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Abstract

This paper considers a foreign currency management problem and presents an optimal dynamic hedging portfolio model based on the associated intertemporal capital asset pricing model. The central idea is that an institution, e.g. the Central Bank or Treasury in a small open economy, which manages foreign government debt and reserves aims to hedge against fluctuations in exchange rates and terms of trade with the outcome being an optimal hedging portfolio, which is itself a function of timevarying variances and covariances. Implementing this economic model calls for a statistical model permitting second moments to change through time, e.g. a multivariate GARCH model. The model herein is applied to Danish data and estimates three types of debt portfolios for Denmark, one with ten, seven, and four currencies. When estimating one type - the ten equation system - it is found that a large share of the foreign debt should be placed in BEF, DEM and a little in CHF. Reserves should be placed, for the majority, in FRF and ESB and the relative shares of each currency changed from quarter to quarter according to the changing covariances. When the number of currencies is reduced to four, CHF, DEM, JPY and USD, Denmark would still have a net debt in DEM and CHF, but the share of USD in the foreign reserves would have increased.

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1. Introduction

This paper presents a dynamic portfolio model in which a small open economy, through the composition of its external debt, is able to hedge against fluctuations in the exchange rates and the terms of trade. This means that an institution which manages government foreign debt and exchange reserves has as its core mission to solve a portfolio problem. A country can, by an optimal structuring of the currency composition of its external debt, reduce the cost of borrowing (see also Kroner and Classens (1991)). The estimated time varying conditional covariances are therefore used to construct such a dynamic debt portfolio for Denmark. Furthermore, the time varying second conditional moments are modeled by use of a Multivariate Generalized Auto--Regressive Conditional Heteroscedastic (MGARCH) model.

In Denmark, a balance of payment deficit has been the rule rather than the exception and, as a result, a government foreign debt has accumulated. To counter this deficit, foreign financing has been sought, government borrowing being one solution. The aim of the Central Bank is to minimize the risk and the cost of borrowing,thereby making portfolio management a major issue. Hence, when the exchange rates fluctuate over time, the foreign currencies allocation of debt also changes. Furthermore, the total exchange rate risk depends not only on the risk in each currency but also on the correlation between the currencies. It is possible, therefore, to reduce risk by allocating the borrowing between different currencies. Large USD and the JPY shares in the Danish debt portfolio during the 1980s made it very sensitive to exchange rate fluctuations.

This paper presents portfolios with four, seven, and ten currencies. To obtain each portfolio two multivariate GARCH models have to be estimated, one which includes the terms of trade and one which does not. The optimal portfolios are calculated by employing the variance covariance matrices estimated by the MGARCH (1,1) models. On the other hand the portfolio share for each currency is found by multiplying the inverse covariance matrix of exchange rate depreciations with the vector of covariances between terms of trade changes and exchange rate depreciations, this being done for every quarter of a year from the second quarter of 1982 onwards.

The estimated results for this ten equation system are that a large share of the Danish foreign government debt should be placed in mainly BEF, DEM and a little in CHF. It is perceived therefore that debt should be allocated mainly in the EMS currencies. Foreign exchange reserves, on the other hand, should be placed for the mainly in FRF and ESB. Furthermore, the relative shares of each currency change from quarter to quarter due to the changing covariances. In the second type of dynamic portfolio model, the number of currencies is reduced to seven and, finally, in the third type the number of currencies is reduced to four, resulting in a seven and four equation system being obtained. The currencies included in the four equation system are CHF, DEM, JPY and

USD, hence, only one EMS currency is included in this portfolio. The estimated results suggest that Denmark should maintain its net debt in DEM and CHF, but increase the share of USD in the placement of currencies.

The structure of the paper is as follows. Section Two presents an analytical model used for currency management and Section Three outlines the econometric technique used in the study. Section Four describes the data and the Danish foreign debt, while Section Five applies the model to Denmark and presents the estimated results for the MGARCH models and the optimal portfolios calculations. Section Six concludes the paper by outlining further extensions of the model. Three Appendixes are attached. Appendix A presents the currency abbreviations, Appendix B the coefficients of correlation between currencies and the multivariate GARCH estimation results, and finally, in Appendix C, the optimal portfolios for each time period are presented. The tables in the text are numbered as I,II.. and tables in Appendix as 1,2..

2. The economic model

Consider a small open economy facing a perfect capital market but exposed to risk from uncertain future changes in exchange rate and commodity prices. The home country seeks to minimize the welfare loss arising from this risk. With a dynamic portfolio model the small open economy can use the currency composition of external debt as a hedging instrument against changes in the exchange rate and commodity prices. The presented model builds on Kroner and Classens (1991).

2.1 The model

The economic model consists of N+1 countries where the N foreign countries are indexed by i = 1,..,N. An asterisk designates variables in the foreign country. The final country in this set up is a small open economy and let us call it the home country and assume that it is risk averse. In the following, the special units of this world economy are presented.

Consumption

One commodity is consumed in the home country and the path of the price P of the domestic commodity is described by a stochastic differential equation written as

$$\frac{dP}{P} = v_p(S,t)dt + \sigma_p(S,t)dZ_p \tag{1}$$

where S by assumption is an S×1 vector of state variables which follows Ito processes[2]. dZ_p is a Wiener process with E[dZ]=0 and VAR[dZ]=dt. $v_p(S,t)$ is the instantaneous mean and $\sigma_p(S,t)$ the instantaneous standard deviation of the percentage rate of change in price and both are assumed to be functions of time t. This means that the expected value of price changes during a short - infinitesimal - interval dt is $\sigma_p(S,t)dt$.

The vector of state variables is understood to include all the state variables which affect the welfare of the country. The first element in the vector of state variables is the change in the logarithm of the price of the commodity available in the domestic country. Some of the other elements which could belong to the vector S are specified later. The use of one price variable instead of multiple variables can be justified if the utility function to be maximized exhibits constant consumption shares.

The price P represents the price of servicing external debt relative to domestic consumption and can, therefore, best be interpreted as the terms of trade, i.e. the export price divided by the import price.

Exchange rates

Each of the N countries have an exchange rate e_i. The exchange rate is measured as the home country currency per unit of the foreign currency. It is assumed that the exchange rates follow a diffusion process similar to the equation which describes the price

[2] The properties of Ito processes and the stochastic differential equations are given in Merton (1971). In Svensson (1987) a reference list on diffusion processes can also be found.

dynamics of the commodity. The dynamics of the exchange rates are given by

$$\frac{de_i}{e_i} = v_{e_i}(S,t)dt + \sigma_{e_i}(S,t)dZ_{e_i} \tag{2}$$

dZ_{e_i} is a Wiener process where E[dZ]=0 and VAR[dZ]=dt. As N currencies exist, there is a vector of N independent Wiener processes. $v_{e_i}(S,t)$ is the instantaneous mean and $\sigma_{e_i}(S,t)$ is the standard deviation of the percentage rate of change in the exchange rates. Equivalently (2) means that the exchange rates depreciations are approximately normal distributed for short interval dt, with mean $v_{e_i}(S,t)dt$ and variance $\sigma_{e_i}(S,t)dt$. The exchange rates are hence lognormal. The stochastic component the second term in (2) is serially uncorrelated no matter how short the interval dt. They are assumed to be functions of time t and the state variable S. Let y(S,t) be the vector of exchange rates changes with the ith element $\frac{de_i}{e_i}$. It should be noted that it is not necessary to assume that the law of one price or the purchasing power parity hold for all currencies, so P is not necessarily equal to $P_i^* e_i$ for all i countries. Due to e.g. trade barriers, oligopolic pricing, transaction costs and/or barriers to international commodity arbitrage, the law of one price does not hold at all points in time. Neither can it be assumed that the changes in the terms of trade are perfectly correlated with the changes in the exchange rates. This would be the case if it was assumed that domestic prices were perfectly sticky.

State Variables

One is now in a position to specify the state vector S, the first element being the percentage change in the price of the commodity consumed in the home country as mentioned above. The next N elements in S are the depreciations of the N exchange rates in the economy.

$$S = \left[\frac{dP}{P}, \frac{de_1}{e_1}, \ldots, \frac{de_N}{e_N} \right] \tag{3}$$

Of course, other variables could be included, e.g. total market values of the domestic or foreign asset and the domestic and foreign money supplies.

Investment opportunities

The home country can invest in liabilities nominated in the N currencies and a liability in the home currency. The domestic price of a foreign liability is the price in foreign currency of that liability multiplied by the exchange rates. It is assumed that in each country a nominal riskless bond exists. Let B be the price in the home currency of the home country's riskless bond with nominal rate of return R. B_i^* is the price of the N foreign bonds, denominated in the N currencies and serving as a secure nominal rate of return at R_i^*. The dynamics of the riskless bonds are given by

$$\frac{dB_i^*}{B_i^*} = R_i^* dt, \qquad i = 1,\dots,N. \tag{4}$$

It is assumed that the nominal rate of return is constant and that the bond markets are always in equilibrium.

The demand for foreign bonds can be divided into two parts. First, the investor has a "speculative" demand (which is excluded from the analysis, because the Central Bank does not speculate against other Central banks). Second, the investor holds foreign bonds because the returns on these are correlated with the changes in the state variables: the commodity price, the N exchange rates, and the other (not specified) state variables. This is called the hedge demand. Because of the assumption of risk aversion in the home country, the hedging component is more important than the speculative component.

Excess returns

Foreign bonds are risk free in their home country, but the exposure to exchange rate movements make them risky for investors from abroad, e.g. from the home country. The excess return of the ith foreign bond for a domestic investor is defined as the return on one unit of domestic currency invested in the foreign bond, financed by borrowing at the interest rate R in the domestic country, i.e.

$$\frac{dH(B_i^*)}{H(B_i^*)} = \frac{dB_i^*}{B_i^*} + \frac{de_i}{e_i} - Rdt \tag{5}$$

where $\frac{dH(B_i^*)}{H(B_i^*)}$ is the excess return. Equation (5) implies - because of the assumption of constant nominal rates - that the excess return on a safe foreign bond is perfectly correlated with the change in the exchange rates. (5) is rewritten by inserting equation (2) and (4), and becomes

$$\frac{dH(B_i^*)}{H(B_i^*)} = (R_i^* + v_{e_i}(S,t)dt - R)dt + \sigma_{e_i}(S,t)dZ_{e_i} \tag{6}$$

Let $\eta(S,t,R,R^*)$ represent the vector of excess returns. It is assumed that the interest rates are constant; this implies that the correlation between the exchange rates y and η is equal to one, which means that they are perfectly correlated. It is not assumed that the uncovered interest rate parity holds[3].

Welfare problem

It is assumed that the countries' welfare problem can be reduced to finding the currency composition of its external debt that minimizes the variance of its external debt service relative to its opportunity cost of foregone consumption. The external debt service is measured by the excess return of the foreign bonds and the foregone consumption is measured by changes in the terms of trade. The country's objective function is

$$\min_b \mathrm{VAR}\left[b'\eta(S,t,R,R^*) - \frac{dP}{P}\right] \tag{7}$$

where b is the vector of optimal holdings of foreign bonds. Solving for the variance operator (7) can be rewritten as

[3] In other words, $R_i^* + v_{e_i}(S,t) - R$ is not necessarily equal to zero.

$$\min_b \left(b'\Omega_{\eta\eta}(S,t)b \ - \ 2b\Omega_{\eta p}(S,t) \ + \ \sigma_p^2(S,t) \right) \tag{8}$$

Where $\Omega_{\eta\eta}(S,t)$ is the NxN matrix of conditional covariances of the excess returns of foreign bonds and $\Omega_{\eta p}(S,t)$ is the N×1 vector of conditional covariances between excess returns and percentages changes in the price variable. Because excess returns are perfectly correlated with exchange rate depreciations, $\Omega_{\eta\eta}(S,t)$ is the same as the conditional covariance matrix of exchange rates depreciations, i.e. $\Omega_{\eta\eta}(S,t)=\Omega_{yy}(S,t)$ and $\Omega_{\eta p}(S,t)$ is the same as the matrix of conditional covariances between the exchange rates depreciations and percentage changes in the price variable $\Omega_{\eta p}(S,t)=\Omega_{yp}(S,t)$. Thus the country's objective function can be written

$$\min_b \left(b'\Omega_{yy}(S,t)b \ - \ 2b\Omega_{yp}(S,t) \ +\sigma_p^2(S,t) \right) \tag{9}$$

Solving the minimization problem gives the following first order condition and thereby the optimal holding of foreign bonds $b^*(S,t)$

$$b^*(S,t) \ = \ \Omega_{yy}(S,t)^{-1}\Omega_{yp}(S,t) \tag{10}$$

The resulting borrowing shares would apply to the country's net foreign liabilities, i.e. debt minus foreign exchange reserves. Positive elements of the vector $b^*(S,t)$ indicate optimal borrowing shares and negative indicate asset shares. The optimal risk-minimizing currency composition is a function of the conditional covariances of the exchange rates depreciations and the conditional covariances of each of the exchange rates with the price variable. The hedging portfolio provides the best hedge against changes in the exchange rates by finding the portfolio that has the maximum correlation with the percentage changes in the state variables.

The correct way of estimating this model is by using an estimation method which allows for time-varying variances and covariances, as the variables in the optimal holding equation are permitted to change with time. If the variance and covariance were assumed constant over time and if this was an appropriate assumption (which it is not), one could perform a OLS regression of the changes in the term of trade on the vector of exchange rate depreciations. The estimated parameters with a suitable scaling would then apply as the optimal holdings.

To model time varying second conditional moments a Multivariate Generalized Autoregressive Conditional Heteroscedasticity model is used, which is outlined in section 3.

