The effect of cross hedging and base currency on global currency hedging

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Abstract

Currency risk can adversely affect the value of an international portfolio, regardless of equity market performance. This makes currency risk management a non-trivial consideration for any international portfolio manager. We have two related objectives. First, we analyse the effectiveness of cross-hedging with various exchange rate forward contracts on an international stock portfolio. Second, we examine the choice of base currency on hedging effectiveness. We generate daily dynamic conditional correlation (DCC)-GARCH hedge ratios from the joint estimation of seven developed countries from January 2002 to April 2010. With USD as the base currency, Australian and Canadian forwards provide effective cross-hedging, both in- and out-of-sample. We obtain comparable in-sample results with AUD as the base currency. But interestingly, most hedging strategies exacerbate return variability out-of-sample. Further analysis reveals that the same unhedged international portfolio in AUD has a substantially lower variability relative to USD. Our findings imply that the number and type of cross-rates to hedge, as well as the choice of base currency, can vastly affect the outcome of multi-currency risk management.

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1. Introduction

Given the high degree of cross-border investments and exchange rate fluctuations, currency hedging has become a crucial part of international investing and risk management. The literature in currency hedging lacks consensus about how currency risk should be managed for an internationally diversified stock portfolio. In this study, we firstly present empirical tests of a number of competing currency hedging strategies for the purpose of portfolio risk management. We then explore the effectiveness of cross hedging an internationally diversified portfolio with fewer currencies than that the portfolio is exposed to. Lastly, we examine the role base currency plays in hedging performance.

We consider portfolio investors holding an internationally diversified equity portfolio such as an international index fund. Each asset in the portfolio represents a stock index in a particular currency. We define currency hedging as the practice of using foreign currencies to achieve a hedger's objective, defined as portfolio variance minimization. The exposure to a foreign currency can be hedged by taking an appropriate short position in a forward contract written on the currency. The hedge ratio of a foreign currency is defined as the amount of exposure being hedged with respect to the total underlying exposure.

A number of static strategies have been proposed in the past. For example, Perold and Schulman (1988) advocate a full hedge. Froot (1993) suggests that no hedge is needed for long-term investors. Black (1989, 1990) develops a universal hedge ratio that partially hedges the currency exposure. Another popular strategy that is supported by Gastineau (1995) is to hedge half of the currency exposure. The most commonly adopted static strategies including no hedge, half hedge and full hedge generally do not account for the correlations among currencies, underlying assets and the cross-correlations between currencies and underlying assets. These strategies are shown to be outperformed by hedging strategies that do take these correlations into account. Black's universal hedge ratio, which is derived in the setting of the international CAPM, does account for the correlation between currencies. However the model has been criticized as having little practical use because it only holds under unrealistic assumptions.

Jorion (1994) proposes three possible ways of including currency in the global mean-variance optimization: First, in a joint, full portfolio optimization, the correlations between currencies and underlying asset classes are accounted for in the optimization process, and the positions in assets and currencies are determined simultaneously. Second, in a two-stage partial portfolio optimization, the underlying asset portfolio is first determined without any currency considerations, currency positions are then optimized given the core portfolio. Third, in a separate portfolio optimization, currency positions are determined separately from underlying asset allocations via two separate optimization processes. The currency management approaches in the partial and separate optimizations are classified as a ‘currency overlay’ strategy.

The joint optimization fully exploits the correlations and cross-correlations among all assets and currencies, and is shown using ex-post data to outperform an overlay strategy in which currency positions and asset positions are not determined simultaneously. Though theoretically sound, the same is not found in ex-ante studies mainly due to high estimation risk. For example, Eun and Resnick (1988) and Larsen and Resnick (2000) find low accuracy in estimating the input parameters (especially the mean) out of sample contributes to the ex-ante poor performance of the joint optimization. On the other hand, hedging for the purpose of risk minimization mitigates estimation risk as the covariance structure is found to be estimated with relative precision (e.g. Jorion, 1985). This approach is adopted in a recent study by Campbell, Medeiros and Viceira (2010) who examine the unconditional demand for currencies for risk management purpose by an investor with a given portfolio of stocks or bonds, using an overlay strategy for hedging.

Papers discussed up to this point largely rely on models that are developed on the strong assumption that the variances of, and the covariances between, the changes in underlying assets and currency forward returns are *constant* over time. Yet empirical evidence suggests otherwise (e.g. Bolleslev, Chou & Kroner, 1992; Longin & Solnik, 1995; Sheedy, 1998), which consequently fuelled the development of a number of dynamic hedging models. This branch of research in the literature of currency hedging attempts to develop hedging strategies that are based on times-series modelling of conditional mean, variances and covariances, thereby producing time-varying conditional hedge ratios. For example, Gagnon, Lypny and McCurdy (1998) base their study on a BEKK trivariate GARCH model; Guo (2003) adopts a multivariate GARCH model with time-varying correlations proposed by Tse and Tsui (2002); Hautsch and Inkmann (2003) employ the Dynamic Conditional Correlation (DCC)-GARCH model developed by Engle (2002). Research in this area commonly documents the ex-post superior performance of a conditional hedging strategy relative to that of unconditional strategies that are time-invariant, and relative to strategies adopting fixed hedge ratios. But little has been said about the performance of these more complicated dynamic hedging strategies ex ante.[2]

Brown et al. (2012) develop a conditional hedging strategy within the standard framework that has been adopted by Campbell et al. (2010) and allow both the mean and the covariance structure of the international portfolio to be time-varying. Their strategy employs a vector autoregression (VAR) to model the conditional mean and the DCC-GARCH to model the conditional covariance structure on a daily basis. The study investigates the conditional hedging strategy implemented via a currency overlay to minimize overall portfolio risk of a given international stock portfolio. Performance of the strategy is compared to that of static hedging (hedge ratios of 0, 0.5 and 1) and unconditional hedging (hedge ratios estimated with OLS regression). They find that conditional hedging dominates alternative hedging strategies *both* in-sample and out-of-sample.

We adopt the same method as used by Brown et.al and consider seven countries, Australia, Canada, Japan, the U.K., Switzerland, Germany and the U.S in our analyses. Our data spans the period Jan 2002 – Apr 2012. The in-sample period is Jan 2002-Dec 2005 and the out-of-sample period is Jan 2006-Apr 2010. We firstly take the perspective of a US investor and explore a number of portfolios investing in two countries and all seven countries respectively, in order to investigate the effect of multicurrency diversification on the effectiveness of hedging. Both in-sample and out-of-sample results demonstrate that all hedging strategies manage to reduce portfolio risk when the underlying asset portfolio is more diversified (e.g. a seven-asset portfolio) while many strategies increase portfolio risk when the portfolio is less diversified (e.g. a two-asset portfolio). We show in section 4 that hedging is more beneficial for certain currencies than others. We suspect that the better hedging result for the more diversified seven-asset portfolio is driven by certain key currencies that are effective in reducing overall portfolio risk. After examining the marginal effect of currencies on hedging performance in section 5, we identify AUD and CAD as the drivers of the risk reduction in the seven-asset portfolio. This result explains why less diversified portfolios that do not have

[2] One exception is the study by Kroner and Sultan (1993) which includes an ex-ante study of the effectiveness of the univariate hedging strategy adopted in the paper. However, this strategy ignores the correlations among currencies, and the cross-correlations between currencies and underlying assets, therefore is sub-optimal.

exposure to these currencies do not enjoy as much benefit from hedging. We also show that for the seven-asset portfolio, hedging with only AUD and CAD achieves more or less the same result as hedging with all currencies both in sample and out of sample. This result has important implications for the effectiveness of cross hedging internationally diversified portfolios. More research in this area seems promising.

