rate,
3. R_M^{DM}: DEM return on the world market portfolio,
4. $v_\$^{DM}$: change in the DEM-USD exchange rate.

The model predicts that the expected DEM return on the US fund, in excess of the return on the DEM-denominated bill is proportional to:
1. The covariance of the DEM return on the US fund with the DEM return on the world portfolio—its market risk, and
2. The covariance of the DEM return of US fund with the change in the exchange rate between the DEM and the US dollar (USD)—its currency risk.

Consider first the definition of currency risk. If returns are continuously compounded, the DEM return on the US fund is equal to the USD return on the US fund, plus the relative change in the DEM/USD exchange rate. This implies that the covariance between the DEM return on the US fund and the relative change in the DEM/USD exchange rate is equal to the sum of the covariance between the USD return on the US fund and the change in the DEM/USD exchange rate, and the variance of the change in the DEM/USD exchange rate.

$$\operatorname{cov}(R_{US}^{DM}, v_\$^{DM}) = \operatorname{cov}(R_{US}^{\$}, v_\$^{DM}) + \operatorname{var}(v_\$^{DM}) \tag{2}$$

Two implications follow. First, exchange-rate volatility, as measured by the variance of the change in the DEM/USD exchange rate, is not an appropriate measure of currency risk. This would be the case only if the covariance between the USD return on the US fund and the change in the DEM/USD exchange rate was zero. Second, currency risk is positive, nil, or negative, depending on the sign and magnitude of the covariance between the USD return on the US fund and the change in the DEM/USD exchange rate.

Suppose that this covariance was negative. When the DEM gains value relative to the USD, the USD return on the US fund is positive. The German investor, who holds the US fund, loses from the devaluation of the USD, but profits from the capital gain on the fund. In this sense, the US fund is a partial hedge against exchange-rate risk. The appropriate measure of currency risk exposure for the US fund is lower than the variance of the DEM/USD exchange-rate change. A special case arises when the covariance is negative and equal in magnitude to the variance. Then, currency risk vanishes. In the extreme case when the covariance is negative and larger in absolute value than the variance, the currency risk that is associated with the US fund becomes negative, because the fund is more than a hedge against fluctuations of the DEM/USD exchange rate.

Suppose conversely that the covariance was positive. When the DEM depreciates relative to the USD, the USD return on the US fund is positive. In this case, currency risk is larger than the variance of the exchange-rate changes. Columns 4, 5, and 6 in Table 1 present a decomposition of the total volatility of the DEM returns of the different assets examined in this study into the domestic volatility component, the exchange-rate volatility component and the covariance component. The currency risk associated with each asset is a function of the last two elements—the exchange-rate volatility and the covariance component. The decomposition in Table 1 shows that especially for equity indices, the covariance component is a large fraction of exchange risk.

Consider now the source of the premium for currency risk. American and German investors hold the US fund. US investors, who care about USD returns, are not affected by exchange risk when holding the US fund. But they are affected by the impact of the change in exchange rates on the USD return of the US fund, which is measured by the covariance between the USD return of the US fund and changes in the DEM/USD exchange rate.

In contrast, currency risk and the impact of exchange-rate changes on the USD return of the US fund affect German investors, who care about DEM-denominated returns. Hence a currency premium arises because German investors hold a fraction of the US fund and because the impact of changes in the DEM/USD exchange rate on the USD return of the US fund affect both US and German holders of the fund.

Table 1. Summary statistics and volatility decomposition of asset excess returns.

Panel a. Summary statistics

	Mean	Std. dev.	Skew.	$\frac{var(r_i^l)}{var(r_i^{DM})}$	$\frac{var(v_l^{DM})}{var(r_i^{DM})}$	$\frac{2cov(r_i^l, v_l^{DM})}{var(r_i^{DM})}$	Weights[a]
US	.370	5.59	-.77**	62.2	36.5	1.2	.35
Japan	.311	6.40	-.13	69.0	22.0	9.1	.31
France	.363	6.42	-.30*	92.5	4.1	3.0	.03
Germany	.407	5.12	-.82**	10.0	0.0	0.0	.04
Nl.	.752	4.81	-.53**	99.5	1.1	-0.5	.02
UK	.518	7.14	.02	79.4	13.9	6.7	.11
EurF	.141	1.25	-.68**	9.9	104.5	-14.5	
EurN	.030	0.54	-.22	15.5	72.9	11.6	
Eur£	.385	6.08	.12	1.3	98.2	0.4	
Eur$	.001	3.41	.18	0.8	97.5	1.7	
Eur¥	.076	3.02	.31*	0.8	98.2	1.0	
World	.332	4.61	-.84**				1.00

Panel b. Unconditional correlations of r_{it}

	Jpn.	Fr.	Ger.	Nl.	UK	EurF	EurN	Eur£	Eur$	Eur¥	Wrld.
US	.321	.473	.374	.667	.564	.178	.064	.568	.609	.240	.884
Jpn.	1	.337	.255	.372	.346	.113	.066	.141	.214	.566	.664
Fr.		1	.508	.549	.529	.287	.040	.087	.126	.146	.591
Ger.			1	.606	.391	-.046	-.067	.083	.099	.019	.480
Nl.				1	.661	.077	.055	.231	.282	.148	.747
UK					1	.257	.168	.082	.250	.202	.696
EurF						1	.348	.183	.275	.282	.188
EurN							1	.026	.120	.081	.094
Eur£								1	.420	.358	.416
Eur$									1	.442	.506
Eur¥										1	.386

Notes: * and ** denote statistical significance and the 5% and 1% levels. [a]As of 31 December 1990. Monthly German mark returns on the equity indices of six countries and the value-weighted world index are from MSCI. The euro-currency one-month deposit rates for the French franc (FRF), Dutch guilder (NLG), German mark (DEM), Japanese yen (JPY), British pound (GBP), and US dollar (USD) are from DRI Inc. and the B.I.S. Excess returns are obtained by subtracting the one-month euro-DEM rate. All returns are continuously compounded and expressed in percentage per month. The sample covers the January 1974 - April 1997 period (280 observations).

This	Is the ...
r_i^{DM}	German mark return on asset i
r_i^l	Local currency return on asset i
v_l^{DM}	Relative change in exchange rate between the German mark and the local currency

In a multi-currency world, the expected return on any asset is affected by a premium for exposure to each source of currency risk.

For example, if Japan was added to the US and Germany in the previous example, the appropriate measure of currency risk for the US fund would include:

1. The covariance between the DEM return on the US fund and the relative change in the DEM/USD exchange rate, and
2. The covariance between the DEM return on the US fund and the relative change in the DEM/JPY exchange rate.