3. Econometric Methodology

The analysis of economic time series data usually involves a study of the mean - the first conditional moment - with an assumption of constant variance. During the work with financial time series data, it has become clear that volatility is a key issue. To model any temporal variation in the conditional variance - which is seen as a measure of the volatility process - becomes of utmost importance for the econometrician.

Engle (1982) introduced a new type of model where he explicitly recognized the difference between the unconditional and conditional variance. This gave birth to the AutoRegressive Conditional Heteroscedasticity model (ARCH). ARCH models deal with the constant variance assumption, and allow the conditional variance to be a time varying function of past errors but leave the unconditional variance constant. The econometrician thus estimates both the conditional mean and variance.

It is not always - if ever - a trivial task to model the conditional mean and variance as both processes are generally unknown functions of an also unknown information set. One approach commonly used is to assume a particular functional form for the mean and variance. This is called the parametric approach because of the fact that the function by assumption is characterized by certain unknown parameters that have to be estimated under an assumption of a given distribution. ARMA models are - within the class of parametric models - predominant for the univariate analysis of the conditional mean. ARCH models have a similar status with respect to the conditional variance. Models with errors described as ARCH processes are found to be successful in modelling various different macroeconomic time series, see Bollerslev et al. (1992). ARCH models are seen as very potential instruments in modelling the clustering of volatility in high frequency speculative prices. Volatility clustering is the phenomenon of a tendency of periods where high volatility are followed by periods of high volatility and periods of low are followed by low volatility.

This phenomenon is widely studied in financial time series. For studies on exchange rate data see e.g. Baillie and Bollerslev (1989). The term structure of interest rate is analyzed, in e.g. Engle et al. (1985) on quarterly US-Treasury bills data and Verner, Lundquist and Nielsen (1991) on monthly US-Treasury bills data, both using an estimate of the conditional variance as a proxy for the time varying risk premium.

When estimating ARCH regressions models, it is often necessary with a relatively long lag structure of past errors in the variance equation. This long lag structure often results in some non-negative variance parameters; therefore, Bollerslev (1986) extended ARCH to Generalized AutoRegressive Conditional Heteroscedasticity models (GARCH). As the intention is to concentrate on the conditional variance and covariance in the empirical work, this section presents the basic notation within the field of GARCH. Even though the empirical work is with multivariate models, the univariate case and afterwards the multivariate set up is presented. The presentation is carried out in this way in order to help the understanding of MGARCH.

3.1 The linear univariate GARCH(p,q) model

A discrete time stochastic process $\{\varepsilon_t\}$ of the following form is referred to as an ARCH model

$$\varepsilon_t = z_t \sigma_t(\psi_{t-1})$$
$$z_t \quad \text{i.i.d.} \qquad E(z_t) = 0 \qquad Var(z_t) = 1 \tag{11}$$

with σ_t as a time varying, positive and measurable function of the information set. ψ_{t-1} is introduced as the information set (sigma-field) of all information through time t-1. The following characterizes the GARCH(p,q) regression model, where $\{\varepsilon_t\}$ are the residuals from a regression

$$\varepsilon_t | \psi_{t-1} = y_t - E[y_t | \psi_{t-1}] \sim N(0, h_t) \tag{12}$$

$$\begin{aligned} h_t &= \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i} \\ &= \omega + A(L)\varepsilon_t^2 + B(L)h_t \end{aligned} \tag{13}$$

A(L) and B(L) are lag polynomial of order q and p respectively. To ensure a well-defined process all the parameters in the infinite-order AR is positive or zero; $p \geq 0$ and $q > 0$, and additionally, that $\omega > 0$, $\alpha_i \geq 0 \; \forall$ i and $\beta_i \geq 0 \; \forall$ i. One can call the last three assumptions the non-negativity requirement. In the following (12) is referred to as the mean equation and (13) as the variance equation.

It is seen that the GARCH(p,q) regression model in (12) and (13) is a fairly general model which embeds ARCH and white noise. If p = 0 the GARCH(p,q) reduces to an ARCH(q) model, and if p = q = 0 the residuals from (12) is simply a white noise process and the conditional variance is constant. From (13) it can be seen that the GARCH(p,q) model allows the conditional variance to be time varying but leaves the unconditional variance constant over time. The GARCH(p,q) model can be described as an univariate ARMA model for the conditional second moment - the variance.

With financial data the ARCH(q) model captures the tendency for volatility clustering, i.e. for large (small) price changes to be followed by large (small) price changes, but of unpredictable sign. In many of the applications with the linear ARCH(q) model, a long lag structure is called for.

The generalisation from ARCH(q) to GARCH(p,q) makes it possible to model a longer memory with a more parsimonious model. Bollerslev (1986) shows how a GARCH(p,q) model - because of the moving average term in the variance - can be seen as an ARCH(∞) model. It is thus possible to specify a model with infinite memory with a modest number of lags. The GARCH(p,q) specification leaves us with a model with a more flexible lag structure, but it should be mentioned - although it should be trivial - that even if it is possible to model infinite memory with a very parsimonious model, this is clearly inferior to modelling the true data generating process. The most simple GARCH(p,q) model is the GARCH(1,1) regression model. This model is obtained by replacing (13) by (15)

$$\varepsilon_t | \psi_{t-1} = y_t - E[y_t | \psi_{t-1}] \sim N(0, h_t) \tag{14}$$

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} \tag{15}$$

This is a very simple model and it seems to have gained a high empirical reputation, and with the modest number of parameters in the variance, the non-negativity requirement is always fulfilled.

Modern finance theory is cast in terms of continuous time stochastic differential equations, but financial data - including exchange rate data - are often available at discrete time intervals only. Nelson (1990) shows that the discrete time GARCH(1,1) model converges to a continuous time diffusion model as the sampling intervals get small. Along similar lines, Nelson (1992) shows that if the true model is a diffusion model with no jumps, then the discrete time variances are consistently estimated by a weighed average of past residuals as in the GARCH(1,1) formulation.

Persistence in variance

As with the mean, specify requirements can be outlined about stationarity in the GARCH(p,q) model in (12) and (13). The model is seen to be covariance stationary if and only if $A(1) + B(1) < 1$. In the GARCH(1,1) model in (14) and (15) this stationarity is ensured iff $\alpha + \beta < 1$. From the various applications of GARCH(1,1) to economic data it is clear that $\alpha + \beta < 1$ is not always fulfilled. Indeed $\alpha + \beta$ often sum to a figure equal to or greater than unity. If $\alpha + \beta = 1$ the process is called Integrated GARCH or IGARCH. Nelson (1990) has a possible explanation of this empirical phenomenon, when he shows that in the diffusion limit for the GARCH(1,1) model $\alpha + \beta$ converges to one as the sampling frequency diminishes.

If the GARCH process is characterized by IGARCH, it is said that there is a high degree of persistence in the variance. Even though many financial time series may exhibit a high degree of persistency in the variance of their univariate time series representation, this persistence is likely to be common among different series, so that certain linear combinations of the variables show no persistence. This is called co-persistence in variance, and it is described further in Bollerslev and Engle (1990). Lumsdaine (1991) shows that the standard asymptotically based inference procedures are generally valid even in the presence of IGARCH effects, although the Monte Carlo evidence presented in Hong (1988) suggests that the sample sizes must be quite large for the asymptotic distributions to provide good approximations.

Normality

It is noticed that an assumption is imposed of a conditional normal distribution for the conditional innovations in the mean in the GARCH(p,q) regression model. Bollerslev (1986) shows that the unconditional distribution for $\{\varepsilon_t\}$ from a GARCH(p,q) model with an assumption of conditional normal $\{\varepsilon_t\}$ have fatter tails than the normal distribution. In other words, the GARCH(p,q) regression model should be able to capture the empirical fact that many financial time series exhibit a leptokurtic unconditional distribution. Despite this, it is still important to secure oneself that the estimated model accounts adequately for this leptokurtosis. After this description of the univariate model, it is straightforward to extend it to the multivariate GARCH(p,q).

3.2 The multivariate GARCH(p,q) model

A multivariate (N-variate) ARCH process will be of the following form

$$\begin{gathered} \varepsilon_t = z_t \Omega_t(\psi_{t-1}) \\ z_t \quad \text{i.i.d.} \qquad E(z_t) = 0 \qquad Var(z_t) = I \end{gathered} \tag{16}$$

where $\{\varepsilon_t\}$ is an (N×1) vector stochastic process, and Ω_t is an (NxN) time varying covariance matrix, positive definite and measurable with respect to the time (t-1) information set ψ_{t-1}.

The following is a multivariate ARCH regression model

$$\varepsilon_t | \psi_{t-1} = y_t - E[y_t | \psi_{t-1}] \sim N(0, H_t) \tag{17}$$

$$Var(\varepsilon_t | \psi_{t-1}) = H_t \tag{18}$$

where $\{y_t\}$ is an (Nx1) time-series vector of interest, and ψ_{t-1} is the σ-field generated by all available information through time (t-1). The setup outlined in (17) and (18) is very general and allows for a variety of models. If each element of H_t depends on q lagged values of ε_t and p lagged values of H_t, the model is then a Multivariate Generalized Autoregressive Heteroscedasticity model of order (p,q) or in short MGARCH(p,q). As simple as the parameterisation is in the univariate case, as many problems rise in the multivariate case. The next section of this chapter will discuss the parameterisation of the MGARCH(p,q) regression model.

3.3 Parameterisation

To conduct a parametric analysis in an empirical work on the basis of (17) and (18), is it necessary to specify a parameterization for the conditional mean and variance but this section concentrates only on the parameterization of the conditional variance equation. There are a number of possible parameterizations and the following presents the vector representation and the constant correlation model and gives the parameterisations in terms of a MGARCH(p,q) model.

The vector representation

The following is defined as the vector representation

$$vech(H_t) = C_0 + C_1 vech(x_t x_t') + \sum_{i=1}^{q} A_i \; vech(\varepsilon_{t-i} \varepsilon_{t-i}') + \sum_{j=1}^{p} B_j \; vech(H_{t-j}) \tag{19}$$

where vech(·) is the vector operator which stacks the lower portion of a symmetric matrix, C_0 is a (N^2x1) parameter vector, C_1 is a (N^2xK^2) parameter matrix, and A_i and

B_j are parameter matrices each with ($N^2 x N^2$) parameters. In a simple 2-equation GARCH(1,1) model without exogenous variables, the model in (9) becomes:

$$H_t = \begin{bmatrix} h_{11.t} \\ h_{12.t} \\ h_{21.t} \\ h_{22.t} \end{bmatrix} = \begin{bmatrix} c_{01} \\ c_{02} \\ c_{03} \\ c_{04} \end{bmatrix} + \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \varepsilon^2_{1.t-1} \\ \varepsilon_{1.t-1}\varepsilon_{2.t-1} \\ \varepsilon_{2.t-1}\varepsilon_{1.t-1} \\ \varepsilon^2_{2.t-1} \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{bmatrix} \begin{bmatrix} h_{11.t-1} \\ h_{12.t-1} \\ h_{21.t-1} \\ h_{22.t-1} \end{bmatrix}$$

Notice that in this direct formulation of (9) there appear to be 36 ($(p+q)N^4+N^2$) parameters to be estimated even without any exogenous variables. Even though many of these parameters are superfluous, a relatively simple model results in an enormous amount of parameters. The number of unique parameters in (4), with K = 0, equals $\frac{1}{2}N(N+1)[1+N(N+1)(p+q)/2]$ i.e. a MGARCH(1,1) model with N = 10 the result is 6105 parameters. It is obvious that this calls for simplification, if it is expected to show anything of empirical interest.

The constant correlation model

Although the above-mentioned models are of theoretical interest, they have not shown any empirical usefulness when applied to MGARCH models, with more than a very modest number of equations. The aim in this paper is to estimate MGARCH models with 10 and 11 equations, and, therefore, a specification with the potential for achieving this is needed. Bollerslev (1990) recommends a simple model, the constant correlation model, CC-model. The CC-model has time varying conditional variances and covariances, but the conditional correlations are assumed to be constant. The general setup from section 3.2 is restated here for convenience.

$$\varepsilon_t | \psi_{t-1} = y_t - E[y_t | \psi_{t-1}] \sim N(0, H_t) \qquad (20)$$

$$\mathrm{Var}(\varepsilon_t | \psi_{t-1}) = H_t \qquad (21)$$

where the ijth element in H_t is denoted h_{ijt}, y_{it} is the ith element in y_t. The conditional correlation is a scale invariant measure of how y_{it} coheres with y_{jt}

$$\rho_{ijt} = \frac{h_{ijt}}{\sqrt{h_{iit}h_{jjt}}} \quad , \qquad \text{where } -1 \leq \rho_{ijt} \leq 1 \tag{22}$$

it is possible to rewrite this as

$$h_{ijt} = \rho_{ij}\sqrt{h_{iit}h_{jjt}} \tag{23}$$

in (23), the time varying conditional covariance is taken as proportional to the square root of the product of the corresponding two time varying conditional variances. The proportionality factor is the conditional correlation, which is assumed to be time invariant. The validity of this last assumption, and thus the validity of (23), remain, of course, an empirical question. This assumption has been tested in e.g. Baillie and Bollerslev (1990) and is generally accepted. Assume that the conditional variance can be decomposed into

$$h_{iit} = \omega_i \sigma_{it}^2 \tag{24}$$

where ω_i is a positive time invariant scalar and $\sigma_{it}^2 > 0$ for all t. Given (23) and (24), the variance-covariance matrix can be partitioned into

$$H_t = \Sigma_t \Gamma \Sigma_t \tag{25}$$

with Σ_t a (NxN) stochastic diagonal matrix with typical elements σ_{it} and Γ a (NxN) time invariant matrix with typical element $\rho_{ij}\sqrt{\omega_i \omega_j}$. In matrix notation it takes the following form

$$H_t = \begin{bmatrix} \sigma_{1t} & & & \\ & \sigma_{2t} & & \\ & & \ddots & \\ & & & \sigma_{NT} \end{bmatrix} \begin{bmatrix} \rho_{11}\omega_1 & \rho_{12}\sqrt{\omega_1\omega_2} & \cdots & \cdots & \rho_{1N}\sqrt{\omega_1\omega_N} \\ \rho_{21}\sqrt{\omega_2\omega_1} & \rho_{22}\omega_2 & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ \rho_{N1}\sqrt{\omega_N\omega_1} & & & & \rho_{NN}\omega_N \end{bmatrix} \begin{bmatrix} \sigma_{1t} & & & \\ & \sigma_{2t} & & \\ & & \ddots & \\ & & & \sigma_{NT} \end{bmatrix}$$

As mentioned above, in order for any parameterization to be reasonable it is required that H_t is positive definite. This is the case if each of the N conditional variances are well-defined and at the same time Γ is p.d. It is thus assumed that each σ_{it}^2 is following a GARCH(p,q) process.