Campbell et al. (2010) suggest that currency hedging demands for a given global portfolio are the same regardless of the currency base. We illustrate that the hedge positions estimated for the seven-asset portfolio within sample are indeed the same for both US and Australian investors. The hedge positions generate the same hedging result in terms of hedged portfolio risk for the two groups of investors both in sample and out of sample. But the benefit of hedging in terms of portfolio risk reduction is drastically different for different base currencies out of sample, with hedging significantly reducing risk for a US investor and adding risk for an Australian investor. This is because the unhedged portfolio risk from the Australian perspective is much smaller than that from the US perspective. This result highlights the impact of base currency on hedging performance and indicates that the optimal hedging practice should be base currency specific.

The rest of the paper is organized in the following way. Section 2 specifies the theoretical model and econometric method used to derive the risk-minimizing conditional hedge ratio. Section 3 describes the data. Section 4 presents the hedging results for selected portfolios from a US investor’s perspective. The marginal effect of hedging and the effectiveness of cross hedging are reported in Section 5. Section 6 presents the hedging results for a seven-asset portfolio from an Australian investor’s perspective. Section 7 concludes.

2. Methodology

As in Brown et al. (2012), we specify the following currency-overlay style conditional hedging strategy (using currency forward contracts) for a risk-minimizing US investor, though the strategy can be readily adapted by investors from any other base currency. Define $S_{i,t}$ as the spot USD price of foreign currency i at time t, and define $P_{i,t}$ as the foreign currency asset value inclusive of dividend reinvestments at time t.

For investments denoted in one foreign currency, unhedged discrete return measured in USD is defined as

$$R_{i,t}^{uh} = \frac{P_{i,t+1}S_{i,t+1}}{P_{i,t}S_{i,t}} - 1 \qquad (2.1)$$

Return on a long forward contract normalized by the current spot exchange rate is defined as

$$f_{i,t} = \frac{S_{i,t+1} - F_{i,t}}{S_{i,t}} \qquad (2.2)$$

where $F_{i,t}$ denotes the one period forward dollar price of foreign currency *i*. The hedged return on investment in country *i* is then given by[3]

$$R_{i,t}^{h} = R_{i,t}^{uh} - h_{i,t} f_{i,t} \qquad (2.3)$$

where $h_{i,t}$ is the hedge ratio of the investment in country *i* at time *t*. We assume that the investor sells forward $h_{i,t}$ dollars worth of currency *i* per dollar invested in the stock market of country *i* at the time the investment was made. For instance $h_{i,t}$ = 0 indicates that the investment in currency *i* is left unhedged,[4] and $h_{i,t}$ =1 implies that the investment is fully hedged. In the case that $h_{i,t}$ is negative, the investment's exposure to currency *i* is increased by buying currency *i* forward. The investment is said to be "over hedged" if $h_{i,t}$ >1. This occurs when the amount of currency *i* sold forward is greater than the underlying exposure in currency *i*. At this stage we have not imposed any constraint on the hedge ratios, though in practice, currency managers are commonly restricted from taking speculative positions in currencies,[5] meaning that the position taken in any currency forward contract cannot exceed the investment exposure to that currency (hedge ratio>1) or exaggerate the exposure (hedge ratio<0). In the empirical analysis, we will explore both constrained ($0 \le \text{hedge ratio} \le 1$) and unconstrained hedge ratios, and compare the hedging results.

We now assume a US investor invests in assets denominated in multiple currencies with predetermined portfolio weights, and wishes to manage the foreign currency exposure embedded in his/her portfolio with a currency overlay. In this set-up, it is assumed that the investor invests in N+1 stock markets (including the domestic market), and is exposed to N foreign currencies with the USD as the base currency.

Let $\mathbf{R} = [R_{1,t}^{uh}, R_{2,t}^{uh}, \ldots, R_{N,t}^{uh}, R_{N+1,t}]'$ be an (N+1)×1 vector of unhedged asset returns in USD

[3] Note that country *i* and foreign currency *i* will be used interchangeably.

[4] The interpretation of the hedge ratio here is consistent with Glen and Jorion (1993) and Jorion (1994), but different from the interpretation of the hedging demand used in Campbell et al. (2010).

[5] See for example Gardner and Stone (1995), Clarke and kritzman (1996) and Xin (2003). This excludes active currency managers whose goal is to add return.

from all countries, with R_{N+1} being the return from the U.S. **W** denotes an (N+1)×1 vector of portfolio weights w_i with w_{N+1} being the weight in the US stock market. Let **f** denote an N×1 vector of forward currency returns $f_{i,t}$. **h** is an N×1 vector of hedge ratios $h_{i,t}$. The hedged gross portfolio return is given by

$$R_p^h = \mathbf{W}'\mathbf{R} - \mathbf{h}'(\mathbf{w} \odot \mathbf{f}) \tag{2.4}$$

where **w** is an N×1 vector of portfolio weights w_i excluding the weight in the U.S., and ⊙represents element-by-element multiplication. So the conditional variance of the hedged portfolio return is given by

$$\begin{aligned} \mathrm{var}_t(R_p^h) \mid \mathrm{I}_{t-1} = \mathrm{var}_t(\mathbf{W}'\mathbf{R}) \mid \mathrm{I}_{t-1} + \mathrm{var}_t[\mathbf{h}'(\mathbf{w} \odot \mathbf{f})] \mid \mathrm{I}_{t-1} \\ -2\,\mathrm{cov}_t[\mathbf{W}'\mathbf{R}, \mathbf{h}'(\mathbf{w} \odot \mathbf{f})] \mid \mathrm{I}_{t-1} \end{aligned} \tag{2.5}$$

Assume the investor's objective is to minimize the variance of the hedged portfolio return with respect to a vector of hedge ratios

$$\min_{\mathbf{h}} \mathrm{var}_t(R_p^h) \mid \mathrm{I}_{t-1} \tag{2.6}$$

Then the first order condition is given by

$$[\mathrm{var}_t(\mathbf{w} \odot \mathbf{f})]\mathbf{h} \mid \mathrm{I}_{t-1} - \mathrm{cov}_t(\mathbf{W}'\mathbf{R}, \mathbf{w} \odot \mathbf{f}) \mid \mathrm{I}_{t-1} = 0 \tag{2.7}$$

The vector of time-varying (conditional) optimal hedge ratios is therefore given by

$$\mathbf{h}^* = \mathrm{var}_t^{-1}(\mathbf{w} \odot \mathbf{f}) \mid \mathrm{I}_{t-1} * \mathrm{cov}_t(\mathbf{W}'\mathbf{R}, \mathbf{w} \odot \mathbf{f}) \mid \mathrm{I}_{t-1} \tag{2.8}$$

Under the assumption that the variances and covariances in equation (2.8) are constant over time, the vector of unconditional optimal hedge ratios can then be written as

$$\mathbf{h}^{**} = \mathrm{var}^{-1}(\mathbf{w} \odot \mathbf{f})\,\mathrm{cov}(\mathbf{W}'\mathbf{R}, \mathbf{w} \odot \mathbf{f}) \tag{2.9}$$

Equation (2.9) implies that the vector of unconditional optimal hedge ratios can be generated by the following OLS regression

$$\mathbf{W}'\mathbf{R} = \alpha + \boldsymbol{\beta}'(\mathbf{w} \odot \mathbf{f}) + \varepsilon \tag{2.10}$$

where **β** is an N×1 vector of coefficients.