This explains why the asset-pricing model incorporates, in addition to the market risk premium, one currency risk premium for each exchange rate.

Over time, as new information becomes available, investors may update their attitude toward risk and their beliefs regarding expected returns and risk. Hence we would expect the parameters of the model to change over time. So we test a conditional version of the model. This amounts to specifying how the moments of the asset-return distribution change over time. The asset-pricing model postulates a relation between expected returns and covariances. So one can freely parameterise only the first or the second moments. We follow the approach of De Santis and Gerard (1997, 1998) who use a parsimonious multivariate, *generalised autoregressive conditional heteroskedasticity* (GARCH) model for the dynamics of the second moments. Finally, we let the price of market risk and currency risk change over time, as a function of the information available to the investors. We restrict the former to be always positive[2] but leave the latter unrestricted.

Summarising, we use a multivariate, GARCH approach to estimate and test an asset-pricing model that includes a market risk premium and multiple currency risk premiums. For each risk source, we let the risk exposure and the risk price change over time. De Santis and Gerard (1997, 1998) discuss the empirical methods in detail.

[2] In the model, the price of market risk is equal to the world's aggregate risk aversion coefficient, which is always positive. See Merton (1980).

2. Portfolio strategies and performance comparisons

2.1. Optimal portfolio weights for national investors

To compare different asset allocation strategies, optimal portfolio weights must be determined. Suppose that the investment-opportunity set, available to investors, consists of m stock market indices, and n short-term, euro-currency deposits. For each national investor, the euro-currency deposit denominated in the domestic currency is perceived as a risk-free asset. Each investor faces a total of N = m + n - 1 risky assets and one risk-less asset.

Similar to the standard solution of a portfolio problem in a single market context, mean-variance optimisation implies that all investors hold a combination of two portfolios: the domestic risk-less asset and the universal (logarithmic) portfolio of risky assets[3]. It is important to stress that, in contrast to the single market solution, the universal portfolio of risky assets includes deposits in each currency, in addition to equity positions. The allocation between the optimal portfolio of risky assets and the risk-free asset varies across national investors as a function of each country's representative investors risk aversion.

In a multiple market context, when investors have access to foreign equity and euro-currency markets, mean-variance optimisation yields additional implications. The first deals with the optimal investments in equity and euro-currency deposits. Portfolio weights for both asset classes should be simultaneously determined to exploit the properties of both sets of risky assets and, in particular, their correlation structure. The second deals with the fraction of wealth invested in euro-currency deposits. One can show that the optimal euro-currency investment can be decomposed into a purely speculative position and an optimal hedge position. The latter is the euro-currency investment that minimises the variance of the overall portfolio given the equity positions. In this sense, investors hold euro-currency deposits for speculative and hedging purposes.

[3] For a lucid and more detailed discussion of international portfolio choice and asset pricing, as well as the references to the original contributions to the field, see Jorion and Khoury, 1996, Ch. 7, pp. 273-322.

2.2. Dynamic asset-allocation strategies

We compare a buy and hold strategy for the world index to dynamic strategies that exploit the predictability of the exposure and the premium for each source of currency and market risk. We investigate four dynamic strategies: the overall optimal dynamic strategy previously described and three other strategies that satisfy the commonly encountered restrictions imposed on investment managers.

1. *Optimal equity-only strategy* (EO). In this strategy, we take the viewpoint of a manager who is constrained to not take direct positions in the currency assets. The portfolio holdings are optimised over the eligible equity indices only. This strategy is clearly suboptimal, because the currency exposure is managed only through the selection of the equity holdings. Further, the manager cannot directly take advantage of the non-zero expected excess returns in currencies. Currency risk affects the holdings indirectly only through its effect on the equity indices expected returns.
2. *Overlay currency hedge strategy* (EO + CH). This strategy corresponds to the case where the role of the equity portfolio manager is distinct from the role of the currency manager. The former chooses her optimal portfolio weights in the same fashion as in the first strategy. Conditional on this choice, the latter optimally hedges the exposure of the fund to currency risk. This implicitly assumes that currency risk commands a zero risk premium and hence no speculative position in currency assets is allowed.
3. *Overlay currency hedge and speculative strategy* (EO + CH&S). This strategy is identical to the second strategy in terms of equity positions, but the mandate of the currency overlay manager allows for optimal hedging and speculation in euro-currency deposits. The manager can take advantage of the existence and predictability of currency risk premium. The overall allocation remains suboptimal because the manager of the equity portion of the fund is prevented from accounting for the correlations between equity and currency assets when selecting the equity positions.
4. *Unrestricted optimal allocation* (OPT(E + C)) strategy corresponds to the unrestricted global optimum portfolio strategy. Portfolio weights of equity and currency assets are selected jointly and take into account the covariances between all assets. In particular, the equity positions reflect their covariance with the currency assets.

2.3. Performance evaluation

The optimal portfolio strategies can be implemented as long as estimates of expected returns and risk are available. The model we estimate to test the conditional CAPM is fully parametric and can be used to generate forecasts of the conditional first and second moments of returns.

The conditional moment estimates are obtained as follows: at the start of each month t, we estimate the model using the data from month 1 to t-1. We then use the estimated model to forecast expected returns and covariances for the next month, to compute the portfolio weights, and generate the optimal asset allocation for the four strategies previously described. When new data become available at month's end, we measure the realised performance and turnover for each portfolio. We re-estimate the model using the new data, use the new estimates to forecast means and covariances, and then generate a new set of optimal portfolio weights for the following month. Since the process starts in January 1989, and the sample extends until April 1997, the procedure requires 99 estimations of the full model.

We first estimate a set of unconstrained optimal portfolios. This assumes that there are no position limits and that transaction costs are negligible. This is unrealistic but provides a starting point for comparison purposes. We also compute the optimal portfolio weights under the constraint that short positions in equities are disallowed, while short positions in euro-currency deposits are unrestricted.

The performance of the different strategies is evaluated on the basis of their average excess returns, standard deviations of excess returns, and Sharpe ratio. All portfolio returns are reported in percent per month in excess of the one-month euro-DEM rate. We compare the performance of the dynamic strategies to the performance of a strategy of buying and holding the world-equity index. In the absence of currency and inflation risk, this is an appropriate proxy of the market portfolio of risky securities held by all investors.

To test the statistical significance of the portfolio performance of the dynamic strategies, we use a procedure similar to the one proposed by Solnik (1993). Because the optimal portfolio weights are determined at the start of each month, it is possible to compare the realised return of each strategy to the return that an uninformed investor expects from the same strategy. We assume that the uninformed investor knows the unconditional mean of the asset return based on the data available at the time the portfolio decision is made. The assumption of joint normality is necessary to conduct t-tests. Accordingly, we assume that the uninformed investor uses the same multivariate, GARCH process to model the time-varying second moments of excess returns. The difference between the realised return on the optimal strategy and the expected return on the uninformed investor's strategy measures the effectiveness of the model in predicting mean returns. A standard t-statistic is used to test the statistical difference in means.