That the correlations are assumed to be constant greatly simplifies the inference procedures, and several studies have found it to be a reasonable empirical working hypotheses; see, for instance, Ballie and Bollerslev (1990), Kroner and Classens (1991) and Ng (1991).

3.4 Estimation of a MGARCH(p,q) model

The method of estimation of a MGARCH(p,q) model is Maximum likelihood and the log likelihood function is derived in the following way. The log likelihood for the general model is

$$L(\theta) = -\frac{TN}{2}\log 2\pi - \frac{1}{2}\sum_{t=1}^{T}\left(\log|H(\theta)_t| + \varepsilon(\theta)_t' H(\theta)_t^{-1}\varepsilon(\theta)_t\right) \tag{26}$$

With θ including the unknown parameters to be estimated, this part of the notation is suppressed further on for the sake of simplicity. By use of equation (25) and rewrite

$$L(\theta) = -\frac{TN}{2}\log 2\pi - \frac{1}{2}\sum_{t=1}^{T}\log|\Sigma_t\Gamma\Sigma_t| - \frac{1}{2}\sum_{t=1}^{T}\varepsilon_t'(\Sigma_t\Gamma\Sigma_t)^{-1}\varepsilon_t \tag{27}$$

Now define $\tilde{\varepsilon}_t = \Sigma_t^{-1}\varepsilon_t$ as a (Nx1) vector of standardized residuals, and note the following

$$-\frac{1}{2}\sum_{t=1}^{T}\log|\Sigma_t\Gamma\Sigma_t| = -\frac{1}{2}\sum_{t=1}^{T}\left(\log|\Sigma_t| + \log|\Sigma_t|\right) - \frac{T}{2}\log|\Gamma|$$
$$= \sum_{t=1}^{T}\log|\Sigma_t| - \frac{T}{2}\log|\Gamma| \tag{28}$$

Use this in (27) to get the final log likelihood function

$$L(\theta) = -\frac{TN}{2}\log 2\pi - \frac{T}{2}\log|\Gamma| - \sum_{t=1}^{T}\log|\Sigma_t| - \frac{1}{2}\sum_{t=1}^{T}\tilde{\varepsilon}_t'\Gamma^{-1}\tilde{\varepsilon}_t \tag{29}$$

This is the likelihood function maximized in the work with the final model

$$y_{it} = \mu_i + \varepsilon_{it} \qquad i=1...N \qquad t=1...T$$
$$h_{iit} = \omega_i + \sum_{l=1}^{p}\alpha_{it}\varepsilon_{it-1}^2 + \sum_{l=1}^{q}\beta_{it}h_{iit-1} \tag{30}$$
$$h_{ijt} = \rho_{ij}\sqrt{(h_{iit}h_{jjt})}$$

It should be noticed that in the MGARCH model the information matrix obtained under the assumption of conditional normality is block diagonal between the parameters in the conditional mean and variance functions of the model. The implication of this is that consistent but not efficient estimates can be obtained in a two stage manner. Of course, to achieve fully efficient estimates, a ML procedure is called for.[4]

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[4]The software used in the estimations is RATS 4.0 and this package provides an algorithm (BFGS) for the purpose of maximizing (20).

4. Data analysis

4.1. Data samples preliminary data analysis

The data consists of two samples, an exchange rate sample and a terms of trade sample. The exchange rate sample takes the form of weekly observations of 12 currencies against the Danish kroner. A full list of currencies and their abbreviations are found in Appendix A. The exchange rate sample ranges from 1981:52 to 1992:9 a total of 532 observations. Monthly data is used for terms of trade (TOT), from December 1981 to January 1992, which is a total of 121 observations[5].

The univariate linear GARCH models

As for other speculative prices, traditional time series models have not been able to capture the stylized facts of short-run exchange rate movements, such as their continuous periods of volatility and stationarity together with their leptokurtic unconditional distributions. ARCH models are ideally suited to modelling such behaviour. The descriptive validity of the univariate ARCH and GARCH models in characterizing short-run exchange rate dynamics have already been well documented, see for instance Baillie and Bollerslev (1989), Bollerslev (1987) and Milhøj (1987).

The ARCH(q) model explicitly allows for temporal dependence by the parameterization of the conditional variance as a linear function of the past q squared residuals. In many applications a more parsimonious representation than the ARCH(q) models is often obtained by the GARCH(p,q) model which is outlined in section 3.1.

In the following is estimated univariate GARCH(1,1) models for the exchange rate depreciations and terms of trade using a parametric estimation method. The univariate ARCH model allows the current conditional variance of a time series to depend on lagged squared residuals in an autoregressive manner. This means that in periods with large unexpected shocks to the variable its estimated variance will increase, and during periods with relative stability its estimated variance will decrease. The results are reported in Table II.

[5] There are missing data points in the TOT series from The Statistical Bureau in Denmark (Danmarks Statistik). They are missing for January, February, April, May, July, and August in 1988. The missing data points are substituted by points generated in the following way. The TOT from January 1977 to December 1987 are used to estimate the best-fitting ARIMA model and afterwards to forecast January and February 1988. On this updated sample a new ARIMA analysis is performed and so on. By this procedure a complete data set for TOT has been obtained.

Table II. Univariate GARCH(1,1) estimation results

	BEF	CAD	CHF	DEM	ESB	FRF
Mean const.	0.097 (0.035)	0.158 (0.030)	-0.071 (0.024)	0.035 (0.009)	0.030 (0.016)	-0.076 (0.050)
Var. const.	0.113 (0.048)	0.033 (0.004)	0.201 (0.043)	0.105 (0.003)	0.084 (0.011)	0.066 (0.023)
ε^2_{t-1}	0.080 (0.035)	0.127 (0.019)	0.340 (0.066)	0.003 (0.001)	1.087 (0.059)	-0.010 (0.003)
h_{iit-1}	0.719 (0.118)	0.860 (0.014)	0.022 (0.145)	-0.984 (0.005)	0.089 (0.047)	0.787 (0.078)

Table II. (cont.) Univariate GARCH(1,1) estimation results

	GBP	ITL	JPY	NLG	USD	XEU	TOT
Mean const.	-0.023 (0.036)	-0.021 (0.011)	0.086 (0.039)	-0.010 (0.007)	0.001 (0.059)	-0.021 (0.010)	0.051 (0.057)
Var. const.	0.063 (0.014)	0.041 (0.048)	0.111 (0.031)	0.012 (0.014)	0.366 (0.087)	0.006 (0.001)	4.306 (0.553)
ε^2_{t-1}	0.104 (0.026)	0.572 (0.053)	0.157 (0.045)	1.050 (0.095)	0.207 (0.054)	0.218 (0.036)	-0.047 (0.027)
h_{iit-1}	0.822 (0.032)	0.167 (0.068)	0.741 (0.054)	0.275 (0.024)	0.605 (0.071)	0.741 (0.028)	-0.930 (0.304)

Notes ( ) are standard deviations.

It is interesting to note that for all individual exchange rate depreciations significant ARCH effects, parameters to ε^2_{it-1} exist in the conditional variance equation and for the majority also significant parameters to h_{iit-1} at the 5% level. Thus, it seems reasonable to reject the homoskedastic model. There are signs of IGARCH in CAD. Integrated GARCH means that periods with little (large) variance are persistent. The estimated parameter values to ε^2_{it-1} and h_{iit-1} is used as starting values in the programs for estimating the multivariate GARCH models.

4.3 The Danish foreign debt

This section does not attempt to do anything other than provide a very brief summary of the trends in the Danish foreign debt, thus it does not attempt to provide a more extensive examination of causes and consequences.

In Denmark, a balance of payment deficit has been the rule rather than the exception. Such a deficit can usually be closed through importing either private or government capital import or by spending the reserves of foreign currency which have been accumulated. Indeed, the need for foreign financing is a result of a balance of payment deficits, and, equally, government borrowing is normally seen as a solution to this. Just as the private borrowing has varied in the 1980s, so has government borrowing. However, as private borrowing is increased, the amount of foreign currency the government has to raise is decreased, given that reserves and debt are constant. Thus, government borrowing can be seen as a residual which is spent on closing the balance of payment deficit.

The development of the Danish government foreign debt from the beginning of the 1980s until the end of 1991 will now be described. At the beginning of the period, the foreign debt increased rapidly, and even doubled between 1980 to 1983, due to the large balance of payment deficit which occurred. Indeed, the yearly deficits ranged from 12 to 19 billion DKK. Exchange rate adjustments were another cause of this rise in foreign debt, especially the appreciation of the USD in the early 1980s, because at that time a large part of the debt was denominated in USD.

From 1984 onwards, the trend reversed and there was a reduction in the government foreign debt. This was in large part due to the fact that private and public net capital import increased significantly and it was even larger than the balance of payment deficit in some years -with the result that towards the end of the period, a balance of payment surplus was produced. In 1991, no new long duration debt was obtained, and only at the end of the year were a few commercial papers acquired. Indeed, the foreign government debt was reduced to 92 billion DKK ultimo 1991. The reason for this reduction can be found in the 14 billion DKK surplus in the balance of payments and a reduction in the foreign reserves. The traditional pattern with the large yearly balance of payment deficits had been broken, and over recent years, a surplus has been obtained.

In 1991, debt management was moved from the Ministry of Finance to the Central Bank. Placing the debt department in the central bank leads to some advantages, such as administration via the coordination of exchange rate assets and liabilities, i.e. the management of net foreign debt[6].

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[6] Foreign debt minus foreign reserves.

Foreign debt and its allocation between currencies

Since the breakdown of the Bretton-Woods exchange rate regime - at the beginning of the 1970s - exchange rates have become more unstable. This is one reason why Denmark entered the "snake" exchange rate arrangement, and in 1979 became a member of the EMS, which ensures that the exchange rates involved only fluctuate within a band. However, relations between the EMS currencies and the USD and JPY have continued to change over the years. See e.g. Figure 1 for a review of the USD exchange rate over the last 10 years. In Appendix B the other exchange rates can be found.

As the exchange rates fluctuate over time, the foreign debt allocation between currencies also changes, see the Table III, as the aim of the Central Bank is to minimize risk. The total exchange rate risks depend not only on the risk in each currency but also on the correlation between the currencies. Therefore, it is possible to reduce risk by allocating the borrowing between different currencies. As can be seen in Table III, the allocation between currencies has changed in the last ten years. The debt has changed in favour of less debt denominated in USD and an increasing share in European currencies. In the period 1980-1983, the USD share was increased from 44% to 67%, but since 1983 it has declined to 13% in 1990 and at the end of 1991, it was 19%.

Table III.

	82	83	84	85	86	87	88	89	90	91
USD	64	67	54	45	46	35	27	24	13	19
DEM	15	13	15	17	18	21	24	26	31	31
CHF	8	6	7	11	10	13	16	15	18	17
JPY	7	8	13	13	8	11	10	9	3	2
XEU	0	0	1	3	5	8	12	15	15	20
NLG	3	2	3	4	5	3	3	3	3	2
GBP	1	2	5	5	3	3	2	1	1	2
FRF	0	0	1	1	2	2	2	3	6	6
DKK	0	0	0	0	1	2	2	2	7	1
OTHERS	2	2	1	1	2	2	2	2	2	1

Note: The Danish government foreign debt allocation, between currencies at the end of the years from 1981-1991, in percent. Source SLOG publications from the Danish Central Bank. For a full list of currency abbreviations see Appendix A.

The large USD share and the JPY share in the Danish debt portfolio made it very sensitive to exchange rate fluctuations. This is the reason why the USD share was reduced and the exchange rate risk was spread out among different currencies. When the USD appreciates, the value of debt denominated in USD increases, and thus it would be preferable to get out of the USD debt. This happened in the 1980s. As a result, a larger share of European currencies is found in the Danish foreign debt portfolio. The amount of DEM, CHF and XEU has been steadily increased over the years.

The large DEM share can be explained by the great possibility of intervention in DEM. Having the FRF in the portfolio has from a historical point of view, given an advantage in respect to interest compared to the DEM. The share of XEU increased from 15 to 20% in 1991; this can be attributed to the reduced foreign debt, which, not having occurred in XEU, automatically led to an increase in the share of XEU.One thing which should be noted in this analysis is that the Central Bank places some restrictions on its preferences in allocation between currencies. This is to avoid the gearing of debt and reserves[7], as speculative behaviour is not part of the goal of managing the foreign debt portfolio.