Econometric model

The DCC-GARCH model first proposed by Engle (2002) is used for the estimation of the conditional variance-covariance matrix. The DCC model is chosen for its apparent advantages over other multivariate GARCH models. The model can be estimated in two steps

– the first is a series of univariate GARCH estimates and the second is the correlation estimate. This two-step estimation procedure enables the estimation of large correlation matrices since the number of parameters to be estimated in the correlation process is independent of the number of series to be correlated. However, this estimation procedure does require the standard errors of the parameters to be modified for consistency and efficiency.

We first model the return series $\mathbf{X_t} = [\mathbf{R}, \mathbf{f}]'$ with a Vector Autoregression (VAR)[6]

$$\mathbf{X_t} = \mathbf{a} + \mathbf{b}_1\mathbf{X_{t-1}} + \mathbf{b_2}\mathbf{X_{t-2}} + \ldots + \mathbf{b_p}\mathbf{X_{t-p}} + \mathbf{e_t} \tag{2.11}$$

where $\mathbf{e_t} \mid \mathrm{I}_{t-1} \sim N(\mathbf{0}, \mathbf{\Sigma_t})$, I_{t-1} is the information set at time *t*-1, and $\mathbf{\Sigma_t}$ is the variance-covariance matrix of the asset returns and currency forward returns at time *t*, conditioning on the information available at time *t*-1. The VAR structure allows each return series to be explained by a constant term and lagged values of all return series. The error terms are then used in the estimation of the covariance structure for the multivariate return series.

Following Engle (2002), the conditional variance-covariance matrix is defined as:

$$\mathbf{\Sigma_t} \equiv \mathbf{D_t}\mathbf{\Lambda_t}\mathbf{D_t} \tag{2.12}$$

where $\mathbf{D_t}$ is the (2N+1)×(2N+1) diagonal matrix of time varying standard deviations from univariate GARCH models with $\sigma_{i,t}$ on the i[th] diagonal, and $\mathbf{\Lambda_t}$ is the time varying correlation matrix. The elements of $\mathbf{D_t}$ are estimated by univariate GARCH models,[7] so the specification for the conditional variance is:

$$\sigma^2_{i,t} = \omega_i + \sum_{p=1}^{P_i} \alpha_{i,p} e^2_{i,t-p} + \sum_{q=1}^{Q_i} \beta_{i,q} \sigma^2_{i,t-q} \tag{2.13}$$

where ω_i , $\alpha_{i,p}$ and $\beta_{i,q}$ are nonnegative, and $\sum_{p=1}^{P_i} \alpha_{i,p} + \sum_{q=1}^{Q_i} \beta_{i,q} < 1$. The dynamic correlation structure proposed by Engle (2002) is:

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[6] All the return series are stationery. This is verified by applying Augmented Dickey-Fuller test to each return series. The Johansen cointegration test result suggests that country stock indices are not cointegrated at price levels. Since the return on a forward contract is calculated with both the spot and forward exchange rates as has been illustrated in equation (2.2), the cointegration test is not performed for the currencies.

[7] A number of models namely EGARCH, GJR, PARCH and GARCH have been explored to determine whether there is asymmetry in currency return volatility. We found little evidence of asymmetric volatility, and in majority of the cases both AIC and SC suggest that GARCH is the best model among the four.

$$\mathbf{Q_t} = (1-\sum_{m=1}^{M}\delta_m - \sum_{l=1}^{L}\eta_l)\bar{\mathbf{Q}} + \sum_{m=1}^{M}\delta_m(\boldsymbol{\varepsilon}_{\mathbf{t-m}}\boldsymbol{\varepsilon}'_{\mathbf{t-m}}) + \sum_{l=1}^{L}\eta_l\mathbf{Q_{t-l}} \quad (2.14)$$

where $\boldsymbol{\varepsilon}_\mathbf{t} = \mathbf{D}_\mathbf{t}^{-1}\mathbf{e}_\mathbf{t}$ is a vector of residuals standardized by their conditional standard deviations, and $\bar{\mathbf{Q}}$ is the unconditional covariance of the standardized residuals resulting from the first stage estimation. δ_m and η_l are nonnegative scalar parameters satisfying $\sum_{m=1}^{M}\delta_m + \sum_{l=1}^{L}\eta_l < 1$.

Define $\mathbf{Q}_t^*$ to be a diagonal matrix composed of the square root of the diagonal elements of $\mathbf{Q_t}$, so we have (with k = 2N+1)

$$Q_t^* = \begin{bmatrix} \sqrt{q_{11}} & 0 & \cdots & 0 \\ 0 & \sqrt{q_{22}} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sqrt{q_{kk}} \end{bmatrix} \quad (2.15)$$

Therefore

$$\boldsymbol{\Lambda}_\mathbf{t} = \mathbf{Q}_t^{*-1}\mathbf{Q_t}\mathbf{Q}_t^{*-1} \quad (2.16)$$

with the ijth element of $\boldsymbol{\Lambda}_\mathbf{t}$ being $\lambda_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii}q_{jj}}}$.

The log-likelihood of the DCC estimator can be written:

$$\begin{aligned} L &= -\frac{1}{2}\sum_{t=1}^{T}((2N+1)\log(2\pi) + \log(|\boldsymbol{\Sigma}_\mathbf{t}|) + \mathbf{e}_t'\boldsymbol{\Sigma}_t^{-1}\mathbf{e_t}) \\ &= -\frac{1}{2}\sum_{t=1}^{T}((2N+1)\log(2\pi) + \log(|\mathbf{D_t}\boldsymbol{\Lambda}_\mathbf{t}\mathbf{D_t}|) + \mathbf{e}_t'\mathbf{D}_t^{-1}\boldsymbol{\Lambda}_t^{-1}\mathbf{D}_t^{-1}\mathbf{e_t}) \\ &= -\frac{1}{2}\sum_{t=1}^{T}((2N+1)\log(2\pi) + 2\log(|\mathbf{D_t}|) + \log(|\boldsymbol{\Lambda}_\mathbf{t}|) + \boldsymbol{\varepsilon}_t'\boldsymbol{\Lambda}_t^{-1}\boldsymbol{\varepsilon}_\mathbf{t}) \end{aligned} \quad (2.17)$$

We model the covariance matrix using a DCC(1,1)-GARCH(1,1) model.[8] Estimating the GARCH and DCC parameters separately result in loss of efficiency relative to a maximum likelihood estimation of all the parameters at once, although consistency is less of an issue. Following the two-step estimation procedure, the standard errors of all the GARCH and DCC parameters are modified according to the theorems provided in Engle and Sheppard (2001).

[8] Results generated using higher orders are similar. We try to keep our model simple as the more heavily-parameterised models tend to forecast poorly out of sample.

This ensures that the standard errors are consistent and asymptotically efficient.

3. Data

The empirical analysis of this study considers 7 countries: the U.S., the U.K., Canada, Australia, Switzerland, Japan and Germany. Initially, the U.S. is considered as the domestic country and the US dollar is the base currency. Later in the study, Australian dollar is used as the base currency for comparison. This study uses daily data[9] over the period January 2002-April 2010. Morgan Stanley Capital International (MSCI) country stock indices[10] in local currencies are used to measure country stock market performance. Unhedged country stock market return measured in US dollar is computed from the country stock index using equation (2.1). Spot and forward exchange rates are quoted in terms of the US dollar, and the return on a long position in a one-day currency forward contract is computed using equation (2.2). All data are sourced from DataStream.