2.4. Portfolio strategies and implementation

The four strategies are implemented using two sets of equity assets and two sets of euro-currency deposits.

In the first implementation, we restrict the equity position to be exclusively invested in the world-equity index. For strategy 1 to 3, we further restrict the portfolio to be fully invested in the world equity index. Hence, in this implementation, strategy 1 corresponds to a passive benchmark investment in the world equity portfolio, while that passive benchmark is enhanced through optimal dynamic currency hedging in strategy 2 and through both currency hedging and speculation in strategy 3. Only in strategy 4 are the positions in both the world index and the currency deposits jointly optimised.

In the second implementation, we exclude the world index from the eligible assets and allow the equity portfolio to include any or all of the country-equity indices. In this implementation, the equity positions are determined by the optimiser for all strategies. Then, we combine the eligible equity assets with either all euro-currency deposits or only the non-EMU euro-currency deposits. This allows us to evaluate the marginal cost of excluding EMU currencies from the menu of investment choices.

3. The data

We perform the estimation and compute the optimal portfolios from the perspective of a German investor. We use monthly returns on stock indices for the six countries with the largest market capitalisation: France, Germany, Japan, the Netherlands, the UK, the US, plus a value-weighted world index, during the January 1974 - April 1997 period. The indices are from Morgan Stanley Capital International (MSCI). We also use euro-currency rates offered in the interbank market in London for one-month deposits in USD, DEM, JPY, GBP, FRF, and NLG. Those rates are obtained from the Bank of International Settlements and from Data Research Incorporated (DRI). For the risk-free rate, we use the one-month euro-currency deposit rate for the currency of reference, i.e., the DEM. Returns on equity and euro-currency deposits are computed in DEM, based on the closing European interbank currency rates from MSCI. Monthly excess returns are computed by subtracting the one-month euro-DEM deposit rate from the monthly return on each security.

The summary statistics of the asset returns in Table 1 reveal interesting facts. The excess returns on the equity indices have higher means but also higher volatility than the excess returns on the euro-deposits. The unconditional correlations among assets reported in *panel b* are relatively low, especially if compared to the average correlation among sectors of the US markets, which according to Elton and Gruber (1992) is close to 0.9.

As we estimate a conditional version of the international asset-pricing model, we let the price of market and currency risk change over time as a function of the new information available to investors. To describe the investor's information set, we use variables similar to those used in previous research. The instruments include:

- A constant
- The dividend yield on the world-equity index in excess of the one-month euro-DEM deposit rate
- The change in the one-month euro-USD deposit rate
- The monthly change in the US term premium, measured as the yield difference between the treasury security with maturity closest to 10 year and the three-month T-bill
- The US default risk premium, measured by the yield difference between Moody's Baa and Aaa rated bonds

Besides common variables, we use a country-specific variable to predict changes in currency risk premiums, i.e., the difference between the real return on the local euro-currency deposit and the real return on the euro-currency deposit in the reference currency, an estimate of the real risk-free rate differential. Real returns are computed by deflating local nominal euro-currency rates by the change in the local consumer price index. Inflation data are from the International Financial Statistics (IFS) database. All variables are used with a one-month lag relative to the excess return series. Table 2 displays summary statistics of the information variables. Of particular interest is the fact that correlations among the instruments are low, which indicates that our proxy of the information set contains no redundant variables.

Table 2. Summary statistics of the information variables.

	Mean	Median	Std. dev.	Min.	Max.
XDYD	-0.241	-0.197	0.213	-0.944	0.177
ΔUSTP	0.008	-0.012	0.553	-1.717	2.982
ΔEuro$	-0.002	-0.005	0.112	-0.544	0.553
USDP	1.177	1.095	0.473	0.560	2.690
$RRD	-0.015	-0.034	0.370	-0.987	0.959
¥RRD	-0.086	-0.050	0.666	-3.113	1.473
FRRD	0.115	0.118	0.407	-1.098	2.324
NRRD	0.015	0.041	0.495	-1.477	2.051
£RRD	0.026	0.120	0.631	-2.995	2.642

Correlations

	XDYD	ΔUSTP	ΔEuro$	USDP	$RRD	¥RRD	FRRD	NRRD
ΔUSTP	-0.114	1						
ΔEuro$	-0.068	-0.330	1					
USDP	0.005	0.116	-0.127	1				
$RRD	0.185	-0.086	0.013	0.308	1			
¥RRD	0.098	-0.076	0.059	0.159	0.340	1		
FRRD	-0.086	0.005	0.011	0.065	0.464	0.280	1	
NRRD	-0.006	-0.054	-0.094	-0.027	0.391	0.447	0.446	1
£RRD	-0.051	-0.157	0.046	-0.050	0.212	0.300	0.367	0.350

Notes: The information set includes:

Column	Represents the ...
XDYD	World dividend yield in excess of the one-month euro-DEM rate
USDP	US default premium
ΔUSTP	One-month change in the US term premium
ΔEuro$	Change in the one-month euro-USD deposit rate
All others	Difference between the local currency one-month euro-deposits real return and the real return on the one-month euro-DEM deposit (FRRD, NRRD, £RRD, $RRD, ¥RRD)

The world-dividend yield is the DEM-denominated dividend yield on the MSCI world index. The US term premium is the yield difference between the T-bond or T-note with maturity closest to 10 years and the three-month T-bill. The US default premium is the yield difference between Moody's Baa and Aaa rates bonds. The real return on one-month euro deposits is equal to the difference between the quoted nominal deposit rate and the previous month change in the consumer price index. Inflation rates are obtained from the IFS database. The sample covers the January 1974 - April 1997 period (280 observations).

4. Empirical evidence

4.1. International CAPM with time-varying prices of risk

We find strong support for a specification of the international CAPM that includes worldwide market risk and exchange risk. Further, we find that the risk exposures and the components of the risk premium vary significantly over time and across assets. Three main results emerge:

1. *Currency fluctuations induce a systematic source of risk in returns.* The EMU component is small relative to the non-EMU component (USD, JPY, and GBP). The most important source of currency risk is linked to the USD.
2. *Currency risk is priced.* The EMU currency risk commands a positive but small risk premium. The non-EMU currency risk premium is negative. This suggests that investors are willing to forego part of their expected returns to hold assets that provide a hedge against non-EMU currency risk.
3. *Currency risk and its impact on asset returns vary over time as a function of changes in economic conditions and the institutional environment.* Since 1990, the risk exposure of international markets to EMU currencies has declined slightly, while their exposure to non-EMU risk has significantly increased.