The administration of the foreign debt portfolio is caused by the exchange rate risk, but other types of risks also exist, such as e.g. interest rate sensitivity, allocation of the duration of the foreign debt, liquidity and credit risks. In relation to the interest rates, it can be observed that the international interest rates declined in the 1980s. This made the government change their loans with high interest rate to loans with a lower interest rate and a longer duration. The interest rates on European currency loans are lower than the interest rate on loans denominated in USD, because the exchange rate risk is lower as a consequence of the EMS collaboration between the EEC countries. The share of loans at fixed interest rates was increased in 1982. Loans issued in USD are for the majority issued with variable interest rate, which makes the debt portfolio sensitive to both exchange rates and interest rate fluctuations.

Denmark started eliminating restrictions on the capital market in the 1960s and the last restriction was dismissed in 1988. The distinction between borrowing inland and abroad has thereby been weakened.In the 1980s, a rising global integration of the capital markets occurred, and new financial instruments appeared in the financial markets e.g. swaps, options, dual-currency bonds and commercial-papers. The variety of new instruments reduced the costs of obtaining loans on the foreign markets. One of the most popular innovations in the financial markets has been that of swaps. When a swap contract is made, the two agents exchange future payments, the possible reasons for this agreement are that the agents involved have e.g. different creditworthiness, expectations

[7] Gearing means that the debt is increased more in currencies where reduced costs are expected, which is favourable with respect to the reserves. And the reserves are increased in currencies with an expected high gain.

on future exchange rates or a desire to hedge the existing portfolio to reduce the risk. Since 1986, the Central Bank has used isolating swaps to reduce risk, and this is done e.g. to exploit favourable market situations in a currency where no further obligations are wanted. For example, the activity on the market for swaps in 1991 was concentrated on interest rate and currency- swaps in four currencies: USD, DEM, CHF and JPY. To maintain the USD share of the foreign debt at a low level, swaps out of USD and into DEM were carried out in particular.

Other interesting things happened in the financial markets in the 1980s, e.g the Eurokroner bond was introduced. A bond in Eurokroners was issued in 1985 for the first time, it gave an extra possibility of currency diversification. Bonds denominated in DKK are bought by both Danes and currency- foreigners. When currency-foreigners buy DKK bonds, the reserves are increased, just as if it was a foreign loan made by Denmark abroad. Today, the amount of DKK bonds in foreign investors' portfolios amount to more than 100 billion DKK, with Germany as the greatest demander.

5. Estimation results and the optimal portfolios

This section summarizes the results from the various estimated multivariate GARCH models. Additionally, it presents the optimal portfolio shares of each exchange rate, calculated on the basis of equation (10) in Section 2. It is worth stressing that the estimated MGARCH models are interesting simply as basic and convenient statistical tools for summarizing the time series dependence in the data.

From an inspection of the correlation matrix of weekly exchange rate depreciations given in Appendix B Table 2, the following is obtained. The CAD is almost perfectly correlated with the USD. This suggests that the CAD adds no information (and hedging potential) beyond that already provided by the USD. The same can be said for NLG and DEM. Therefore, NLG is also dropped from the analysis. This leaves us with ten exchange rate depreciating series and the TOT change series.

First, the multivariate GARCH models are estimated. Secondly, six different portfolios with four, seven, and ten currencies are calculated. To obtain each portfolio two multivariate GARCH models have to be estimated, one which includes the terms of trade and one which does not.

5.1 The multivariate GARCH model with ten currencies

Let us begin with a system for ten exchange rate depreciations and estimate a GARCH (1,1). The results are reported in Table IV.

Table IV. Multivariate GARCH(1,1) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	-0.047 (0.013)	0.011 (0.028)	0.053 (0.001)	-0.029 0.018	-0.002 (0.003)
Var. const.	0.182 (0.001)	0.078 (0.042)	0.242 (0.002)	0.147 (0.010)	0.068 (0.000)
ε^2_{it-1}	6.206 (0.134)	0.137 (0.008)	0.019 (0.000)	1.834 (0.033)	-0.010 (0.000)
h_{iit-1}	0.348 (0.020)	-0.492 (0.034)	-0.821 (0.002)	0.226 (0.031)	0.792 (0.000)
Q(10)	7.43	65.59*	32.60*	40.71*	8.64
Q2(10)	0.05	17.07	14.09	1.31	0.11

Table IV (cont.) Multivariate GARCH(1,1) estimation results

	GBP	ITL	JPY	USD	XEU
Mean const.	-0.274 (0.009)	-0.028 (0.004)	0.042 (0.054)	-0.173 (0.069)	-0.025 (0.001)
Var. const.	-0.173 (0.002)	0.093 (0.002)	1.998 (0.034)	4.819 (0.083)	0.017 (0.000)
ε^2_{it-1}	0.156 (0.002)	1.423 (0.054)	0.322 (0.038)	-0.096 (0.014)	0.036 (0.004)
h_{iit-1}	0.848 (0.003)	0.247 (0.027)	-0.071 (0.050)	0.123 (0.059)	0.866 (0.002)
Q(10)	44.80*	32.54*	37.70*	52.70*	27.63*
Q2(10)	14.74	3.39	30.61*	39.95*	3.28

Notes( ) are standard deviations. Final Log L -612.70. Q(10) and Q2(10) are Q-statistics on serial correlation in the standardized residuals in levels and in squares respectively. A * indicate rejection of the null of no serial correlation at a five percent significance level.

The general outcome of the estimated models at a five percent significant level are the following:

-The estimated parameters to ε^2_{it-1} are significantly different from zero for all exchange rate depreciations.

-The estimated parameters to the lagged conditional variance, h_{iit-1} are always significantly different from zero, except for JPY.

-The constant in the variance equations is in general positive and significant, and the constant in the means is significant for the majority of exchange rate depreciations.

-Unfortunately, a few negative ARCH parameter estimates are obtained which contradict the assumptions mentioned in Section 3.

These findings suggest that the variances and covariances change through time and that an ARCH estimation procedure should give better covariance estimates at any point in time than OLS.

When the constant in the mean equation is significantly positive, it captures the upward trend in exchange rates, while a significant negative value captures a negative trend in exchange rates. Additionally, the constant term is insignificant, so there is no trend in the exchange rate series.

It is necessary to check whether the estimated MGARCH model is successful or not. A reasonable measure of success is to check if the standardized residuals are characterised by white noise behaviour. If this is the case, the model has successfully captured the ARCH phenomenon in the series. If not, the model must be rejected.

Testing the residuals for linear dependence up to an order of ten lags with a Ljung-Box test is reported as Q(10) in Table IV. The MGARCH estimation does not alter the conclusion about autocorrelation from the results presented in section 4. Therefore, an autoregressive term is added to the mean equations in the multivariate GARCH(1,1) system, to capture this autocorrelation.

Q2(10) in Table IV. is a test for serial dependence in the squared standardized residual series from the mean equation. The test shows that the ARCH effects we found in the exchange rate depreciations series, reported in section 4, are removed from BEF, CHF, GBP and DEM. This indicates that the MGARCH model has removed some but not all of the ARCH effects.

There is no sign of IGARCH in the system. This has been tested by a Wald test. Restricting the parameters in each conditional variance equation to sum to one at the same time is very significantly rejected. When treating the equations one by one only the GBP appear to be integrated in the variance, so this does not open up to the possibility of copersistence in variance. The test results are shown in Hong (1988) to be asymptotically normal. The results of including an autoregressive term in the specification of the mean in the ten equation model are presented in Table V.

Table V. Multivariate GARCH(1,1) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	-0.015 (0.010)	-0.010 (0.026)	0.011 (0.002)	0.008 (0.018)	-0.046 (0.006)
y_{it-1}	0.058 (0.003)	0.215 (0.053)	0.225 (0.007)	0.117 (0.060)	0.057 (0.002)
Var. const.	0.163 (0.001)	0.309 (0.033)	0.249 (0.002)	0.157 (0.018)	0.069 (0.000)
ε^2_{it-1}	-0.012 (0.001)	0.438 (0.102)	0.019 (0.000)	2.154 (0.059)	-0.009 (0.000)
h_{iit-1}	0.477 (0.021)	0.248 (0.036)	-0.802 (0.002)	0.130 (0.043)	0.796 (0.000)
Q(10)	14.85	22.09*	24.15*	21.97*	5.26
Q2(10)	1.66	10.59	13.75	1.36	0.21

Table V. (cont.) Multivariate GARCH(1,1) estimation results

	GBP	ITL	JPY	USD	XEU
Mean Const.	-0.050 (0.007)	-0.027 (0.006)	0.044 (0.048)	0.014 (0.056)	-0.016 (0.001)
y_{it-1}	0.188 (0.010)	0.216 (0.037)	0.260 (0.048)	0.306 (0.045)	0.189 (0.005)
Var. const.	0.202 (0.003)	0.079 (0.002)	1.886 (0.029)	1.167 (0.103)	0.019 (0.000)
ε^2_{it-1}	0.020 (0.007)	0.392 (0.160)	0.134 (0.066)	0.457 (0.099)	0.008 (0.003)
h_{iit-1}	0.885 (0.003)	0.441 (0.032)	-0.069 (0.061)	0.460 (0.046)	0.857 (0.002)
Q(10)	15.37	12.04	7.77	12.65	16.33
Q2(10)	48.59*	4.11	27.52*	9.45	5.34

Notes ( ) are standard deviations. Final Log L -388.37. Q(10) and Q2(10) are Q-statistics on serial correlation in the standardized residuals in levels and in squares respectively. A * indicate rejection of the null of no serial correlation at a five percent significance level.

The conclusions are altered to some extent; there are fewer insignificant estimates on the parameters and, especially, none of the AR-terms are insignificant. There are fewer violations of the above-mentioned non-negativity constraint in the estimated conditional variance. The Q(10) statistics indicate that the model with the AR-term is able to remove some serial correlation. The main conclusion with regard to ARCH effects is that some are eliminated. A formal LR test leads to the conclusion that the model with AR-term in the mean is to be preferred.

Turning our attention to the GARCH(1,1) models, where the TOT is added, gives an 11 equation system which has to be estimated. Terms of trade are only available monthly which means that monthly covariances must be used. When data is less frequently available the ARCH effect is often not as important. The same pattern of conclusions as reported for the GARCH(1,1) is achieved, see Table 7 in Appendix B. Expanding the system by an AR term in the mean equation brings significant parameter estimates to all the AR terms. The results are reported in Table 8. Performing a LR test makes us conclude that the model with AR terms is to be preferred.

5.2 The multivariate GARCH model with seven currencies

The second category of models which is formulated is multivariate GARCH(1,1) for seven exchange rate depreciations. Compared to the models outlined above we have now deleted three EMS currencies; BEF, ESB, and ITL. Thus, we have no exchange rate depreciation series included with the IGARCH behaviour we found in Section 4.2. The first observations from the results reported in Table 9 and 10 in Appendix C are:

-The constant in the variance equation is always positive and highly significant, but the constant in the mean equation is less significant compared to the models above.

-The parameters to the ARCH terms are always significant and very few problems with the negativity constraint are obtained, which is different from the results of the 10 equation estimation.

Adding an AR term to the mean equation changes the above-mentioned results very little, although the AR term is always significant, see Table VI.

Table VI. Multivariate GARCH(1,1) estimation results

	CHF	DEM	FRF	GBP
Mean const.	0.010 (0.025)	0.031 (0.011)	-0.007 (0.018)	-0.028 (0.039)
$y_{i\,t-1}$	0.209 (0.050)	0.133 (0.027)	0.010 (0.004)	0.101 (0.030)
Var. const.	0.126 (0.065)	0.186 (0.011)	0.067 (0.001)	0.112 (0.024)
$\varepsilon^2_{i\,t-1}$	0.320 (0.120)	0.007 (0.003)	-0.010 (0.000)	0.049 (0.016)
$h_{ii\,t-1}$	0.616 (0.141)	-0.938 (0.022)	0.791 (0.003)	0.901 (0.020)

Table VI. (cont.) Multivariate GARCH(1,1) estimation results

	JPY	USD	XEU
Mean Const.	0.063 (0.050)	0.004 (0.063)	0.007 (0.012)
$y_{i\,t-1}$	0.247 (0.045)	0.301 (0.043)	0.117 (0.022)
Var. const.	0.199 (0.075)	0.762 (0.273)	0.011 (0.002)
$\varepsilon^2_{i\,t-1}$	0.258 (0.097)	0.417 (0.127)	0.013 (0.005)
$h_{ii\,t-1}$	0.769 (0.067)	0.565 (0.105)	0.890 (0.018)

Notes( ) are standard deviations. Final Log L -348.45

This indicates that the last mentioned model is to be preferred of the two GARCH(1,1) models.

The estimation results for the 8 equation system, seven exchange rate depreciations and the term of trade changes are reported in Table 11 and 12 in Appendix B. The only important difference to the above-mentioned results is that none of the parameters to the lagged exchange rate depreciations and the term of trade changes series is significant.

5.3 The multivariate GARCH model with four currencies

The third type of model is a four equation system with CHF, DEM, JPY and USD. CHF is entailed because it is a European currency which does not form part of the EMS. The USD and JPY are chosen because they are the greatest non-European currencies and very powerful worldwide and the DEM is the biggest currency in the EMS, and as a result, it is included. The estimation outcomes are presented in Table VII. and VIII.