Summary statistics of daily stock market returns and currency forward returns for the in-sample period Jan 2002- Dec 2005 and out-of-sample period Jan 2006 – Apr 2010 are reported in Table 1. For each period, when comparing the standard deviation of country stock returns measured in local currency with that of the returns measured in USD, with a few exceptions, the risk of unhedged USD foreign stock returns is typically higher than the risk of the corresponding stock return in local currency. This demonstrates the contribution of currency risk to the overall risk of holding foreign assets. It is interesting to observe that the average currency forward return is positive for all countries considered in all time periods except for GBP. This means that buying foreign currency forward during the sample period would have on average generated positive return for a US investor. In many cases, the average currency forward return is comparable to the corresponding average stock index return in local currency. This indicates that currency hedging which involves selling foreign currencies forward would result in substantial loss in expected return during the sample period. This is attributable to the weakening of USD against almost all the major currencies during the sample period. This in turn explains the fact that for all countries and all time periods except for the U.K. in panel B, unhedged USD returns are on average higher than the

[9] Using daily data exposes the study to a non-synchronous trading problem as stock markets from different time-zones open and close at different times. As a robustness check, the same analyses are also performed using weekly data. The results obtained using weekly data are similar to the results reported in the paper, and are available on request.
[10] These series include dividend reinvestments after deducting withholding tax.

corresponding local currency returns within sample.

Table 1 Summary statistics (US perspective)

The table reports descriptive statistics of stock market returns and currency forward returns for the periods: Jan 2002-Dec 2005 and Jan 2006-Apr 2010. Mean local currency return is the average daily stock market return measured in local currency. Mean USD return is the average daily unhedged stock market return11 measured in US dollars. Mean currency forward return12 is the average daily return on a long position in a one-day currency forward contract. Daily data on MSCI country stock indices, spot exchange rates and one-day forward exchange rates are obtained from DataStream. Mean and standard deviation are in percentage terms.

%	Australia	Canada	Japan	UK	Switzerland	Germany	USA
	Panel A: January 2002-December 2005						
mean stock return (local currency)	0.044	0.045	0.051	0.025	0.031	0.019	0.019
standard deviation (local currency)	0.645	0.827	1.144	1.104	1.207	1.650	1.082
mean currency forward return	0.023	0.027	0.020	0.008	0.029	0.026	-
standard deviation	0.663	0.513	0.586	0.515	0.649	0.582	-
mean stock return (USD)	0.082	0.076	0.063	0.041	0.052	0.045	0.019
standard deviation (USD)	0.977	0.982	1.302	1.095	1.148	1.565	1.082
	Panel B: January 2006-April 2010						
mean stock return (local currency)	0.026	0.030	-0.022	0.024	0.004	0.017	0.014
standard deviation (local currency)	1.420	1.588	1.717	1.481	1.350	1.577	1.586
mean currency forward return	0.017	0.017	0.034	-0.010	0.027	0.014	-
standard deviation	1.094	0.774	0.738	0.728	0.704	0.658	-
mean stock return (USD)	0.059	0.049	-0.003	0.020	0.024	0.032	0.014
standard deviation (USD)	2.117	1.965	1.671	1.842	1.486	1.871	1.586

It is also interesting to observe that Japan was hit the hardest by the GFC, judging from the negative local currency stock market return (-0.022%) reported in panel B of Table 1, when its pre-crisis return was the highest among all countries (0.051%) as reported in panel A. But the mean return on yen forwards has increased from the pre-crisis level of 0.020% (panel A) to 0.034% for the crisis period (Panel B),[13] which means that on average the yen has strengthened more during the GFC than it did in the previous period. And the impact of the crisis on a US investor's return is partially mitigated by the strong performance of the yen during the crisis period when return is measured in USD. These results point to the fact that in the recent GFC, investors viewed the Japanese yen as a 'safe haven' currency, and chose to hold the yen over other currencies when the market was in turmoil. This at least partially stems from the fact that the GFC was initiated in the U.S. and investor confidence in the US dollar was relatively low. Another possible explanation for the appreciation of the yen during the GFC is the unwinding of currency carry trades. The yen has long been used as a funding

[11] This is computed using equation (2.1).
[12] This is computed using equation (2.2).
[13] Average forward return on all other currencies has declined in the second sub-period.

currency[14] for carry trades due to the near-zero interest rate in Japan, as investors borrow the yen and invest in high-yield currencies such as the Australian dollar. When the market is turbulent, carry traders sell assets in high-yield currencies to serve their debt in the yen, thereby pushing up the price of the yen.

Table 2 reports unconditional correlations of daily stock market returns denominated in US dollars. It illustrates that there is high correlation among the stock market returns of Switzerland, Germany and the U.K. This is expected given the close linkage between European economies. The correlation is also high among the US, Canadian and German stock markets. But most of the correlations in the table are far from perfect, which suggests that benefit can be derived from international diversification. It is noticeable from Table 2 that the correlations in panel B are in general higher than their counterparts in panel B, and the difference in correlations is statistically significant at the 5% level in most cases. This suggests that the selected stock markets tend to co-move more during the crisis period, which is consistent with previous studies documenting increased correlations between international stock markets in periods of high volatility, especially in market downturns (see Lin, Engle & Ito, 1994; Longin & Solnik, 2001 for example).

[14] See for example Galati and Melvin (2004), McCauley and McGuire (2009).

Table 2 USD stock market return correlations

The table reports unconditional correlations among unhedged daily country stock market returns measured in USD for the periods: Jan 2002-Dec 2005 and Jan 2006-Apr 2010. All correlations are statistically significant at the 5% level. The significance indicators in Panel B (*** and ** represent 1% and 5% significance levels respectively) show the statistical difference between the correlations in Panel B and the correlations in Panel B.

	Australia	Canada	Japan	UK	Switzerland	Germany	US
	Panel A: January 2002-December 2005						
Australia	1.00						
Canada	0.33	1.00					
Japan	0.43	0.23	1.00				
UK	0.34	0.47	0.20	1.00			
Switzerland	0.32	0.43	0.22	0.75	1.00		
Germany	0.23	0.55	0.17	0.72	0.71	1.00	
USA	0.04	0.60	0.08	0.41	0.37	0.61	1.00
	Panel B: January 2006-April 2010						
Australia	1.00						
Canada	0.48***	1.00					
Japan	0.60***	0.21	1.00				
UK	0.62***	0.69***	0.24	1.00			
Switzerland	0.59***	0.62***	0.27	0.86***	1.00		
Germany	0.58***	0.67***	0.23	0.88***	0.85***	1.00	
USA	0.21***	0.71***	-0.01**	0.53***	0.46**	0.57	1.00

Table 3 reports unconditional correlations among daily returns of long forward contracts on the selected currencies. We observe very high correlation among the forward returns of 'European currencies', namely the Euro, Swiss franc and British pound. This again reflects the close relationship between the European countries. High correlations are also reported for some other currency pairs. But the imperfect correlations imply that hedging with a portfolio of currencies could reduce the aggregate risk of the hedge instruments. Comparing the numbers in Panel A and Panel B, the correlations in Panel B are in many cases lower than their counterparts in Panel A. It is worth noting that JPY has quite high correlations with AUD (0.45), CAD (0.32) and GBP (0.47) respectively in the in-sample period, but those correlations turned negative in the out-of-sample period which covers the GFC. The correlation between JPY and EUR also decreased from 0.54 to 0.19 over the two sub-periods. The difference in correlations for all these currency pairs over the two sub-periods is statistically significant at the 1% level. The only currency that tends to co-move strongly with the yen through the whole data period is the Swiss franc.