These results suggest that an international asset-pricing model, which only uses the world market portfolio to measure risk and explain conditional expected returns, is misspecified. The tests reveal the relative economic importance of the different sources of currency risk. The estimation also shows that changes in the DEM value of the USD and the FRF significantly affect portfolio returns while the GBP, the JPY, and the NLG have little impact. Not surprisingly, USD risk is the most significant source of currency risk.

4.2. The size of the risk premium

Our approach provides direct estimates of the conditional second moments and of the premium associated with each risk factor. We decompose the total risk premium on each asset in three components: the premium associated with market risk, the EMU currency risk premium and the non-EMU risk premium. Table 3 displays summary statistics of the risk premiums of all assets. The size and dynamics of each premium component vary across markets. Several interesting regularities emerge from their time-series plots. As an example, Figure 1 displays the decomposition of the total premium into market and currency component for the world index.

Although, over the entire sample, the average premium for currency risk appears to be only a small fraction of the average total premium, over long subperiods, currency premiums are usually an economically significant fraction of the total premium.

First, consider the period before 1990. The average values of the aggregate currency premiums are large and vary from an average of -1.23% for the US index to a positive premium of 1.8% for the French index. During the same period, the estimated premiums for market risk are all large and positive. Hence the total premiums are mostly positive and rather large. Interestingly, before 1990, the premium associated with non-EMU currency risk is negative for most assets, while the EMU premiums are mostly positive and of similar magnitudes. During that period, non-EMU risk dominates and aggregate currency premiums are significantly negative for US, German, and Dutch assets as well as the euro-pound deposit, while for Japanese and French assets, EMU risk is larger and aggregate currency premiums are significantly positive. For the world and UK equity indices, non-EMU and EMU premiums are of offsetting magnitudes.

Second, consider the last seven years in the sample. Negative premiums for foreign-exchange risk often more than offset a positive market premium, which yields negative total premiums. Although this is partially explained by a significant decrease in the magnitude of the market risk premium for all assets, it is mostly due to a significant increase in the magnitude of the negative premium for non-EMU currency risk for most assets, while EMU premiums decrease insignificantly. In the 1990s, non-EMU risk becomes the dominant component of aggregate currency risk.

Not surprisingly, the currency risk component drives a larger fraction of the total premium associated with euro-currency deposits. However, note that the covariances with the market portfolio, which measure the amount of systematic market risk, are not negligible, which is interesting. Market premiums account for a significant fraction of the total premium. Moreover, for each country, the size and dynamics of the currency risk premium in the equity and euro-currency market are very similar.

Table 3. Estimated average risk premiums.

Panel a. Equity indices

	US	Jap.	Fr.	Ger.	Nl.	UK	Wrld.
Total premiums							
Overall	5.72	6.34	7.62	3.25	5.13	9.55	6.33
	(1.46)	(1.10)	(0.87)	(0.58)	(0.82)	(1.23)	(1.19)
Pre-90	9.71	9.06	9.93	4.53	7.82	12.14	9.48
	(1.53)	(1.25)	(0.94)	(0.69)	(0.91)	(1.45)	(1.28)
ΔPost-90	-13.6	-9.29	-7.86	-4.35	-7.00	-8.84	-10.75
	(1.92)	(1.44)	(1.11)	(0.77)	(1.11)	(1.79)	(1.60)
Market premiums							
Overall	8.46	6.30	6.36	4.09	6.10	9.06	7.70
	(1.14)	(0.77)	(0.84)	(0.52)	(0.83)	(1.40)	(1.03)
Pre-90	10.94	7.76	8.11	5.19	7.84	11.79	9.84
	(1.39)	(0.98)	(1.04)	(0.63)	(1.02)	(1.77)	(1.27)
ΔPost-90	-8.45	-4.99	-5.97	-3.78	-5.94	-9.32	-7.31
	(1.42)	(1.03)	(1.07)	(0.66)	(1.05)	(1.80)	(1.30)
EMU currency premiums							
Overall	1.22	1.03	2.06	-0.39	0.37	1.82	1.07
	(0.26)	(0.24)	(0.33)	(0.11)	(0.15)	(0.50)	(0.23)
Pre-90	1.28	1.10	2.08	-0.31	0.27	1.81	1.07
	(0.36)	(0.33)	(0.46)	(0.15)	(0.21)	(0.71)	(0.32)
ΔPost-90	-0.21	-0.23	-0.09	-0.26	0.37	0.03	-0.01
	(0.39)	(0.39)	(0.49)	(0.16)	('0.23)	(0.74)	(0.35)
Non-EMU currency premiums							
Overall	-3.95	-0.99	-0.79	-0.48	-1.34	-1.34	-2.44
	(0.64)	(0.60)	(0.21)	(0.09)	(0.23)	(0.62)	(0.47)
Pre-90	-2.51	0.21	-0.26	-0.36	-0.92	-1.47	-1.44
	(0.67)	(0.72)	(0.20)	(0.10)	(0.23)	(0.81)	(0.50)
ΔPost-90	-4.93	-4.07	-1.79	-0.31	-1.42	0.45	-3.43
	(1.16)	(0.88)	(0.39)	(0.22)	(0.48)	(1.14)	(0.86)

Table 3. continued ...

Panel b. Euro currency deposits

	Eur$	Eur¥	EurF	EurN	Eur£
Total premiums					
Overall	0.26	1.47	1.42	0.13	1.66
	(0.82)	(0.72)	(0.27)	(0.14)	(0.48)
Pre-90	2.38	3.30	1.69	0.11	1.45
	(0.84)	(0.78)	(0.37)	(0.19)	(0.63)
ΔPost-90	-7.23	-6.22	-0.94	0.05	0.70
	(1.31)	(0.97)	(0.41)	(0.19)	(0.87)
Market premiums					
Overall	2.80	1.86	0.38	0.13	1.63
	(0.34)	(0.25)	(0.05)	(0.03)	(0.23)
Pre-90	3.55	2.37	0.50	0.03	2.09
	(0.40)	(0.30)	(0.06)	(0.04)	(0.28)
ΔPost-90	-2.57	-1.74	-0.40	-0.16	-1.59
	(0.43)	(0.31)	(0.07)	(0.04)	(0.29)
EMU currency premiums					
Overall	1.14	1.01	1.36	0.12	0.72
	(0.15)	(0.16)	(0.30)	(0.13)	(0.19)
Pre-90	1.03	0.96	1.45	0.07	0.59
	(0.20)	(0.23)	(0.43)	(0.19)	(0.26)
ΔPost-90	0.38	0.19	-0.31	0.16	0.46
	(0.22)	(0.24)	(0.43)	(0.19)	(0.27)
Non-EMU currency premiums					
Overall	-3.67	-1.40	-0.32	-0.12	-0.69
	(0.67)	(0.62)	(0.10)	(0.04)	(0.49)
Pre-90	-2.19	-0.03	-0.25	-0.14	-1.23
	(0.73)	(0.72)	(0.12)	(0.05)	(0.64)
ΔPost-90	-5.05	-4.67	-0.24	0.05	1.83
	(1.17)	(0.92)	(0.16)	(0.06)	(0.84)