Table VII. Multivariate GARCH(1,1) estimation results

	CHF	DEM	JPY	USD
Mean const.	0.000 (0.027)	0.032 (0.011)	0.069 (0.051)	-0.010 (0.074)
Var. const.	0.183 (0.147)	0.212 (0.016)	0.213 (0.082)	0.872 (0.351)
$\varepsilon^2_{i\,t-1}$	0.462 (0.216)	0.006 (0.002)	0.306 (0.101)	0.423 (0.146)
$h_{ii\,t-1}$	0.476 (0.316)	-0.984 (0.008)	0.747 (0.065)	0.560 (0.117)

Notes ( ) are standard deviations. Final Log L -393.34

Table VIII. Multivariate GARCH(1,1) estimation results

	CHF	DEM	JPY	USD
Mean const.	0.004 (0.026)	0.024 (0.012)	0.059 (0.051)	0.005 (0.067)
$Y_{i\,t-1}$	0.224 (0.055)	0.169 (0.041)	0.253 (0.049)	0.337 (0.050)
Var. const.	0.148 (0.095)	0.203 (0.016)	0.196 (0.073)	0.717 (0.270)
$\varepsilon^2_{i\,t-1}$	0.347 (0.148)	0.004 (0.002)	0.254 (0.089)	0.414 (0.133)
$h_{ii\,t-1}$	0.568 (0.203)	-0.981 (0.009)	0.772 (0.060)	0.586 (0.104)

Notes ( ) are standard deviations. Final Log L -361.73

The general results of these regressions are:

-The ARCH parameters are significant, and only one negative parameter estimate is achieved.

-The constant in the conditional variance equations is again significant.

-The constant in the mean equations is often insignificant.

-Adding an AR term to the mean equation turns out to be significant and a LM test indicates that the general model is preferred.

Including TOT in the system changes the result in one important way, fewer ARCH terms are significant and a few of the constants in the conditional variance equation become insignificant - remember that monthly data are now considered. Including an AR term reduces the amount of significant parameters.

5.4 The optimal portfolios

Finally, the optimal portfolios are calculated by using the variance covariance matrices estimated by the GARCH(1,1) models. The portfolio share for each currency is found by multiplying the inverse covariance matrix of exchange rate depreciations with the vector of covariances between terms of trade changes and exchange rate depreciations. This is done for every quarter year from 1982:2 to 1991:4. This gives six portfolios with ten, seven, and four currencies, which are described below. The results for ten currencies are presented in Table 1 in Appendix C and a graphic representation is presented in Figure 1 below.

Optimal net foreign currency portfolio
(shares in percent - 10 currencies)

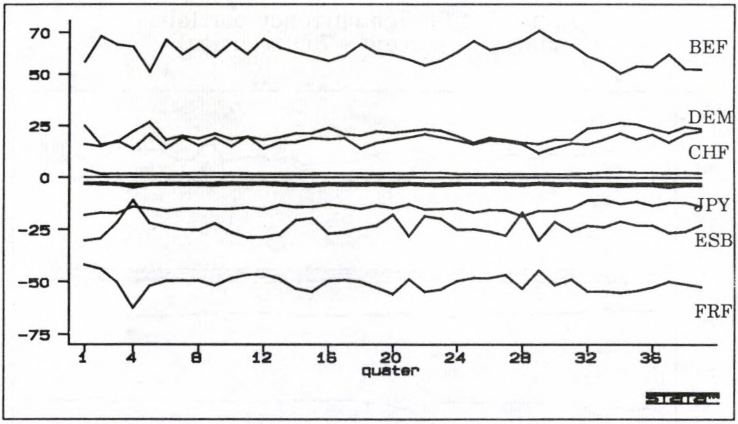

Figure 1

The positive values indicate that Denmark should borrow in these currencies and negative values in which currencies Denmark should place its reserves. It can be seen that a large share of the foreign debt should be placed in BEF, between 50 and 70 % over the data period. Denmark should also place its debt in DEM and a little less in CHF. Very little debt should be placed in GBP. Thus, it is perceived that debt should be allocated only in the EMS currencies. Reserves should be placed for the majority in FRF, in ESB and JPY. Very few reserves should be located in USD, XEU and ITL.

Adding an autoregressive term to the mean equation does not change the portfolio very much, since roughly the same results as above are obtained, see Table 2 in Appendix C. The only difference is that the series are more volatile through the time period.

The relative shares of currencies change from quarter to quarter due to the changing covariances, but the effective currency distribution of the portfolios does not change much through time once the correlations between the European currencies are accounted for. Removing ITL, ESB and BEF makes the DEM share increase considerably, which is not surprising as other EMS currencies are removed. The results are reported in Tables 3 and 4, and presented in Figure 2.

Optimal net foreign currency portfolio
(shares in percent - 7 currencies)

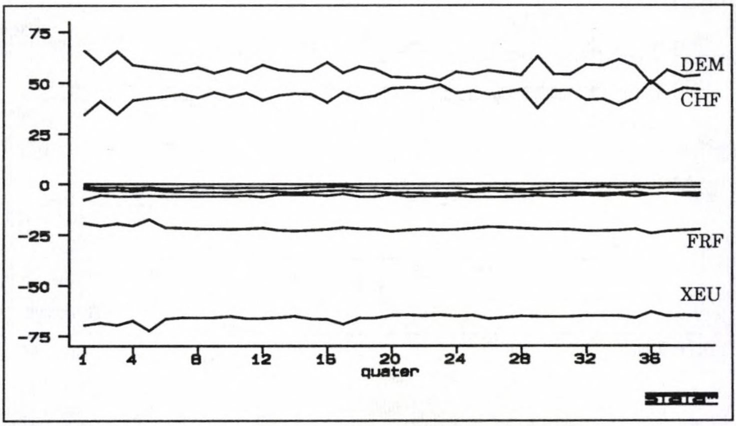

Figure 2

The CHF is also increased. This is the case for the whole period. The placement of currencies has to be done in FRF which increases a great deal together with XEU. Including an AR term changes the results very little.

In Tables 5 and 6 the results of dealing with four currencies are reported. A net debt in DEM and CHF should still result, but the share of USD in the placement of currencies increases. Sometimes the results show that borrowing in JPY is preferable. See also Figure 3.

Optimal net foreign currency portfolio.
(shares in percent - 4 currencies)

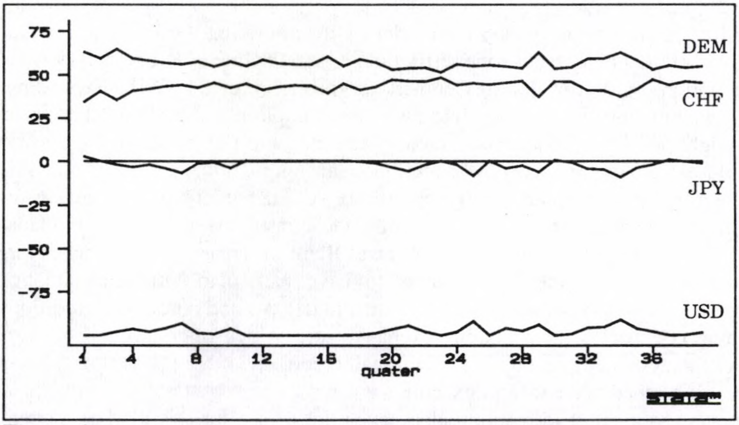

Figure 3

The most striking feature of this portfolio is the heavy weight in European currencies. The combined European share is always more stable than the individual shares. The debt should therefore always be allocated between the European currencies.

6. Conclusion and possible extensions

This paper presents a model in which a small open economy is able through the composition of its external debt to optimally hedge against fluctuations in exchange rates and the terms of trade. In the model, estimated timevarying conditional covariances were used to construct such a dynamic hedge portfolio for Denmark. Three types of debt portfolios were presented for Denmark, with the assumption being that it wanted to hedge its terms of trade against exchange rate fluctuations. The portfolio estimates using ten currencies indicated that a large share of the foreign debt should be placed in BEF, DEM, and a little in CHF, whilst the major part of the reserves should be placed in FRF and ESB. The relative shares of each currency change from quarter to quarter given the changing covariances. However, when the number of currencies is reduced to four, CHF, DEM, JPY and USD, Denmark should still keep its net debt in DEM and CHF, although the share of USD in the currencies placement would increase.

It would be interesting to extend the model by incorporating the fact that the Danish currency is limited by a target zone restriction, e.g. in the line of Krugman (1991). This is an important constraint due to Denmark' membership of the EMS. Expanding the model, by removing the constant interest rate assumption and adding other financial assets, might make the model more practical and useful to Denmark. This suggests that one could extend this work in the direction of an international Capital Asset Pricing Model, e.g. as in Engel and Rodrigues (1989). Another interesting extension of the model would be achieved by incorporating the constraints the portfolio managers actually face. One of these is that the Central Bank or Treasury has to meet foreign exchange demand, i.e the requirements to have particular currencies among the exchange reserves in order to finance government deficits and purchases. Additionally, developing countries with a floating exchange rate, which often suffer from limited access to financial markets due to institutional, credit, and other constraints, also often lack the experience necessary to execute short term hedging strategies with financial instruments. As a result they might also have a lot of use for this kind of model.

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Appendix A

Currencies in the data set and their abbreviations.

Belgian franc	BEF
Canadian dollar	CAD
Swiss franc	CHF
German mark	DEM
Spanish pesetas	ESB
French franc	FRF
British pound	GBP
Italian lire	ITL
Japanese yen	JPY
Dutch guilder	NLG
U.S. dollar	USD
European currency unit	XEU

Appendix B

Table 1. Univariate GARCH(1,1) estimation results

	BEF	CAD	CHF	DEM	ESB	FRF
Mean const.	0.097 (0.035)	0.158 (0.030)	-0.071 (0.024)	0.035 (0.009)	0.030 (0.016)	-0.076 (0.050)
Var. const.	0.113 (0.048)	0.033 (0.004)	0.201 (0.043)	0.105 (0.003)	0.084 (0.011)	0.066 (0.023)
$\varepsilon^2_{i\,t-1}$	0.080 (0.035)	0.127 (0.019)	0.340 (0.066)	0.003 (0.001)	1.087 (0.059)	-0.010 (0.003)
$h_{ii\;t-1}$	0.719 (0.118)	0.860 (0.014)	0.022 (0.145)	-0.984 (0.005)	0.089 (0.047)	0.787 (0.078)

Table 1. (cont.) Univariate GARCH(1,1) estimation results

	GBP	ITL	JPY	NLG	USD	XEU	TOT
Mean const.	-0.023 (0.036)	-0.021 (0.011)	0.086 (0.039)	-0.010 (0.007)	0.001 (0.059)	-0.021 (0.010)	0.051 (0.057)
Var. const.	0.063 (0.014)	0.041 (0.048)	0.111 (0.031)	0.012 (0.014)	0.366 (0.087)	0.006 (0.001)	4.306 (0.553)
$\varepsilon^2_{i\,t-1}$	0.104 (0.026)	0.572 (0.053)	0.157 (0.045)	1.050 (0.095)	0.207 (0.054)	0.218 (0.036)	-0.047 (0.027)
$h_{ii\;t-1}$	0.822 (0.032)	0.167 (0.068)	0.741 (0.054)	0.275 (0.024)	0.605 (0.071)	0.741 (0.028)	-0.930 (0.304)

Notes
( ) are standard deviations.

Table 2. Coefficients of correlations

	BEF	CAD	CHF	DEM	ESB	FRF	GBP	ITL	JPY	NLG	USD	XEU
BEF	1.000	0.176	0.036	0.213	0.195	0.247	0.107	0.121	-0.035	0.291	0.002	0.376
CAD		1.000	-0.239	-0.078	0.281	0.051	0.305	0.322	0.390	0.008	0.935	0.203
CHF			1.000	0.374	0.020	0.178	0.172	0.169	0.272	0.364	-0.050	0.344
DEM				1.000	0.166	0.358	0.132	0.341	0.087	0.904	-0.065	0.700
ESB					1.000	0.262	0.347	0.342	0.108	0.215	0.280	0.431
FRF						1.000	0.162	0.425	0.083	0.396	0.029	0.646
GBP							1.000	0.144	0.132	0.207	0.271	0.677
ITL								1.000	0.231	0.339	0.339	0.514
JPY									1.000	0.098	0.424	0.160
NLG										1.000	0.018	0.741
USD											1.000	0.185
XEU												1.000

Table 3. Multivariate GARCH(1,1) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	-0.047 (0.013)	0.011 (0.028)	0.053 (0.001)	-0.029 0.018	-0.002 (0.003)
Var. const.	0.182 (0.001)	0.078 (0.042)	0.242 (0.002)	0.147 (0.010)	0.068 (0.000)
$\varepsilon^2_{i\,t-1}$	6.206 (0.134)	0.137 (0.008)	0.019 (0.000)	1.834 (0.033)	-0.010 (0.000)
$h_{ii\,t-1}$	0.348 (0.020)	-0.492 (0.034)	-0.821 (0.002)	0.226 (0.031)	0.792 (0.000)
Q(10)	7.43	65.59*	32.60*	40.71*	8.64
Q2(10)	0.05	17.07	14.09	1.31	0.11

Table 3 (cont.) Multivariate GARCH(1,1) estimation results

	GBP	ITL	JPY	USD	XEU
Mean const.	-0.274 (0.009)	-0.028 (0.004)	0.042 (0.054)	-0.173 (0.069)	-0.025 (0.001)
Var. const.	-0.173 (0.002)	0.093 (0.002)	1.998 (0.034)	4.819 (0.083)	0.017 (0.000)
$\varepsilon^2_{i\,t-1}$	0.156 (0.002)	1.423 (0.054)	0.322 (0.038)	-0.096 (0.014)	0.036 (0.004)
$h_{ii\,t-1}$	0.848 (0.003)	0.247 (0.027)	-0.071 (0.050)	0.123 (0.059)	0.866 (0.002)
Q(10)	44.80*	32.54*	37.70*	52.70*	27.63*
Q2(10)	14.74	3.39	30.61*	39.95*	3.28

Notes

( ) are standard deviations. Final Log L -612.70. Q(10) and Q2(10) are Q-statistics on serial correlation in the standardized residuals in levels and in squares respectively. A * indicate rejection of the null of no serial correlation at a five percent significance level.