Table 3 USD currency forward return correlations

The table reports unconditional correlations among daily returns of long forward contracts on various currencies for the periods: Jan 2002-Dec 2005 and Jan 2006-Apr 2010. All correlations are statistically significant at the 5% level. The significance indicators in Panel B (*** and ** represent 1% and 5% significance levels respectively) show the statistical difference between the correlations in Panel B and the correlations in Panel B.

	AUD	CAD	JPY	GBP	CHF	EUR
	Panel A: January 2002-December 2005					
AUD	1.00					
CAD	0.54	1.00				
JPY	0.45	0.32	1.00			
GBP	0.56	0.39	0.47	1.00		
CHF	0.55	0.45	0.55	0.74	1.00	
EUR	0.60	0.47	0.54	0.75	0.95	1.00
	Panel B: January 2006-April 2010					
AUD	1.00					
CAD	0.65***	1.00				
JPY	-0.26***	-0.17***	1.00			
GBP	0.61*	0.53***	-0.02***	1.00		
CHF	0.40***	0.37**	0.42***	0.51***	1.00	
EUR	0.63	0.56***	0.19***	0.68***	0.87***	1.00

The unconditional correlations among stock market returns and currency forward returns are reported in Table 4. With a few exceptions, the correlations are quite low. It is therefore reasonable to leave some currency exposure unhedged for diversification purposes, because natural hedges exist in portfolios. Depending on portfolio composition, it might even be attractive to increase the portfolio's exposure to certain currencies, given the negative correlation between the US stock market and the currency forward return on the three European currencies reported in Panel A. This is particularly true for investors based in the U.S. On the other hand, high correlation between AUD and the Australian stock market probably indicates that most if not all of the exposure in AUD should be hedged.

Table 4 USD stock-market-return and currency-forward-return correlations

The table reports unconditional correlations between unhedged stock market return and currency forward returns for the periods: Jan 2002-Dec 2005 and Jan 2006-Apr 2010. All returns are measured in US dollar and are on daily basis. The underlined correlation coefficients are not significant at the 5% level. The significance indicators in Panel B (*** and ** represent 1% and 5% significance levels respectively) show the statistical difference between the correlations in Panel B and the correlations in Panel B.

	Australia	Canada	Japan	UK	Switzerland	Germany	US
	Panel A: January 2002-December 2005						
AUD	0.75	0.33	0.28	0.27	0.27	0.19	-0.01
CAD	0.42	0.54	0.20	0.19	0.22	0.17	0.03
JPY	0.29	0.14	0.48	0.04	0.13	0.03	-0.05
GBP	0.34	0.17	0.15	0.22	0.16	0.06	-0.10
CHF	0.32	0.13	0.14	0.02	0.19	-0.01	-0.17
EUR	0.37	0.16	0.17	0.06	0.20	0.04	-0.16
	Panel B: January 2006-April 2010						
AUD	0.79**	0.55***	0.36**	0.70***	0.66***	0.67***	0.26
CAD	0.54***	0.64***	0.21	0.61***	0.59***	0.60***	0.28
JPY	-0.24***	-0.27**	0.15***	-0.36	-0.20***	-0.29	-0.28
GBP	0.48***	0.43***	0.26***	0.64***	0.53***	0.52	0.20***
CHF	0.25*	0.17	0.19	0.22	0.42***	0.32	-0.06
EUR	0.47***	0.39***	0.28***	0.50***	0.61***	0.59	0.13***

It is interesting to observe that correlations between JPY and all stock markets except the Japanese market are negative in the out-of-sample period (Panel B), despite the fact that most of the corresponding correlations are positive in the first sub-period (Panel A). This suggests that JPY was, to some degree, a hedge against the decline in the world stock market during the GFC. From the results documented in Table 3, JPY also has low or negative correlation with most currencies. So with hindsight, exposure to the yen should be considered as a natural hedge for the position in stocks and other currencies and ought to be left unhedged during the GFC. The rest of the correlations in Panel B of Table 4 are generally higher than their counterparts in Panel A, and the difference in correlation in most cases is statistically significant at the 1% level. These results raise questions about the effectiveness of static hedging strategies which use fixed hedge ratios regardless of the currency being hedged and market conditions. On the other hand, the DCC model may capture some of the changes in the correlations although not perfectly, as the model reverts back to its in-sample mean.

4. Currency hedging from a US perspective

This section presents both in-sample and out-of-sample hedging results of currency overlay strategies. The analysis examines a number of equally weighted portfolios of various stock market compositions and estimates both unconditional and conditional hedge ratios for the currencies to which a certain stock portfolio is exposed. A number of static hedge ratios are also included as benchmarks for performance comparison. The unconditional hedge ratios are estimated using OLS regression based on equation (2.9). The conditional hedge ratios are computed, based on equation (2.8), from conditional covariance matrix estimated with the DCC-GARCH model. Other static hedging strategies considered include: i) Full hedge, under which 100% of the portfolio's currency exposure is hedged by taking a long position in currency forward contracts. ii) Half hedge, under which only 50% of the currency exposure embedded in the portfolio is hedged. And iii) No hedge, under which the currency exposure of the portfolio is left unhedged. All hedges are implemented as a currency overlay from a US perspective.

In order to compare the performance of conditional hedging with the other hedging strategies out of sample, we make one-step-ahead forecasts of the covariance structure of asset and currency returns using VAR and DCC-GARCH parameters estimated within sample. Daily conditional hedge ratios for the out-of-sample period are then calculated from the forecasted covariance matrix for various portfolios. Given that the out-of-sample period (Jan 2006-Apr 2010) covers the 2008 global financial crisis (GFC), the performance of the conditional hedging strategy could be affected by a potential structural break in the data. Therefore the same analysis is also conducted for a pre-crisis period Jan 2006 to Dec 2006 for comparison, as the crisis arguably started around mid-2007.[15]

Given the fact that in practice, portfolio managers are often prohibited from taking speculative positions[16] in currency forward contracts when implementing hedging strategies, constrained hedge ratios (hedge ratios lie within the range [0,1]) are also computed for completeness. Hedging results of all the overlay strategies are compared for each stock portfolio considered.

4.1 Two-asset portfolios

We examine hedging strategies for six two-asset-portfolios each containing the US stock index and the stock index of another country. Each stock portfolio is exposed to only one foreign currency and the exposure is hedged by taking a short position in forward contracts

[15] The GFC is commonly believed to have begun in mid-2007 as a result of losses on mortgage backed securities (see Mizen, 2008, Caballero & Kurlat, 2009, Brunnermeier, 2009 among many others). For example, In June 2007, two hedge funds run by Bear Stearns that had large holdings of subprime mortgages sustained great losses and filed for bankruptcy.

[16] This results from a short position taken in a currency forward contract that exceeds the underlying exposure to that currency.

written on that currency.