Notes: The table reports the average of the risk premiums estimated from the model for the overall sample period, the subperiod before June 1990, and the difference in average premiums before and after June 1990. The total risk premium is measured as the sum of the market risk premium and the aggregate currency premium. The currency premium is the sum of the premium associated with EMU currencies, i.e., FRF and NLG, and the premium associated with the non-EMU currencies, i.e., GBP, USD, and JPY. All estimates are reported in percent per year, Newey-West standard errors in parentheses.

Figure 1a. Risk premiums—world.

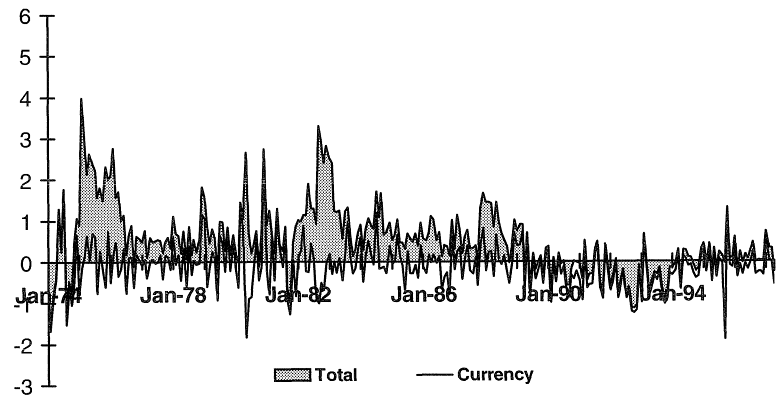
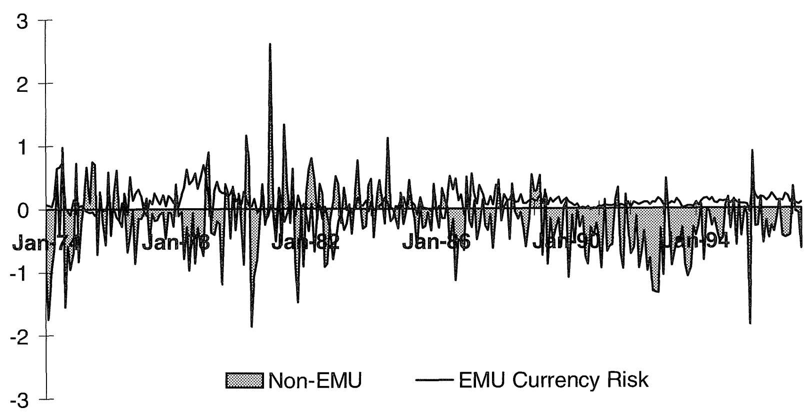


Figure 1b. Currency premium decomposition—world.



4.3. Dynamic asset-allocation strategies

Table 4 describes the performance and turnover of the different dynamic allocation strategies when equity positions are combined with all the euro-currency deposits. Table 5 reports the performance statistics for the same set of strategies when currency positions are restricted to non-EMU euro-currency deposits.

Table 4. Dynamic portfolios strategies out-of-sample performance—all currencies included.

	$\overline{R_p^e}$ (s.d)	t-test [Sharpe]	$\iota'\overline{\omega_s}$ [Avg. Turn]	$\overline{TR_p}$ (s.d)
Panel a: World index and all euro deposits				
PW	0.062	-4.24	1.000	0.620
	(4.474)	[0.014]	[0.000]	(4.449)
PW + CH	0.066	-4.63	0.773	0.624
	(3.594)	[0.013]	[0.346]	(3.573)
PW + CH&S	0.084	-2.11	1.176	0.642
	(3.613)	[0.023]	[0.450]	(3.595)
OPT(W + C)	0.064	3.95	0.937	0.622
	(1.294)	[0.049]	[0.748]	(1.298)
Panel b: Country indices and all euro deposits				
EO	0.010	-5.96	0.035	0.568
	(0.213)	[0.046]	[0.025]	(0.288)
EO + CH	-0.045	-9.41	0.070	0.554
	(0.164)	[-0.027]	[0.108]	(0.246)
EO + CH&S	0.014	-2.41	0.373	0.572
	(0.441)	[0.032]	[0.239]	(0.472)
OPT(E + C)	0.069	4.25	1.001	0.627
	(1.295)	[0.053]	[0.745]	(1.298)

Notes: This table reports out-of-sample performance statistics for dynamic asset-allocation strategies combining equity and euro-currency deposit positions in both EMU and non-EMU currencies. The actively managed portfolios are obtained by performing mean variance optimisation using the start-of-month out-of-sample forecasts of expected returns and covariance matrix generated by the estimated ICAPM model. We consider two variations of four strategies:

1. Passive world equity index investment [PW] or optimal equity only strategy [EO].
2. Strategy one plus optimal overlay currency hedge [PW + CH or EO + CH].
3. Strategy one plus optimal overlay currency hedge and speculation [PW + CH&S or EO + CH&S].
4. Unrestricted optimal portfolio of equity and euro-currency deposits [OPT(W + C) or OPT(E + C)].

For all strategies, we rule out short positions in equities. Column 2 reports month's end realised excess return of the dynamic asset allocation strategies (with the standard deviation in parentheses). Column 3 displays the t-test on the mean difference between the realised return and the unconditional expected return, and, in brackets, the Sharpe ratio of the strategy. Column 4 reports the average proportion of the total portfolio invested in the risky assets and, in brackets, the average total turnover. Column 5 displays the average realised total return of the strategy (with the standard deviation in parentheses). All the figures are reported in percent per month.

Table 5. Dynamic portfolios strategies out-of-sample performance—only non-EMU currencies included.