Table 4. Multivariate GARCH(1,1) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	-0.015 (0.010)	-0.010 (0.026)	0.011 (0.002)	0.008 (0.018)	-0.046 (0.006)
$y_{i\,t-1}$	0.058 (0.003)	0.215 (0.053)	0.225 (0.007)	0.117 (0.060)	0.057 (0.002)
Var. const.	0.163 (0.001)	0.309 (0.033)	0.249 (0.002)	0.157 (0.018)	0.069 (0.000)
$\varepsilon^2_{i\,t-1}$	-0.012 (0.001)	0.438 (0.102)	0.019 (0.000)	2.154 (0.059)	-0.009 (0.000)
$h_{ii\,t-1}$	0.477 (0.021)	0.248 (0.036)	-0.802 (0.002)	0.130 (0.043)	0.796 (0.000)
Q(10)	14.85	22.09*	24.15*	21.97*	5.26
Q2(10)	1.66	10.59	13.75	1.36	0.21

Table 4. (cont.) Multivariate GARCH(1,1) estimation results

	GBP	ITL	JPY	USD	XEU
Mean Const.	-0.050 (0.007)	-0.027 (0.006)	0.044 (0.048)	0.014 (0.056)	-0.016 (0.001)
$y_{i\,t-1}$	0.188 (0.010)	0.216 (0.037)	0.260 (0.048)	0.306 (0.045)	0.189 (0.005)
Var. const.	0.202 (0.003)	0.079 (0.002)	1.886 (0.029)	1.167 (0.103)	0.019 (0.000)
$\varepsilon^2_{i\,t-1}$	0.020 (0.007)	0.392 (0.160)	0.134 (0.066)	0.457 (0.099)	0.008 (0.003)
$h_{ii\,t-1}$	0.885 (0.003)	0.441 (0.032)	-0.069 (0.061)	0.460 (0.046)	0.857 (0.002)
Q(10)	15.37	12.04	7.77	12.65	16.33
Q2(10)	48.59*	4.11	27.52*	9.45	5.34

Notes

( ) are standard deviations. Final Log L -388.37. Q(10) and Q2(10) are Q-statistics on serial correlation in the standardized residuals in levels and in squares respectively. A * indicate rejection of the null of no serial correlation at a five percent significance level.

Table 5. Multivariate GARCH(1,2) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	0.030 (0.008)	0.008 (0.052)	0.035 (0.000)	0.007 0.046	-0.075 (0.004)
Var. const.	0.111 (0.004)	0.217 (0.038)	0.106 (0.000)	0.088 (0.021)	0.067 (0.002)
$\varepsilon^2_{i\,t\,1}$	0.656 (0.238)	0.393 (0.116)	0.003 (0.001)	1.102 (0.059)	-0.086 (0.239)
$h_{ii\;t\,-1}$	-0.012 (0.023)	0.046 (0.066)	-0.984 (0.000)	0.089 (0.035)	0.734 (0.056)
$h_{ii\;t\;2}$	0.513 (0.030)	0.523 (0.063)	-0.337 (0.397)	0.502 (0.026)	-0.398 (0.397)

Table 5. (cont.) Multivariate GARCH(1,2) estimation results

	GBP	ITL	JPY	USD	XEU
Mean const.	-0.022 (0.003)	-0.021 (0.007)	0.055 (0.075)	0.033 (0.113)	-0.021 (0.001)
Var. const.	0.063 (0.001)	0.043 (0.003)	0.120 (0.027)	0.383 (0.070)	0.006 (0.000)
$\varepsilon^2_{i\,t\,-1}$	0.105 (0.003)	0.673 (0.097)	0.005 (0.348)	0.281 (0.261)	0.217 (0.001)
$h_{ii\;t\,-1}$	0.811 (0.033)	0.186 (0.018)	0.099 (0.109)	0.075 (0.148)	0.732 (0.013)
$h_{ii\;t\,-2}$	0.073 (0.228)	0.518 (0.017)	-0.452 (0.251)	-0.249 (0.330)	0.084 (0.205)

Notes
( ) are standard deviations. Final Log L value -17739.25

Table 6. Multivariate GARCH(2,1) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	0.029 (0.000)	0.007 (0.029)	0.036 (0.000)	-0.173 (0.036)	-0.099 (0.002)
Var. const.	0.099 (0.002)	0.416 (0.020)	0.106 (0.000)	0.168 (0.009)	0.072 (0.001)
$\varepsilon^2_{i\,t-1}$	0.161 (0.112)	0.984 (0.070)	0.003 (0.000)	2.021 (0.138)	0.119 (0.023)
$\varepsilon^2_{i\,t-2}$	0.512 (0.050)	0.906 (0.449)	0.501 (0.000)	1.362 (0.120)	0.601 (0.015)
$h_{ii\,t-1}$	-0.088 (0.010)	0.529 (0.094)	-0.984 (0.000)	0.468 (0.032)	0.814 (0.004)

Table 6. (cont.) Multivariate GARCH(2,1) estimation results

	GBP	ITL	JPY	USD	XEU
Mean const.	-0.055 (0.002)	-0.087 (0.004)	-0.120 (0.043)	-0.218 (0.044)	-0.013 (0.000)
Var. const.	0.068 (0.001)	0.050 (0.001)	0.312 (0.022)	1.154 (0.083)	0.006 (0.000)
$\varepsilon^2_{i\,t-1}$	0.156 (0.007)	0.657 (0.016)	0.610 (0.043)	0.736 (0.052)	0.197 (0.003)
$\varepsilon^2_{i\,t-2}$	0.893 (0.051)	0.827 (0.045)	-0.065 (0.030)	-0.314 (0.000)	0.482 (0.003)
$h_{ii\,t-1}$	0.878 (0.007)	0.255 (0.012)	0.936 (0.046)	0.799 (0.068)	0.734 (0.001)

Notes
( ) are standard deviations. Final Log L value -2443.33

Table 7. Multivariate GARCH(1,1) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	-0.008 (0.012)	-0.020 (0.125)	-0.007 (0.008)	-0.194 (0.064)	-0.137 (0.020)
Var. const.	0.403 (0.011)	1.837 (0.306)	0.562 (0.022)	2.132 (0.176)	0.483 (0.020)
$\varepsilon^2_{i\,t-1}$	0.604 (0.113)	0.609 (0.214)	0.033 (0.034)	1.260 (0.190)	-0.002 (0.027)
$h_{ii\,t-1}$	-0.041 (0.001)	0.097 (0.110)	-0.024 (0.004)	-0.067 (0.003)	0.420 (0.014)

Table 7. (cont.) Multivariate GARCH(1,1) estimation results

	GBP	ITL	JPY	USD	XEU	TOT
mean const.	-0.347 (0.011)	-0.217 (0.026)	0.380 (0.233)	-0.110 (0.297)	-0.110 (0.008)	0.011 (0.144)
Var. const.	3.203 (0.076)	1.090 (0.036)	5.428 (0.181)	12.679 (2.798)	0.229 (0.007)	8.450 (0.209)
$\varepsilon^2_{i\,t-1}$	0.054 (0.024)	0.006 (0.093)	0.258 (0.070)	-0.177 (0.164)	0.101 (0.013)	-0.081 (0.005)
$h_{ii\,t-1}$	0.598 (0.019)	-0.004 (0.080)	0.332 (0.085)	0.398 (0.139)	0.388 (0.021)	-0.941 (0.001)

Notes

( ) are standard deviations. Final Log L value -560.12

Table 8. Multivariate GARCH(1,1) estimation results

	BEF	CHF	DEM	ESB	FRF
Mean const.	-0.017 (0.017)	-0.057 (0.103)	-0.049 (0.002)	-0.229 (0.000)	-0.212 (0.011)
$y_{i\,t-1}$	0.168 (0.008)	0.158 (0.082)	0.059 (0.004)	0.048 (0.008)	0.187 (0.019)
Var. const.	0.374 (0.008)	1.355 (0.148)	0.466 (0.011)	2.063 (0.093)	0.405 (0.010)
$\varepsilon^2_{i\,t-1}$	0.524 (0.087)	0.592 (0.138)	0.080 (0.017)	0.918 (0.130)	-0.038 (0.014)
$h_{ii\,t-1}$	-0.017 (0.000)	0.258 (0.088)	-0.040 (0.002)	-0.069 (0.001)	0.466 (0.008)

Table 8. (cont.) Multivariate GARCH(1,1) estimation results

	GBP	ITL	JPY	USD	XEU	TOT
mean const.	-0.345 (0.006)	-0.245 (0.020)	0.197 (0.119)	-0.218 (0.196)	-0.146 (0.003)	0.068 (0.028)
$y_{i\,t-1}$	0.089 (0.010)	0.075 (0.030)	0.354 (0.075)	0.159 (0.047)	0.109 (0.005)	-0.136 (0.013)
Var. const.	3.020 (0.056)	0.965 (0.019)	8.280 (0.241)	26.400 (2.504)	0.222 (0.002)	7.428 (0.236)
$\varepsilon^2_{i\,t-1}$	0.062 (0.022)	0.021 (0.022)	0.181 (0.073)	-0.077 (0.042)	0.026 (0.012)	-0.044 (0.001)
$h_{ii\,t-1}$	0.553 (0.014)	-0.035 (0.025)	-0.180 (0.022)	-0.610 (0.031)	0.336 (0.015)	-0.932 (0.002)

Notes

( ) are standard deviations. Final Log L value -544.06

Table 9. Multivariate GARCH(1,1) estimation results

	CHF	DEM	FRF	GBP
Mean const.	0.004 (0.029)	0.037 (0.012)	-0.023 (0.026)	-0.036 (0.050)
Var. const.	0.151 (0.089)	0.193 (0.012)	0.068 (0.002)	0.138 (0.035)
$\varepsilon^2_{i\,t\,1}$	0.407 (0.194)	0.008 (0.002)	-0.101 (0.001)	0.050 (0.017)
$h_{ii\,t\,1}$	0.548 (0.208)	-0.946 (0.017)	0.793 (0.007)	0.883 (0.027)

Table 9. (cont.) Multivariate GARCH(1,1) estimation results

	JPY	USD	XEU
Mean const.	0.070 (0.053)	-0.147 (0.076)	0.004 (0.014)
Var. const.	0.212 (0.083)	0.839 (0.309)	0.012 (0.001)
$\varepsilon^2_{i\,t\,1}$	0.292 (0.098)	0.403 (0.129)	0.013 (0.005)
$h_{ii\,t\,1}$	0.753 (0.066)	0.565 (0.109)	0.884 (0.014)

Notes
( ) are standard deviations. Final Log L -383.92.

Table 10. Multivariate GARCH(1,1) estimation results

	CHF	DEM	FRF	GBP
Mean const.	0.010 (0.025)	0.031 (0.011)	-0.007 (0.018)	-0.028 (0.039)
$y_{i\,t-1}$	0.209 (0.050)	0.133 (0.027)	0.010 (0.004)	0.101 (0.030)
Var. const.	0.126 (0.065)	0.186 (0.011)	0.067 (0.001)	0.112 (0.024)
$\varepsilon^2_{i\,t-1}$	0.320 (0.120)	0.007 (0.003)	-0.010 (0.000)	0.049 (0.016)
$h_{ii\,t-1}$	0.616 (0.141)	-0.938 (0.022)	0.791 (0.003)	0.901 (0.020)

Table 10. (cont.) Multivariate GARCH(1,1) estimation results

	JPY	USD	XEU
Mean Const.	0.063 (0.050)	0.004 (0.063)	0.007 (0.012)
$y_{i\,t-1}$	0.247 (0.045)	0.301 (0.043)	0.117 (0.022)
Var. const.	0.199 (0.075)	0.762 (0.273)	0.011 (0.002)
$\varepsilon^2_{i\,t-1}$	0.258 (0.097)	0.417 (0.127)	0.013 (0.005)
$h_{ii\,t-1}$	0.769 (0.067)	0.565 (0.105)	0.890 (0.018)

Notes
( ) are standard deviations. Final Log L -348.45

Table 11. Multivariate GARCH(1,1) estimation results

	CHF	DEM	FRF	GBP
Mean const.	0.076 (0.078)	0.072 (0.034)	-0.111 (0.028)	-0.130 (0.882)
Var. Const.	1.121 (0.111)	0.183 (0.018)	0.119 (0.010)	0.069 (0.050)
$\varepsilon^2_{i\,t\,1}$	0.259 (0.072)	0.382 (0.063)	0.542 (0.056)	0.014 (0.000)
$h_{ii\;t\;1}$	-0.165 (0.045)	-0.073 (0.029)	0.371 (0.019)	-0.127 (0.367)

Table 11. (cont.) Multivariate GARCH(1,1) estimation results

	JPY	USD	XEU	TOT
Mean Const.	0.402 (0.124)	-0.373 (0.234)	-0.232 (0.029)	0.049 (0.021)
Var. Const.	0.498 (0.096)	13.553 (1.832)	0.170 (0.016)	4.320 (0.056)
$\varepsilon^2_{i\,t\,1}$	0.170 (0.039)	0.114 (0.134)	0.236 (0.063)	-0.047 (0.001)
$h_{ii\;t\;1}$	0.778 (0.033)	-0.408 (0.193)	-0.025 (0.085)	-0.930 (0.001)