The effectiveness of conditional hedging, measured as the percentage portfolio risk reduction relative to no hedge for the *in-sample period* is reported in Table 5, along with hedging results of unconditional hedging and static hedging. The table illustrates that there is a sizable reduction in risk from conditional hedging for portfolios containing Australia (11.9%), Canada (4.6%) and Japan (6.1%) respectively. But the risk reduction is not superior to that of a simple 100% hedge, probably due to the fact that investments in these currencies are recommended to be fully hedged if not over hedged, therefore a 100% hedge could prove to be just as effective and contains no estimation error.[17] On the other hand, risk reduction from conditional hedging for portfolios containing the U.K. (2.2%), Switzerland (3.3%) and Germany (4.8%) respectively is relatively low. But conditional hedging has clearly outperformed other hedging strategies, as the 100% hedging strategy resulted in added risk for all three portfolios, and unconditional hedging had virtually no risk reduction. Also, constraining the hedge ratios to lie between 0 and 1 results in a deterioration of the performance of both conditional and unconditional hedging.

We also conducted an F-test for equal variance analysis firstly using conditional hedging and then using no hedge as the benchmark. The F-test result shows that the variance reduction achieved with conditional hedging relative to no hedging is generally not statistically significant except for AUD and JPY. The difference between conditional hedging and other hedging strategies is also not statistically significant, except for the difference between conditional hedging and 100% hedging for CHF and EUR, as well as the difference between conditional hedging and 50% hedging for EUR (as shown in the stdev column). On the other hand, the risk reduction achieved by all hedging strategies relative to no hedge is significant at the 1% level for the portfolio containing Australia (as shown in the %down column). However, the risk reduction produced by various strategies lacks statistical significance for the rest of the portfolios except the one invested in Japan.

[17] The percentage risk reduction from conditional hedging is slightly lower than that from 100% hedging for portfolios containing Australia and Canada, though the difference is not statistically significant. This is likely to be caused by specification error of the conditional hedge model, but the phenomenon disappears when more assets are included in the portfolio.

Table 5 Hedging results comparison for two-asset portfolios (2002-2005)

The table reports the mean and the standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression), constrained unconditional hedge, conditional hedge (hedge ratio based on dynamic conditional covariance matrix) and constrained conditional hedge. All constrained hedge ratios are bounded by 0 and 1. Each portfolio contains the US stock index and the index of a foreign country with equal weights, the first row of the table indicates with which foreign country's stock index the portfolio is formed. All calculations are based on daily observations over the period January 2002 to December 2005. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge.[18] The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging strategy	Australia			Canada			Japan		
	mean	stdev	%down	mean	stdev	%down	mean	stdev	%down
no hedge	0.050	0.742***	0.0	0.047	0.924	0.0	0.041	0.879**	0.0
half hedge	0.043	0.677	8.7***	0.039	0.894	3.3	0.036	0.844	4.0
full hedge	0.037	0.649	12.5***	0.032	0.881	4.7	0.031	0.832	5.3*
unconditional	0.036	**0.649**	12.6***	0.031	**0.880**	4.8	0.031	0.832	5.3*
const'd uncon	0.037	0.649	12.5***	0.032	0.881	4.7	0.031	0.832	5.3*
conditional	0.038	0.654	11.9***	0.031	0.882	4.6	0.028	**0.825**	6.1**
const'd con	0.038	0.654	11.9***	0.033	0.882	4.6	0.032	0.830	5.6*
hedging strategy	UK			Switzerland			Germany		
	mean	stdev	%down	mean	stdev	%down	mean	stdev	%down
no hedge	0.030	0.914	0.0	0.035	0.924	0.0	0.032	1.192	0.0
half hedge	0.028	0.916	-0.1	0.027	0.936	-1.3	0.024	1.208**	-1.3
full hedge	0.026	0.933	-2.1	0.020	0.975**	-5.4*	0.018	1.241***	-4.1
unconditional	0.030	0.914	0.1	0.033	0.925	-0.1	0.033	1.191	0.1
const'd uncon	0.030	0.914	0.1	0.033	0.925	-0.1	0.031	1.192	0.0
conditional	0.032	**0.895**	2.2	0.040	**0.894**	3.3	0.044	**1.135**	4.8
const'd con	0.032	0.903	1.2	0.034	0.912	1.3	0.032	1.181	1.0

The hedging result for two-asset portfolios over the year 2006 is presented in Table 6. It appears that no hedging strategy is consistently better than the other strategies during this period. Conditional hedging performs the best among all hedging strategies for three out of the six portfolios examined, but it is outperformed by unconditional hedging for two portfolios. For the portfolio containing the U.K., both conditional hedging and unconditional hedging underperform a simple 100% hedge. However, the difference between conditional hedging and alternative hedging strategies lack statistical significance. The difference between conditional hedging and no hedge is significant at 5% level only for the portfolio invested in Australia. These results are largely comparable to the in-sample results for two-

[18] For example, %down for full hedge = ($stdev_{no\ hedge}$ - $stdev_{full\ hedge}$)/$stdev_{no\ hedge}$ *100

asset portfolios.

Table 6 Hedging results comparison for two-asset portfolios (2006)

This table reports mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression within-sample), constrained unconditional hedge, conditional hedge (hedge ratio estimated with forecasts of dynamic conditional covariance matrix based on in-sample VAR-DCC-GARCH parameters) and constrained conditional hedge. The constrained hedge ratios are bounded by 0 and 1. Each portfolio contains the US stock index and the index of a foreign country with equal weights, the first row of the table indicates with which foreign country's stock index the portfolio is formed. All calculations are based on daily return observations over the period January 2006 to December 2006. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging	Australia			Canada			Japan		
strategy	mean	stdev	%down	mean	stdev	%down	mean	stdev	%down
no hedge	0.082	0.623**	0.0	0.061	0.728	0.0	0.043	0.763	0.0
half hedge	0.075	0.569	8.7	0.060	0.688	5.5	0.038	0.717	6.0
full hedge	0.069	0.541	13.1**	0.058	0.668	8.2	0.034	0.693	9.2
unconditional	0.067	**0.540**	13.4**	0.058	**0.667**	8.4	0.034	0.694	9.1
const'd uncon	0.069	0.541	13.1**	0.058	0.668	8.2	0.034	0.694	9.1
conditional	0.066	0.544	12.7**	0.056	0.674	7.4	0.039	**0.691**	9.4
const'd con	0.068	0.543	12.9**	0.056	0.669	8.2	0.038	0.695	8.9
hedging	**UK**			**Switzerland**			**Germany**		
strategy	**mean**	**stdev**	**%down**	**mean**	**stdev**	**%down**	**mean**	**stdev**	**%down**
no hedge	0.080	0.650	0.0	0.076	0.652	0.0	0.089	0.758	0.0
half hedge	0.067	0.619	4.9	0.064	0.616	5.4	0.076	0.724	4.5
full hedge	0.054	**0.612**	5.9	0.053	0.611	6.3	0.063	0.708	6.5
unconditional	0.074	0.631	3.0	0.074	0.646	0.9	0.094	0.775	-2.3
const'd uncon	0.074	0.631	3.0	0.074	0.646	0.9	0.089	0.758	0.0
conditional	0.061	0.615	5.4	0.060	**0.608**	6.7	0.068	**0.707**	6.7
const'd con	0.061	0.615	5.4	0.060	0.608	6.7	0.069	0.708	6.5

Table 7 reports the hedging performance of various strategies for two-asset portfolios during the period covering the GFC. In contrast to the result for the pre-crisis period, conditional hedging consistently outperforms other hedging strategies for all six portfolios. Conditional hedging is statistically significantly better than unconditional hedging for portfolios containing Japan, the U.K. and Germany. It is also statistically significantly better than both no hedge and half hedge for four of the portfolios. Similar to the result for the in-sample period, all hedging strategies manage to reduce risk for portfolios containing Australia and Canada. However, this time the risk reductions achieved by all hedging strategies have strong statistical significance.