	$\overline{R_P^e}$ (Std.dev.)	t-test [Sharpe]	$\iota'\overline{\omega_s}$ [Avg. Turn]	$\overline{TR_p}$ (Std.dev.)
Panel a. World index and non-EMU euro deposits				
PW	0.062	-4.24	1.000	0.620
	(4.474)	[0.014]	[0.000]	(4.449)
PW + CH	0.069	-1.26	0.019	0.628
	(3.574)	[0.019]	[0.064]	(3.556)
PW + CH&S	0.094	-3.61	0.010	0.652
	(3.607)	[0.026]	[0.102]	(3.587)
OPT(W+C)	0.077	13.84	-0.027	0.635
	(1.270)	[0.061]	[0.221]	(1.267)
Panel b. Country indices and non-EMU euro deposits				
EO	0.014	2.54	0.034	0.572
	(0.185)	[0.073]	[0.024]	(0.264)
EO + CH	0.010	1.31	-0.007	0.568
	(0.146)	[0.067]	[0.023]	(0.239)
EO + CH&S	0.034	15.53	-0.042	0.592
	(0.426)	[0.080]	[0.066]	(0.453)
OPT(E+C)	0.081	13.80	-0.028	0.639
	(1.272)	[0.064]	[0.221]	(1.269)

Notes: This table reports out of sample performance statistics for dynamic asset allocation strategies combining equity and euro-currency deposit positions only in non-EMU currencies. The actively managed portfolios are obtained by performing mean variance optimisation using the start-of-month out-of-sample forecasts of expected returns and covariance matrix generated by the estimated ICAPM model. We consider two variations of four strategies:

1. Passive world equity index investment [PW] or optimal equity only strategy [EO].
2. Strategy one plus optimal overlay currency hedge [PW + CH or EO + CH].
3. Strategy one plus optimal overlay currency hedge and speculation [PW + CH&S or EO + CH&S].
4. Unrestricted optimal portfolio of equity and euro-currency deposits [OPT(W + C) or OPT(E + C)].

For all strategies, we rule out short positions in equities. Column 2 reports month's end realised excess return of the dynamic asset allocation strategies (with the standard deviation in parentheses). Column 3 displays the t-test on the mean difference between the realised return and the unconditional expected return, and, in brackets, the Sharpe ratio of the strategy. Column 4 reports the average proportion of the total portfolio invested in the risky assets and, in brackets, the average total turnover. Column 5 displays the average realised total return of the strategy (with the standard deviation in parentheses). All the figures are reported in percent per month.

The first row in Table 4 reports, as a benchmark, the performance of a passive strategy of holding the world equity market index portfolio. It shows that over the test period, holding the world index portfolio yields a low realised excess return and high volatility. The performance t-statistic is significantly negative. This indicates that during the 1989-1997 test period, the realised return on the world portfolio was significantly below the mean world market return over the 1974-1989 pre-test period.

Next, the results show that both overlay strategies, the simple overlay hedge, or the overlay hedge combined with a speculative currency position, yield limited benefits in terms of return enhancement and volatility reduction. They generate a slight performance improvement when combined with a position in the world index, but a lower performance when combined with an optimal portfolio of the equity indices.

The unconstrained, optimal, dynamic strategy that combines the equity and the euro-currency deposits generates the higher excess returns at lower relative risk. In both panels, this strategy yields the highest Sharpe ratio and is the only one to generate a significantly positive test statistic. For example, compared to the passive strategy of holding the world-equity index, which has a Sharpe ratio of .014, the unconstrained, optimal, dynamic strategy yields a Sharpe ratio of .05, which is 3.5 times as large. Although the dynamic-strategy, realised, excess return of .06% per month is of similar magnitude as the return of the passive strategy, its volatility is significantly lower at 1.3% versus 4.5% per month.

Figure 2 illustrates the evidence and displays the cumulative return associated with an investment of DEM 100 at the start of the test period for each of the four strategies. The optimal dynamic strategies achieve a slightly higher total return than the passive strategy during the last eight years, while encompassing significantly lower volatility. The small performance enhancement associated with the dynamic currency overlay strategies is also evident. This suggests that most of the gains from the dynamic asset allocation strategies arise from taking advantage of the correlation structure between stocks and currency returns, and the predictability of the currency risk premiums.

Figure 2. Dynamic (all) currency hedges—world index.

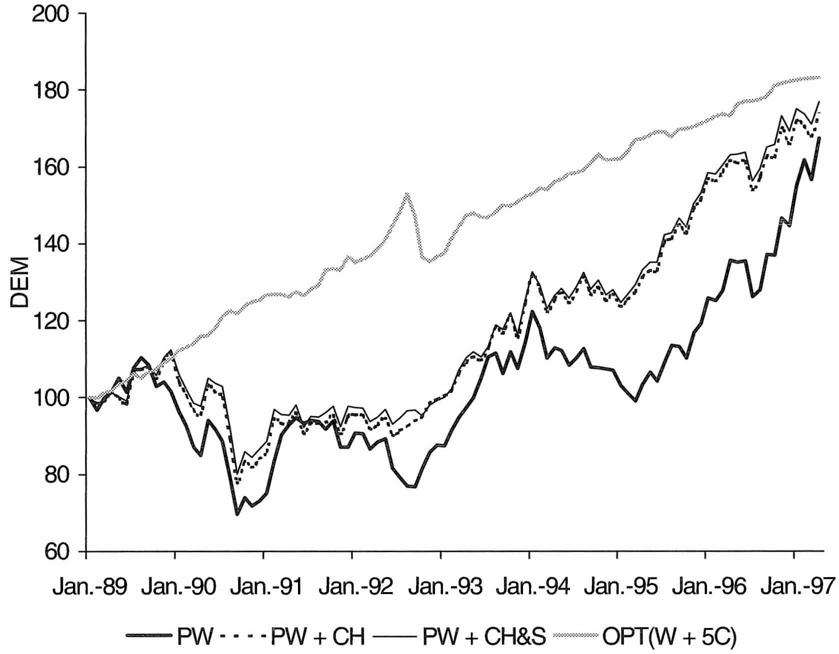
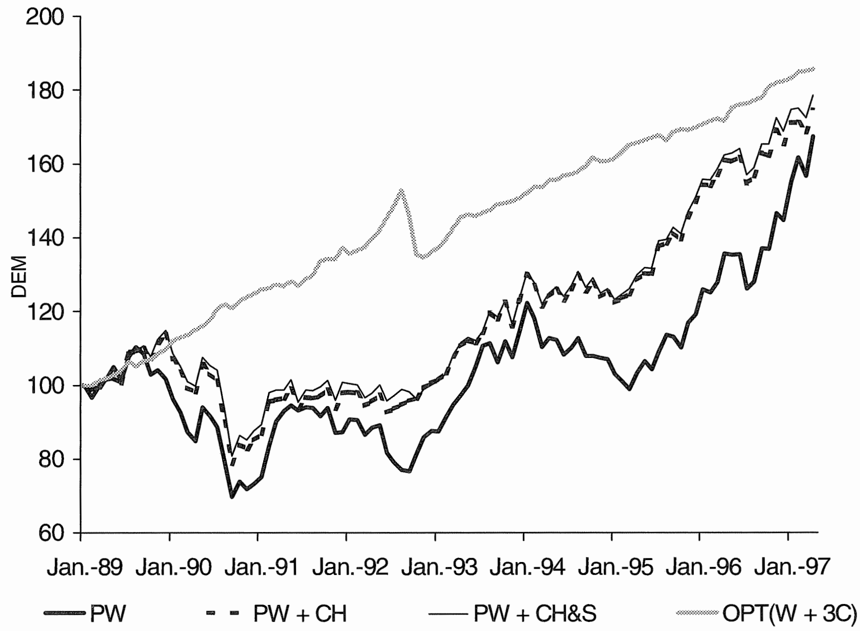


Figure 3. Dynamic non-EMU currency hedges—world index.