Notes

( ) are standard deviations. Final Log L -364.44

Table 12. Multivariate GARCH(1,1) estimation results

	CHF	DEM	FRF	GBP
Mean const.	0.073 (0.077)	0.067 (0.029)	-0.113 (0.028)	-0.173 (0.839)
$y_{i\,t\,1}$	0.014 (0.045)	-0.006 (0.056)	0.028 (0.091)	0.452 (0.509)
Var. const.	1.134 (0.095)	0.185 (0.017)	0.119 (0.010)	0.106 (0.000)
$\varepsilon^2_{i\,t\,1}$	0.262 (0.071)	0.383 (0.062)	0.545 (0.055)	0.016 (0.003)
$h_{ii\,t\,1}$	-0.161 (0.041)	-0.072 (0.028)	0.372 (0.018)	-0.201 (0.000)

Table 12. (cont.) Multivariate GARCH(1,1) estimation results

	JPY	USD	XEU	TOT
Mean Const.	0.401 (0.124)	-0.396 (0.217)	-0.227 (0.021)	0.048 (0.021)
$y_{i\,t\,1}$	0.048 (0.092)	0.052 (0.087)	-0.001 (0.053)	-0.003 (0.010)
Var. const.	0.507 (0.089)	13.768 (1.632)	0.172 (0.014)	4.323 (0.055)
$\varepsilon^2_{i\,t\,1}$	0.174 (0.036)	0.119 (0.132)	0.242 (0.059)	-0.047 (0.001)
$h_{ii\,t\,1}$	0.781 (0.030)	-0.390 (0.171)	-0.015 (0.073)	-0.930 (0.001)

Notes

( ) are standard deviations. Final Log L -363.35

Table 13. Multivariate GARCH(1,1) estimation results

	CHF	DEM	JPY	USD
Mean const.	0.000 (0.027)	0.032 (0.011)	0.069 (0.051)	-0.010 (0.074)
Var. const.	0.183 (0.147)	0.212 (0.016)	0.213 (0.082)	0.872 (0.351)
$\varepsilon^2_{i\,t\,1}$	0.462 (0.216)	0.006 (0.002)	0.306 (0.101)	0.423 (0.146)
$h_{ii\,t\,1}$	0.476 (0.316)	-0.984 (0.008)	0.747 (0.065)	0.560 (0.117)

Notes
( ) are standard deviations. Final Log L -393.34

Table 14. Multivariate GARCH(1,1) estimation results

	CHF	DEM	JPY	USD
Mean const.	0.004 (0.026)	0.024 (0.012)	0.059 (0.051)	0.005 (0.067)
$y_{i\,t\,1}$	0.224 (0.055)	0.169 (0.041)	0.253 (0.049)	0.337 (0.050)
Var. const.	0.148 (0.095)	0.203 (0.016)	0.196 (0.073)	0.717 (0.270)
$\varepsilon^2_{i\,t\,-1}$	0.347 (0.148)	0.004 (0.002)	0.254 (0.089)	0.414 (0.133)
$h_{ii\,t\,-1}$	0.568 (0.203)	-0.981 (0.009)	0.772 (0.060)	0.586 (0.104)

Notes
( ) are standard deviations. Final Log L -361.73

Table 15. Multivariate GARCH(1,1) estimation results

	CHF	DEM	JPY	USD	TOT
Mean const.	0.083 (0.124)	0.105 (0.047)	0.424 (0.236)	-0.145 (0.312)	0.108 (0.149)
Var. const.	1.809 (0.415)	0.361 (0.068)	1.277 (0.846)	19.262 (13.753)	8.539 (1.324)
$\varepsilon^2_{i\,t\ 1}$	0.429 (0.318)	0.622 (0.280)	0.306 (0.210)	-0.090 (0.306)	-0.068 (0.006)
$h_{ii\ t\ 1}$	0.114 (0.139)	-0.095 (0.040)	0.704 (0.169)	-0.056 (0.834)	-0.947 (0.017)

Notes
( ) are standard diviations. Final Log L -341.92

Table 16. Multivariate GARCH(1,1) estimation results

	CHF	DEM	JPY	USD	TOT
Mean const.	0.075 (0.126)	0.084 (0.055)	0.177 (0.224)	-0.104 (0.346)	0.091 (0.149)
$y_{i\,t\ 1}$	0.222 (0.102)	0.289 (0.141)	0.351 (0.104)	0.262 (0.108)	-0.127 (0.101)
Var. const.	1.509 (0.681)	0.403 (0.131)	0.929 (0.732)	30.653 (6.364)	7.936 (1.393)
$\varepsilon^2_{i\,t\ -1}$	0.466 (0.338)	0.337 (0.411)	0.157 (0.216)	-0.107 (0.210)	-0.050 (0.064)
$h_{ii\ t\ -1}$	0.172 (0.241)	-0.120 (0.172)	0.811 (0.164)	-0.815 (0.134)	-0.937 (0.043)

Notes
( ) are standard diviations. Final Log L -333.20

Appendix C

Table 1. Optimal portfolios, 10 currencies.

Period	BEF	CHF	DEM	ESB	FRF	GBP	ITL	JPY	USD	XEU
1982:2	55.84	15.89	24.67	-30.50	-41.83	3.60	-2.85	-18.18	-3.20	-3.45
1982:3	68.03	14.75	15.68	-29.48	-43.83	1.54	-2.60	-17.04	-3.67	-3.38
1982:4	64.10	17.49	16.79	-21.77	-50.39	1.63	-3.02	-17.43	-3.61	-3.78
1983:1	63.02	13.46	21.87	-11.00	-62.33	1.64	-3.29	-14.29	-5.05	-4.04
1983:2	50.84	20.79	26.65	-22.05	-52.02	1.72	-3.16	-15.02	-3.90	-3.84
1983:3	66.32	14.03	18.00	-23.93	-49.74	1.64	-2.73	-16.25	-3.86	-3.50
1983:4	59.41	19.08	19.89	-25.25	-49.51	1.61	-2.77	-15.15	-3.59	-3.73
1984:1	64.32	15.19	18.69	-25.39	-49.44	1.80	-2.73	-14.99	-3.65	-3.79
1984:2	58.28	18.80	20.98	-22.32	-51.74	1.94	-2.85	-15.14	-4.03	-3.92
1984:3	64.78	14.91	18.45	-26.53	-48.42	1.86	-2.64	-15.14	-3.63	-3.65
1984:4	59.34	19.39	19.53	-29.03	-46.75	1.74	-2.64	-14.60	-3.53	-3.45
1985:1	66.78	13.67	17.86	-28.67	-46.40	1.69	-2.57	-15.66	-3.37	-3.34
1985:2	62.49	16.62	19.22	-27.55	-48.63	1.67	-2.84	-13.43	-4.02	-3.52
1985:3	60.31	16.79	21.14	-20.81	-53.39	1.76	-3.28	-14.32	-4.30	-3.89
1985:4	58.30	18.84	21.15	-19.61	-54.77	1.70	-3.11	-14.17	-4.54	-3.80
1986:1	56.26	18.22	23.66	-27.15	-49.72	1.86	-2.74	-13.04	-3.74	-3.62
1986:2	58.81	18.73	20.64	-26.50	-49.24	1.82	-2.69	-13.93	-4.00	-3.64
1986:3	64.34	13.81	20.03	-24.47	-50.16	1.81	-2.67	-15.12	-3.92	-3.66
1986:4	59.95	16.42	22.00	-23.26	-52.83	1.64	-2.80	-13.63	-3.81	-3.65
1987:1	58.92	18.00	21.25	-17.93	-55.93	1.83	-3.01	-14.81	-4.43	-3.90
1987:2	56.78	19.13	22.27	-28.38	-48.78	1.81	-2.70	-12.95	-3.65	-3.54
1987:3	54.09	20.71	23.10	-18.61	-54.77	2.10	-3.08	-15.54	-4.11	-3.90
1987:4	56.30	19.22	22.50	-19.85	-53.69	1.99	-3.07	-15.32	-4.25	-3.82
1988:1	60.52	17.77	19.95	-25.22	-49.68	1.76	-2.74	-14.86	-3.83	-3.68
1988:2	65.78	15.86	16.68	-24.97	-48.26	1.67	-2.68	-16.99	-3.44	-3.67
1988:3	61.55	17.76	19.05	-25.97	-48.31	1.65	-2.74	-15.77	-3.67	-3.54
1988:4	62.99	17.43	17.91	-27.86	-46.66	1.67	-2.57	-15.92	-3.44	-3.55
1989:1	65.88	15.82	16.68	-16.97	-53.25	1.61	-3.04	-18.67	-4.00	-4.07
1989:2	70.57	11.67	16.14	-30.31	-44.52	1.62	-2.51	-16.01	-3.20	-3.46
1989:3	65.97	14.23	18.08	-21.37	-51.69	1.72	-2.84	-16.15	-4.08	-3.87
1989:4	63.93	16.23	18.14	-26.00	-48.95	1.70	-2.78	-14.90	-3.73	-3.63
1990:1	58.53	15.95	23.57	-23.30	-54.66	1.95	-2.96	-11.13	-4.36	-3.59
1990:2	55.35	18.08	24.34	-24.00	-54.57	2.23	-2.89	-10.81	-4.03	-3.70
1990:3	50.25	21.05	26.25	-21.25	-55.11	2.45	-2.91	-12.64	-4.34	-3.75
1990:4	53.76	18.39	25.58	-23.08	-54.37	2.27	-2.99	-11.61	-4.08	-3.87
1991:1	53.46	20.74	23.52	-23.15	-52.61	2.28	-2.84	-13.61	-3.99	-3.81
1991:2	59.49	16.88	21.58	-26.62	-49.89	2.05	-2.75	-12.16	-4.86	-3.73
1991:3	52.43	21.02	24.29	-26.03	-51.26	2.25	-2.78	-12.18	-4.07	-3.68
1991:4	52.13	22.18	23.49	-22.96	-52.45	2.20	-2.84	-14.03	-3.97	-3.75

Table 2. Optimal portfolio, 10 currencies, AR-term.

Period	BEF	CHF	DEM	ESB	FRF	GBP	ITL	JPY	USD	XEU
1982:2	38.24	24.39	34.02	-23.68	-52.07	3.34	-2.18	-14.01	-5.07	-2.99
1982:3	39.41	21.31	38.32	-16.33	-62.87	0.96	-2.19	-9.88	-5.44	-3.29
1982:4	53.70	19.45	24.86	-17.78	-56.73	1.99	-3.02	-14.47	-4.10	-3.90
1983:1	54.31	16.46	27.33	-8.03	-65.24	1.90	-3.08	-13.14	-6.40	-4.11
1983:2	54.19	20.30	22.81	-21.28	-51.40	2.70	-2.93	-16.44	-4.27	-3.68
1983:3	64.50	15.36	18.04	-23.22	-49.30	2.10	-2.86	-16.87	-4.14	-3.61
1983:4	60.84	17.42	19.49	-24.45	-48.83	2.26	-2.89	-16.32	-3.72	-3.80
1984:1	58.26	17.52	21.70	-22.33	-51.63	2.52	-2.94	-14.96	-4.34	-3.80
1984:2	58.34	17.58	21.97	-19.71	-53.42	2.12	-2.93	-15.76	-4.27	-3.91
1984:3	60.64	16.55	20.71	-26.76	-47.66	2.10	-2.66	-15.45	-3.91	-3.56
1984:4	59.00	17.93	20.79	-27.15	-47.24	2.28	-2.74	-15.56	-3.69	-3.61
1985:1	60.60	16.74	20.64	-26.46	-47.88	2.02	-2.65	-15.50	-3.99	-3.52
1985:2	44.20	20.94	33.13	-21.93	-55.91	1.73	-2.60	-11.20	-4.89	-3.46
1985:3	50.75	18.37	29.21	-18.22	-57.19	1.68	-2.80	-13.21	-4.84	-3.75
1985:4	37.64	22.05	39.24	-12.51	-66.15	1.07	-2.44	-9.71	-5.53	-3.66
1986:1	47.66	20.98	29.20	-23.40	-53.44	2.17	-2.67	-12.42	-4.49	-3.58
1986:2	55.48	18.07	24.61	-24.24	-51.14	1.84	-2.62	-14.36	-4.07	-3.57
1986:3	58.03	16.83	23.28	-22.55	-51.94	1.86	-2.65	-14.67	-4.60	-3.59
1986:4	54.27	19.05	24.38	-22.16	-52.29	2.29	-2.89	-14.58	-4.41	-3.68
1987:1	56.59	17.63	23.81	-16.88	-56.29	1.96	-3.00	-15.34	-4.48	-4.01
1987:2	56.33	18.52	22.91	-26.69	-48.53	2.24	-2.76	-14.49	-3.95	-3.57
1987:3	58.37	17.99	21.11	-16.78	-55.50	2.54	-3.19	-16.22	-4.32	-3.99
1987:4	57.74	17.59	22.41	-17.94	-54.76	2.26	-3.01	-15.84	-4.57	-3.88
1988:1	57.11	17.56	23.43	-23.80	-50.90	1.89	-2.68	-14.91	-4.04	-3.68
1988:2	62.23	16.23	19.50	-22.13	-50.81	2.04	-2.92	-16.44	-3.87	-3.83
1988:3	57.82	18.49	21.42	-23.25	-50.54	2.27	-2.87	-15.67	-3.98	-3.70
1988:4	61.03	17.22	19.54	-25.69	-48.12	2.21	-2.81	-16.07	-3.64	-3.67
1989:1	59.89	16.44	21.67	-13.78	-57.86	2.00	-3.20	-16.57	-4.44	-4.15
1989:2	63.31	15.80	18.69	-28.71	-45.27	2.20	-2.5[illegible]	-16.00	-4.04	-3.40
1989:3	56.63	16.43	24.92	-17.88	-55.61	2.02	-2.87	-14.81	-4.97	-3.86
1989:4	52.16	18.87	27.15	-22.15	-53.58	1.81	-2.71	-13.58	-4.30	-3.68
1990:1	48.89	19.38	29.66	-20.40	-55.85	2.08	-2.77	-12.30	-5.04	-3.64
1990:2	56.12	17.91	23.48	-23.41	-51.87	2.49	-2.90	-13.71	-4.37	-3.74
1990:3	57.41	18.17	21.95	-21.63	-52.24	2.46	-2.97	-14.83	-4.57	-3.75
1990:4	56.25	18.22	22.85	-23.99	-50.81	2.67	-2.89	-14.13	-4.47	-3.71
1991:1	62.15	16.48	19.12	-24.25	-49.14	2.25	-2.88	-16.11	-3.84	-3.78
1991:2	41.30	20.46	36.83	-18.37	-59.75	1.41	-2.40	-10.23	-5.74	-3.51
1991:3	46.98	21.19	29.69	-22.69	-54.63	2.14	-2.69	-11.94	-4.46	-3.59
1991:4	58.92	17.16	22.03	-22.94	-50.87	1.89	-2.75	-15.94	-3.75	-3.75

Table 3. Optimal portfolios, 7 currencies.