Table 7 Hedging results comparison for two-asset portfolios (2006-2010)

This table presents mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression within-sample), constrained unconditional hedge, conditional hedge (hedge ratio estimated with forecasts of dynamic conditional covariance matrix based on in-sample VAR-DCC-GARCH parameters) and constrained conditional hedge. The constrained hedge ratios are bounded by 0 and 1. Each portfolio contains the US stock index and the index of a foreign country with equal weights, the first row of the table indicates with which foreign country's stock index the portfolio is formed. All calculations are based on daily observations over the period January 2006 to April 2010. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging	Australia			Canada			Japan		
strategy	mean	stdev	%down	mean	stdev	%down	mean	stdev	%down
no hedge	0.037	1.451***	0.0	0.032	1.643***	0.0	0.006	1.144	0.0
half hedge	0.033	1.268***	12.6***	0.027	1.551***	5.6*	-0.003	1.174	-2.6**
full hedge	0.029	1.123	22.6***	0.023	1.479	10.0***	-0.011	1.231***	-7.6**
unconditional	0.028	1.102	24.1***	0.023	1.467	10.7***	-0.011	1.227***	-7.2**
const'duncon	0.029	1.123	22.6***	0.023	1.479	10.0***	-0.011	1.227***	-7.2**
conditional	0.023	**1.080**	25.6***	0.018	**1.399**	14.8***	0.016	**1.095**	4.3
const'd con	0.024	1.125	22.4***	0.022	1.479	10.0***	0.004	1.141	0.2
hedging	UK			Switzerland			Germany		
strategy	mean	stdev	%down	mean	stdev	%down	mean	stdev	%down
no hedge	0.017	1.499***	0.0	0.019	1.314	0.0	0.023	1.534***	0.0
half hedge	0.019	1.416**	5.5*	0.012	1.289	1.9	0.020	1.472**	4.0
full hedge	0.022	1.354	9.7***	0.005	1.289	1.9	0.016	1.426	7.0**
unconditional	0.018	1.454***	3.0	0.018	1.310	0.3	0.025	1.561***	-1.8
const'd uncon	0.018	1.454***	3.0	0.018	1.310	0.3	0.023	1.534***	0.0
conditional	0.026	**1.304**	13.0***	0.000	**1.275**	2.9	0.001	**1.387**	9.6***
const'd con	0.020	1.358	9.4***	0.007	1.272	3.1	0.013	1.429	6.9**

It is interesting to note that all hedging strategies increase the risk of the portfolio containing Japan over this period with the exception of conditional hedging, which reduces the portfolio risk by 4.3%. Although conditional hedging is not statistically significantly better than no hedge, it is significantly better than half hedge, full hedge and unconditional hedging at 5% level. From Table 4, JPY had a correlation of -0.28 with the US stock market during this period. Its correlation with the Japanese stock market also dropped significantly compared to the in-sample period. This helps explain why the static and unconditional hedging strategies that try to reduce the exposure to JPY end up adding risk to the portfolio. It also emphasises the value of conditional hedging especially during the times of market turbulence, as conditional hedging constantly adjusts the hedge ratios as new market data becomes available.

In summary, the conditional hedging strategy generally outperforms alternative hedging strategies in terms of portfolio risk reduction both in and out of sample, though conditional hedging is not found to be statistically significantly different from unconditional hedging in many cases. We find that performance of various hedging strategies differs across portfolios depending on portfolio composition. Also, there is clear evidence of the superior ex-ante performance of the conditional hedging strategy relative to other strategies during the period covering the GFC. In many cases, the dominance of conditional hedging is statistically significant. Restricting the hedge ratios to lie between 0 and 1 tends to reduce the effectiveness of both the conditional and unconditional hedging strategies.

4.2 Seven-asset portfolio

This sub-section repeats the above analysis for an equally weighted portfolio formed with all 7 stock markets and 6 currencies. The hedging results for the in-sample period presented in Table 8 show that conditional hedging which reduces portfolio risk by 14% is superior to all other hedging strategies in terms of risk reduction. The full hedge realizes the least amount of risk reduction. Also, the performance of various hedging strategies tends to improve as diversification increases. For example, the full hedge helps in reducing risk for the seven-asset portfolio, even though it tends to add risk to some less diversified two-asset portfolios we examined before. This is attributable to increased currency risk due to the increase in the level of foreign investments, which make currency hedging more beneficial. Also, increased diversification provides more natural hedges among currencies given that correlations between currencies are not perfect. The F-test result illustrates that conditional hedging is statistically significantly better than other hedging strategies except for unconditional hedging, and both conditional and unconditional hedging significantly reduce portfolio risk. Besides, the effectiveness of hedging is greatly reduced when the hedge ratio is constrained to lie between 0 and 1. This is true for both unconditional hedging and conditional hedging.

Table 8 Hedging results comparison for seven-asset portfolio (2002-2005)

This table presents mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression), constrained unconditional hedge, conditional hedge (hedge ratio based on dynamic conditional covariance matrix) and constrained conditional hedge. All constrained hedge ratios are bounded by 0 and 1. The portfolio contains all seven stock indices. All calculations are based on daily observations over the period January 2002 to December 2005. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. % down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging	Aus-Can-Jap-UK-Swit-Ger-US		
strategy	mean	stdev	% down
no hedge	0.054	0.812***	0.0
half hedge	0.044	0.776***	4.5
full hedge	0.035	0.790***	2.8
unconditional	0.040	0.714	12.1***
const'd uncon	0.043	0.752**	7.4**
conditional	0.039	**0.698**	14.0***
const'd con	0.040	0.753**	7.3**

Now we shift our focus to the ex-ante hedging results. Table 9 documents the performance of the hedging strategies for year 2006. Conditional hedging manages to lower the risk of the portfolio by 22.2%, higher than the risk reduction achieved by any other strategy. However, conditional hedging is only statistically significantly better than no hedge, but not other hedging strategies. Also, putting a constraint on the hedge ratio leads to less favourable hedging results.

Table 9 Hedging results comparison for seven-asset portfolio (2006)

This table presents mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression within-sample), constrained unconditional hedge, conditional hedge (hedge ratio estimated with forecasts of dynamic conditional covariance matrix based on in-sample VAR-DCC-GARCH parameters) and constrained conditional hedge. The constrained hedge ratios are bounded by 0 and 1. The portfolio contains all seven stock indices. All calculations are based on daily observations over the period January 2006 to December 2006. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging	Aus-Can-Jap-UK-Swit-Ger-US		
strategy	mean	stdev	% down
no hedge	0.084	0.728***	0.0
half hedge	0.070	0.644	11.5***
full hedge	0.055	0.603	17.2***
unconditional	0.077	0.608	16.5***
const'd uncon	0.073	0.629	13.5***
conditional	0.061	**0.566**	22.2***
const'd con	0.067	0.614	15.7***

The hedging result presented in Table 10 for the period covering the GFC again shows that all hedging strategies manage to reduce portfolio risk when the portfolio is more diversified. This is comparable to the result documented for the pre-crisis period as well as the in-sample period, and serves to re-emphasise the importance of diversification for its impact on hedging effectiveness of all the strategies out of sample. In addition, conditional hedging generates an impressive portfolio risk reduction of 35.3%, which is significantly better than the risk reduction of 10% and 17.6% achieved with the half hedge and full hedge respectively, despite the fact that static hedging is more widely used in practice. Conditional hedging also outperforms unconditional hedging, although the difference between the two is not statistically significant. When the hedge ratios are constrained to lie between 0 and 1, both the conditional and unconditional hedging strategies come close to a simple full hedge.