The purpose of Table 5 is to investigate the impact of excluding EMU currencies from the menu of available assets. Overall the results are similar to those in Table 4. Unconstrained, optimal, dynamic strategies dominate in terms of (1) Sharpe ratios, and (2) the performance t-statistic. But the comparison of Tables 4 and 5 yields surprising results. For all the strategies, the realised returns are higher, and the volatilities are lower, thereby generating higher Sharpe ratios when EMU currencies are excluded from the available assets. This suggests that there is little or no additional economic benefit from including EMU deposits in the menu of assets. It may also indicate that there are significant estimation costs of including more assets in the model. The larger the model to estimate, the lower the precision of the estimates, and the less reliable the forecasts of means and covariances used in the optimisation. Excluding EMU currencies seems to have little cost in terms of expected returns but to yield significant gains in terms of noise reduction. This could also stem from the choice of EMU currencies. The volatility of the DEM-FRF (and specially the DEM-NLG) exchange rates is significantly lower than the volatility of the DEM exchange rates of most other currencies. The results may have been different had we used the Italian lira or the Spanish peseta. Alternatively, the differences in Tables 4 and 5 could stem from the multivariate GARCH inability to cope with the possibility of sudden large realignments within the ERM, a major source of risk for many EMU currencies.

The performance of the different strategies that include and exclude EMU currencies are plotted in Figures 2 and 3 for the strategies involving the world index, and in Figures 4 and 5 for the strategies involving the six equity indices. The difference between the dynamic strategies that include or exclude the EMU deposits is clearly small. This suggests that in an international portfolio framework, most economically significant risk arises from non-EMU currencies, the USD, the JPY, and the GBP. The adoption of the euro is likely to yield little benefit or cost to international investors, irrespective of their country of origin[4].

The graphs also display the failure of the forecasting model during the European Monetary System currency crisis in the second half of 1992. The model seems unable to deal with severe disruptions in currency markets. The dismal performance of the optimal portfolio re-

[4] Recall that the optimal portfolio of risky assets is the same for investors of all countries, irrespective of their currency of reference.

flects this. When the five months from August 1992 to December 1992 are excluded from the sample, the Sharpe ratios of the optimal strategy almost double.

Next, we examine the position and turnover of the different strategies. Column 3 in Tables 3 and 4 reports the average proportion of the total portfolio invested in risky assets. The remainder, one minus this estimate, is the average proportion invested in the risk-free asset. The optimal strategies that include all the euro-currency deposits require having an average between 77% and 118% of one's portfolio invested in risky assets. These numbers drop to an average net short position of 2.8% in risky assets, and 102.8% in the risk-free asset, when EMU currencies are excluded. Because all equity positions are restricted to be positive, the short position in risky assets is the one associated with the euro-currency deposits. The turnover figures exhibit a similar pattern. The average fraction of the total portfolio traded each month amounts to 75% (22%) when EMU currencies are included (excluded). Most of the turnover is concentrated in the EMU euro-currency deposits.

Figure 4. Dynamic (all) currency hedges—six equity indices.

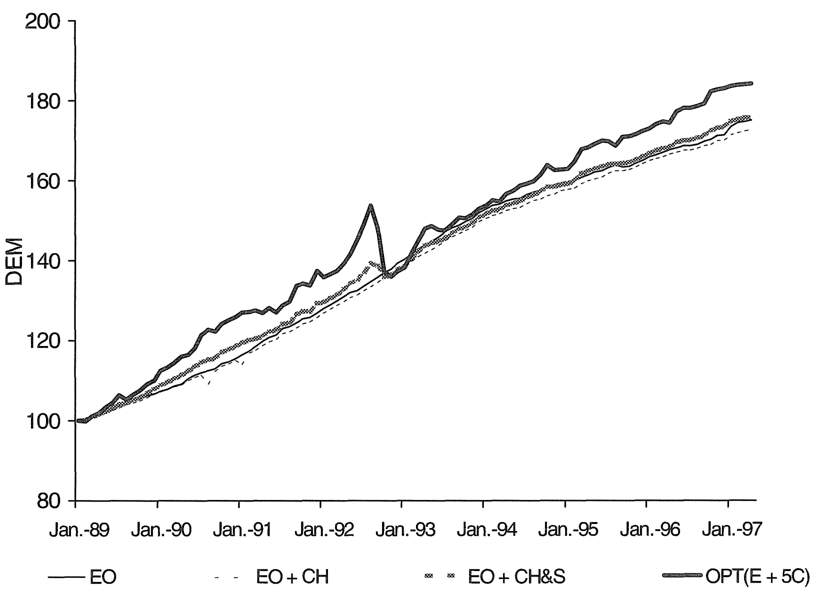
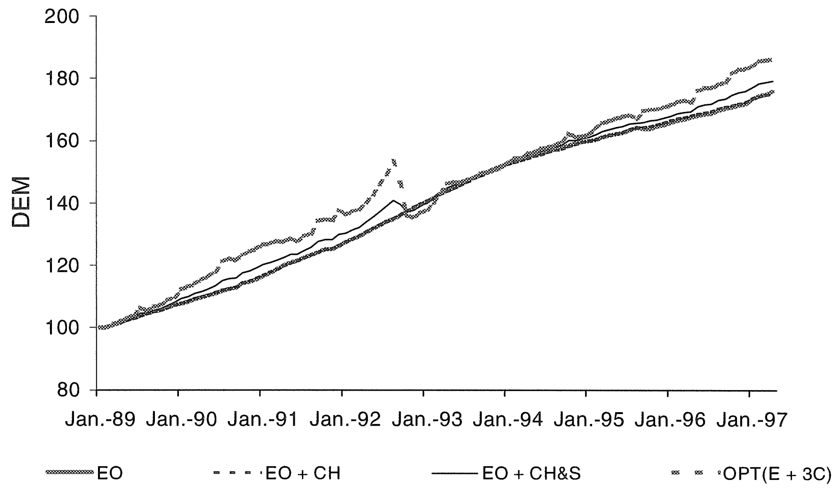


Figure 5. Dynamic non-EMU currency hedges—six equity indices.