Period	CHF	DEM	FRF	GBP	JPY	USD	XEU
1982:2	34.25	65.75	-69.55	-2.19	-1.16	-7.77	-19.33
1982:3	40.88	59.12	-68.63	-3.40	-1.84	-5.60	-20.53
1982:4	34.51	65.49	-69.62	-3.17	-1.62	-5.96	-19.63
1983:1	41.38	58.62	-67.57	-3.57	-2.10	-6.09	-20.67
1983:2	42.28	57.72	-72.42	-2.83	-1.58	-5.72	-17.45
1983:3	43.17	56.83	-66.50	-3.70	-2.42	-5.93	-21.44
1983:4	44.28	55.72	-66.00	-3.94	-2.14	-6.13	-21.79
1984:1	42.60	57.40	-65.96	-4.07	-1.74	-6.08	-22.15
1984:2	45.23	54.77	-65.93	-4.08	-1.84	-5.97	-22.17
1984:3	43.02	56.98	-65.23	-4.32	-2.06	-5.96	-22.43
1984:4	45.00	55.00	-66.25	-3.88	-1.76	-5.89	-22.22
1985:1	41.37	58.63	-66.27	-3.70	-1.91	-6.37	-21.74
1985:2	43.60	56.40	-65.87	-3.89	-2.12	-5.35	-22.76
1985:3	44.43	55.57	-65.17	-4.22	-2.15	-5.33	-23.12
1985:4	44.31	55.69	-66.60	-3.74	-1.66	-5.34	-22.67
1986:1	40.09	59.91	-66.88	-3.40	-1.52	-5.83	-22.37
1986:2	45.14	54.86	-69.11	-3.21	-1.24	-4.90	-21.55
1986:3	42.24	57.76	-66.11	-3.64	-1.89	-6.32	-22.04
1986:4	43.47	56.53	-66.06	-3.59	-1.87	-6.24	-22.23
1987:1	47.11	52.89	-64.91	-4.40	-2.09	-5.19	-23.41
1987:2	47.60	52.40	-64.58	-4.22	-2.15	-6.21	-22.84
1987:3	47.11	52.89	-64.97	-4.41	-2.17	-6.13	-22.31
1987:4	48.91	51.09	-64.52	-4.62	-2.16	-5.95	-22.74
1988:1	44.70	55.30	-65.18	-4.46	-2.04	-5.75	-22.58
1988:2	45.79	54.21	-64.94	-4.12	-2.70	-6.39	-21.85
1988:3	44.12	55.88	-66.56	-3.62	-2.07	-6.41	-21.35
1988:4	45.16	54.84	-65.97	-3.90	-2.10	-6.45	-21.57
1989:1	46.39	53.61	-65.17	-3.99	-2.67	-6.26	-21.92
1989:2	37.16	62.84	-65.48	-4.21	-2.31	-5.73	-22.28
1989:3	45.89	54.11	-65.54	-3.99	-1.92	-6.14	-22.40
1989:4	46.11	53.89	-65.52	-4.00	-2.08	-5.80	-22.60
1990:1	41.33	58.67	-64.96	-4.38	-1.78	-5.61	-23.27
1990:2	41.75	58.25	-65.01	-4.38	-1.41	-5.96	-23.24
1990:3	38.62	61.38	-65.06	-4.59	-1.96	-5.37	-23.02
1990:4	42.04	57.96	-66.04	-4.00	-1.38	-6.18	-22.39
1991:1	50.67	49.33	-63.12	-5.18	-2.10	-5.08	-24.53
1991:2	44.00	56.00	-65.31	-4.61	-1.56	-4.99	-23.53
1991:3	47.07	52.93	-64.82	-4.65	-1.66	-5.80	-23.07
1991:4	46.51	53.49	-65.37	-4.42	-1.65	-6.08	-22.48

Table 4. Optimal portfolios, 7 currencies, AR-term.

Period	CHF	DEM	FRF	GBP	JPY	USD	XEU
1982:2	34.72	65.28	-69.24	-2.28	-1.25	-8.03	-19.20
1982:3	40.48	59.52	-68.52	-3.42	-1.80	-5.68	-20.58
1982:4	34.46	65.54	-69.43	-3.28	-1.74	-5.94	-19.61
1983:1	41.06	58.94	-67.93	-3.46	-1.93	-6.24	-20.43
1983:2	42.61	57.39	-72.56	-2.81	-1.56	-5.89	-17.19
1983:3	43.40	56.60	-66.61	-3.60	-2.45	-6.02	-21.31
1983:4	44.70	55.30	-65.92	-3.85	-2.31	-6.24	-21.67
1984:1	43.03	56.97	-65.85	-4.04	-1.85	-6.18	-22.08
1984:2	44.12	55.88	-65.98	-4.09	-1.89	-5.84	-22.19
1984:3	43.19	56.81	-65.24	-4.26	-2.15	-6.17	-22.18
1984:4	44.48	55.52	-66.16	-3.92	-1.83	-5.78	-22.31
1985:1	41.72	58.28	-66.11	-3.73	-2.03	-6.50	-21.63
1985:2	44.66	55.34	-65.49	-4.02	-2.20	-5.31	-22.98
1985:3	45.56	54.44	-65.00	-4.20	-2.22	-5.43	-23.15
1985:4	44.15	55.85	-66.67	-3.68	-1.72	-5.40	-22.54
1986:1	40.60	59.40	-66.73	-3.42	-1.51	-5.89	-22.44
1986:2	44.51	55.49	-69.08	-3.18	-1.37	-4.86	-21.52
1986:3	43.34	56.66	-66.11	-3.57	-1.86	-6.43	-22.02
1986:4	44.18	55.82	-65.90	-3.57	-2.01	-6.23	-22.28
1987:1	45.38	54.62	-65.09	-4.31	-2.16	-5.21	-23.23
1987:2	49.06	50.94	-64.21	-4.26	-2.27	-6.19	-23.07
1987:3	48.38	51.62	-64.52	-4.47	-2.36	-6.15	-22.50
1987:4	49.06	50.94	-64.49	-4.59	-2.25	-6.07	-22.60
1988:1	45.47	54.53	-64.87	-4.54	-2.14	-5.63	-22.81
1988:2	46.01	53.99	-64.83	-4.15	-2.72	-6.34	-21.95
1988:3	43.53	56.47	-66.45	-3.67	-2.18	-6.39	-21.31
1988:4	44.90	55.10	-65.98	-3.87	-2.18	-6.55	-21.42
1989:1	46.24	53.76	-65.19	-3.96	-2.67	-6.31	-21.87
1989:2	38.17	61.83	-65.39	-4.14	-2.38	-5.94	-22.15
1989:3	45.56	54.44	-65.38	-4.05	-2.03	-5.98	-22.56
1989:4	47.40	52.60	-65.11	-4.09	-2.21	-5.81	-22.78
1990:1	42.54	57.46	-64.67	-4.40	-1.87	-5.60	-23.46
1990:2	43.55	56.45	-64.59	-4.43	-1.55	-6.06	-23.37
1990:3	39.05	60.95	-64.89	-4.60	-2.06	-5.48	-22.98
1990:4	42.06	57.94	-65.79	-4.04	-1.49	-6.12	-22.55
1991:1	52.03	47.97	-63.14	-5.06	-2.11	-5.16	-24.53
1991:2	44.81	55.19	-64.95	-4.69	-1.71	-5.01	-23.64
1991:3	46.94	53.06	-64.61	-4.73	-1.78	-5.74	-23.15
1991:4	46.75	53.25	-65.15	-4.50	-1.73	-6.03	-22.59

Table 5. Optimal portfolios, 4 currencies.

Period	CHF	DEM	JPY	USD
1982:2	34.44	62.87	2.69	-100.00
1982:3	40.56	59.25	0.19	-100.00
1982:4	35.36	64.64	-2.06	-97.94
1983:1	40.80	59.20	-3.36	-96.64
1983:2	41.88	58.12	-1.94	-98.06
1983:3	43.29	56.71	-3.97	-96.03
1983:4	44.02	55.98	-6.68	-93.32
1984:1	42.51	57.49	-1.16	-98.84
1984:2	45.28	54.72	-0.60	-99.40
1984:3	42.48	57.52	-3.66	-96.34
1984:4	44.82	54.87	0.31	-100.00
1985:1	41.22	58.60	0.18	-100.00
1985:2	43.07	56.60	0.33	-100.00
1985:3	43.85	56.09	0.06	-100.00
1985:4	43.58	56.04	0.38	-100.00
1986:1	39.44	60.35	0.21	-100.00
1986:2	44.72	54.95	0.33	-100.00
1986:3	41.34	58.66	-0.15	-99.85
1986:4	42.93	57.07	-1.21	-98.79
1987:1	47.09	52.91	-3.58	-96.42
1987:2	46.24	53.76	-5.54	-94.46
1987:3	46.12	53.88	-1.92	-98.08
1987:4	48.39	51.47	0.14	-100.00
1988:1	43.98	56.02	-1.93	-98.07
1988:2	45.07	54.93	-8.03	-91.97
1988:3	44.28	55.53	0.19	-100.00
1988:4	45.27	54.74	-4.07	-95.93
1989:1	46.23	53.77	-2.38	-97.62
1989:2	37.26	62.74	-6.10	-93.90
1989:3	46.13	53.41	0.47	-100.00
1989:4	45.88	54.13	-0.66	-99.34
1990:1	41.01	58.99	-4.24	-95.76
1990:2	40.83	59.17	-4.71	-95.29
1990:3	37.38	62.62	-8.73	-91.27
1990:4	41.60	58.40	-3.71	-96.29
1991:1	46.97	53.03	-2.06	-97.94
1991:2	44.12	55.14	0.75	-100.00
1991:3	46.17	53.83	-0.16	-99.84
1991:4	45.31	54.69	-1.34	-98.66

Table 6. Optimal portfolios, 4 currencies, AR-term.

Period	CHF	DEM	JPY	USD
1982:2	34.36	64.85	0.79	-100.00
1982:3	39.90	60.10	-1.47	-98.53
1982:4	34.98	65.02	-6.54	-93.46
1983:1	39.92	60.08	-2.03	-97.97
1983:2	41.90	58.10	-5.05	-94.95
1983:3	43.73	56.27	-4.42	-95.58
1983:4	44.48	55.52	-7.67	-92.33
1984:1	42.43	57.57	-0.83	-99.17
1984:2	44.00	56.00	-1.86	-98.14
1984:3	43.00	57.00	-5.58	-94.42
1984:4	44.82	54.90	0.28	-100.00
1985:1	42.26	57.74	-3.10	-96.90
1985:2	44.35	55.22	0.43	-100.00
1985:3	45.46	54.38	0.16	-100.00
1985:4	43.59	56.13	0.28	-100.00
1986:1	40.35	59.56	0.08	-100.00
1986:2	44.08	55.63	0.29	-100.00
1986:3	43.18	56.82	-1.14	-98.86
1986:4	43.05	56.95	-0.35	-99.65
1987:1	43.73	56.27	-4.69	-95.31
1987:2	46.83	53.17	-4.44	-95.56
1987:3	46.84	53.16	-3.47	-96.53
1987:4	49.09	50.81	0.09	-100.00
1988:1	45.07	54.93	-1.52	-98.48
1988:2	46.08	53.92	-7.04	-92.96
1988:3	44.09	55.91	-0.94	-99.06
1988:4	45.48	54.52	-5.22	-94.78
1989:1	46.66	53.34	-3.79	-96.21
1989:2	38.76	61.24	-5.81	-94.19
1989:3	44.69	54.62	0.68	-100.00
1989:4	46.60	53.32	0.08	-100.00
1990:1	38.80	61.20	-2.39	-97.61
1990:2	39.47	60.53	-5.30	-94.70
1990:3	36.93	63.07	-9.07	-90.93
1990:4	40.80	59.20	-3.53	-96.47
1991:1	48.32	51.56	0.12	-100.00
1991:2	43.51	55.79	0.70	-100.00
1991:3	45.84	54.15	0.01	-100.00
1991:4	46.01	53.99	-1.95	-98.05

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