Tables 6 and 7 provide a more detailed description of the average position and turnover in the different securities. For the optimal portfolios of euro-currency deposits and equity indices, more than 95% of the turnover reflects trading in euro currencies. This pattern is clear from the relative size of equity and euro-currency deposit positions. Several interesting results emerge:

First, as one moves from a pure currency-hedge strategy to a hedge-plus-speculative strategy, the average size of the euro-currency positions increases.

Next, for strategies that include a hedging and a speculative component, the euro-currency deposit positions are much larger on average than the equity holdings. Similarly, the minimum and maximum portfolio weight for equities is always much smaller than those of euro-currency deposits. For example, the optimal dynamic strategy calls for shorting up to 70% of the portfolio value in NLG. The largest equity position called for by the optimal strategy is 17.5% in the US market or 31.7% in the world index. Not surprisingly, given the short sale restriction for equities, the position in equities is never negative. But note that the restriction is never binding for the US and Japanese equity indices, nor does it bind the position in the UK index when EMU currencies are excluded.

Lastly, extreme weights prevail more often when EMU currencies are included than when they are excluded. This reinforces the conclusion that including then EMU currencies yields little benefit while increasing noise in the optimisation.

Table 6. Portfolio weights—out-of-sample dynamic strategies including all currencies.

Panel a. World index and all euro deposits

	Wrld.	Eur$	Eur¥	EurF	EurN	Eur£
PW	100.00					
PW+CH	100.00	-47.64	-27.21	-6.95	94.99	-25.92
PW+CH&S	100.00	-55.80	-28.44	-3.25	124.98	-19.90
OPT(W+C)	2.63	-25.80	-4.30	10.60	93.20	17.41
Min.	0.41	-67.61	-43.14	-75.00	-70.27	-66.48
Max.	31.74	25.83	39.23	119.27	318.52	85.69
Turn.	0.69	8.21	6.52	11.54	40.13	7.91

Panel b. Country indices and all euro deposits

	US	Jap.	Fr.	Ger.	Nl.	UK	Eur$	Eur¥	EurF	EurN	Eur£
EO	.21	.93	.87	.23	.28	1.04					
EO+CH	.21	.93	.87	.23	.28	1.04	-.04	-1.15	-2.29	-2.39	-1.29
E+CH&S	.21	.93	.87	.23	.28	1.04	-1.49	-.36	5.09	4.01	.42
OPT (E+C)	1.29	.68	.12	.11	.14	.31	-25.81	-4.38	1.29	94.28	17.51
Min.	1.95	.08	.00	.00	.00	.00	-67.58	-42.89	-79.43	-7.01	-66.10
Max.	17.53	8.61	.68	.87	.74	4.14	25.83	38.69	119.20	318.76	85.70
Turn.	.39	.17	.02	.02	.03	.09	8.24	6.48	11.64	39.66	7.83

Notes: The table reports the average portfolio proportions invested in the different assets for the eight dynamic portfolio strategies examined in Table 4. For the unconstrained optimal strategies, we also report maximum and minimum weights and average portfolio turnover per month over the sample period. All figures are reported in percent.

Table 7 shows that the turnover is lower but still significant at 22% per month for the strategies that exclude EMU currencies. Also in this case, most of the turnover is concentrated in euro-currency deposits. Given that trading currencies is far less costly than trading equities, this turnover pattern does not seem prohibitive. This also suggests that most gains from the dynamic strategies can be traced to the predictability of the euro-currency deposit returns. Investors benefit from dynamic allocation strategies as long as they optimally manage currency risk.

Table 7. Portfolio weights—out-of-sample dynamic strategies including only non-EMU currencies.

Panel a. World and non-EMU euro deposits

	Wrld.	Eur$	Eur¥	Eur£
PW	100.00			
PW+CH	100.00	-47.65	-26.44	-24.00
PW+CH&S	100.00	-54.91	-27.74	-16.36
OPT(W+C)	3.03	-23.20	-4.60	22.21
Min.	0.91	-62.31	-37.61	-55.01
Max.	22.27	16.43	28.52	83.29
Turn.	0.69	7.91	5.32	8.31

Panel b. Country indices and non-EMU euro deposits

	US	Jap.	Fr.	Ger.	Nl.	UK	Eur$	Eur¥	Eur£
EO	.31	.83	.27	.62	.28	1.09			
EO+CH	.31	.83	.27	.62	.28	1.09	-.11	-3.73	-1.78
EO+CH&S	.31	.83	.27	.62	.28	1.09	-7.38	-5.03	5.87
OPT(E+C)	1.49	.78	.12	.11	.14	.39	-23.31	-4.73	22.31
Min.	.49	.18	.00	.00	.00	.07	-62.28	-37.69	-56.60
Max.	12.31	6.01	.38	.47	.54	4.01	16.38	28.49	83.27
Turn.	.39	.17	.01	.01	.01	.09	7.92	5.34	8.33

Notes: The table reports the average portfolio proportions invested in the different assets for the eight dynamic portfolio strategies examined in Table 5. For the unconstrained optimal strategies, we also report maximum and minimum weights and average portfolio turnover per month over the sample period. All figures are reported in percent.

5. Conclusion

To summarise, we find that EMU and non-EMU currency risk command a statistically and economically significant premium over the last 25 years. Our results indicate that the exposures and the price of currency risk vary significantly over time. In particular, the exposure of international markets to non-EMU risk has significantly increased during the 1990s, while exposure to EMU risk has slightly declined. Our comparison of international portfolio strategies indicate that significantly superior performance can be achieved by adopting dynamic strategies that jointly optimise currency and equity positions. We find that most of the benefits of these strategies accrue from managing non-EMU currency risk. We conclude that, in an international portfolio framework, most economically significant risk arises from non-EMU currencies, the USD, the JPY, and the GBP.

The adoption of the euro is likely to have a limited impact on international asset prices, risk, and expected returns.

Our results emphasise the importance of conditional analysis in which risk exposures and risk premiums vary over time. Unconditionally, the premium for currency risk is smaller than the premium for market risk. But an unconditional analysis would fail to detect important regularities in the dynamics of the risk premiums and conclude that currency risk is not an important pricing factor. By the same token, portfolio strategies that ignore currency risk and the variability of risk exposures and risk premiums would fail to provide investors with the full benefit of risk reduction and return enhancement. Even with the advent of the euro, the issue of currency risk will not disappear, and will be one of the toughest challenges to portfolio managers in the 21st century. Our approach represents a first step toward meeting this challenge.

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