Table 10 Hedging results comparison for seven-asset portfolio (2006-2010)

This table presents mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression within-sample), constrained unconditional hedge, conditional hedge (hedge ratio estimated with forecasts of dynamic conditional covariance matrix based on in-sample VAR-DCC-GARCH parameters) and constrained conditional hedge. The constrained hedge ratios are bounded by 0 and 1. The portfolio contains all seven stock indices. All calculations are based on daily observations over the period January 2006 to April 2010. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging	Aus-Can-Jap-UK-Swit-Ger-US		
strategy	mean	stdev	% down
no hedge	0.028	1.378***	0.0
half hedge	0.021	1.240**	10.0**
full hedge	0.014	1.136	17.6***
unconditional	0.022	0.970	29.6***
const'd uncon	0.019	1.204**	12.6**
conditional	0.030	**0.891**	35.3***
const'd con	0.022	1.108	19.6***

In summary, we find that all hedging strategies help reduce risk for the seven-asset portfolio which, in comparison with the two-asset portfolios, highlights the effect of multicurrency diversification on the performance of hedging strategies. Conditional hedging dominates alternative hedging strategies both in sample and out of sample, though it is not statistically significantly different from unconditional hedging.

5. Marginal effect of hedging and the effectiveness of cross hedging

The preceding section documents an interesting fact that all hedging strategies manage to reduce portfolio risk when the underlying asset portfolio is more diversified while many strategies increase portfolio risk when the portfolio is less diversified. We consider this a benefit of multicurrency diversification, as currency risk represents a greater source of risk with increased diversification, and hedging in general is more beneficial when currency risk is high. Also, more natural hedges among currencies are available with increased diversification knowing that correlations between currencies are not perfect.

Based on our results, the more diversified the underlying portfolio is, the more likely that all hedging strategies help in reducing portfolio risk. Also, with a few exceptions, the percentage risk reduction achieved by the same hedging strategy is higher for a more diversified portfolio. It is then natural to ask if the desirable hedging result for a more diversified portfolio is driven by any particular currency/currencies, as a less diversified portfolio could have excluded the currency/currencies that is/are the most effective at reducing portfolio risk. To answer this question, we examine the marginal effect on hedging, of every single currency as well as three currency pairs for a relatively more diversified portfolio.

The test is carried out for an equally-weighted portfolio composed of all seven stock markets and for the seven strategies adopted in the preceding chapters. Instead of using all six currencies for hedging and estimating hedge ratios for each currency, we impose a zero hedge ratio for the currency/currencies being tested. For example, to test the marginal effect of AUD on hedging the currency risk embedded in the seven-asset portfolio, we assign a hedge ratio of 0 to AUD (that is, we do not hedge the AUD risk of the portfolio) and then numerically estimate the hedge ratios for the other five currencies that will minimize the portfolio variance. The same analysis is conducted for three currency pairs, namely AUD-CAD, AUD-JPY and CHF-EUR. These currency pairs are chosen for their distinctive characters:

i) AUD and CAD are commonly known as commodity currencies which are highly correlated with the price of commodities that Australia and Canada produce. These currencies can experience large swings in value due to changes in commodity prices and general market conditions;

ii) As we have discussed before, AUD and JPY are a popular pair for currency carry trades, due to the near zero interest rate in Japan and the high interest rate in Australia. The value of these currencies can fluctuate widely with carry trade activities;

iii) Campbell et al. (2010) suggest that CHF and EUR are negatively correlated with the world stock market and are therefore effective in reducing equity risk. These so called ‘reserve currencies’ also tend to increase in value during market turmoils due to ‘flight to quality’.

When testing for the marginal effect of a pair of currencies, we restrict the hedge ratio for both currencies in the pair to be zero.

Figure 1 Marginal effect for in-sample period (Jan 2002-Dec 2005)

This figure illustrates the marginal effect of currency/currencies on hedging performance for an equally-weighted seven-asset portfolio over the period January 2002 to December 2005. The vertical-axis shows the hedged portfolio risk as a percentage of the unhedged portfolio risk. The horizontal-axis shows which currency or currency pair has been excluded from hedging. The 'original' portfolio employs all six currencies for hedging.[19] The seven strategies considered for this test are (as previously defined): no hedge, half hedge, full hedge, unconditional hedge, constrained unconditional hedge, conditional hedge and constrained conditional hedge.

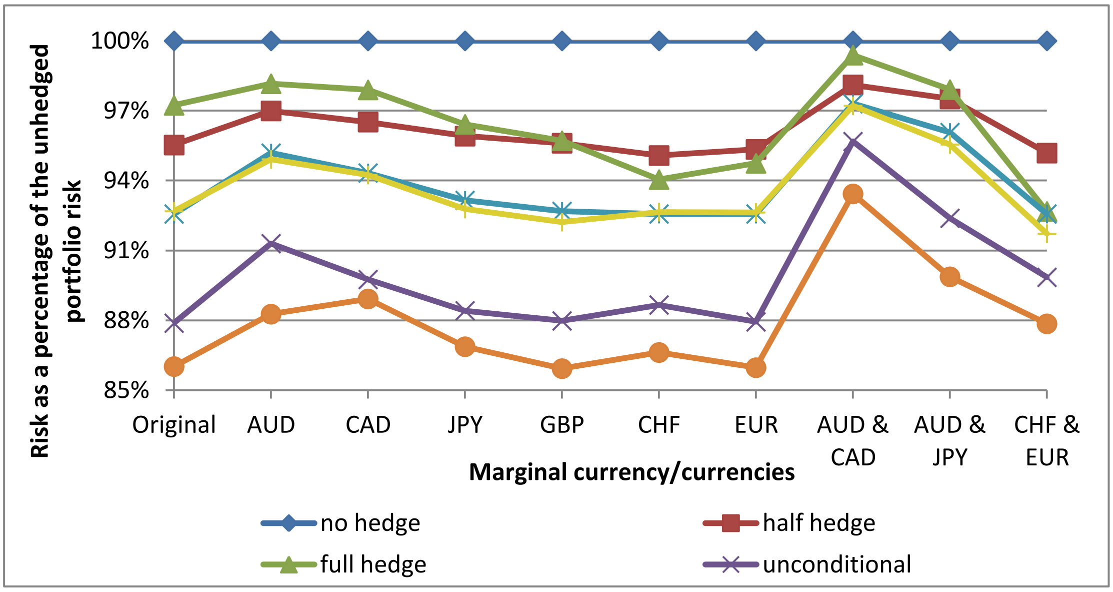


Figure 1 illustrates the marginal effect of single currency and currency pairs on the performance of seven hedging strategies for the period January 2002 to December 2005. The status quo is the 'original' portfolio which employs all six currencies for hedging, as has been examined in section 4. The horizontal-axis shows which currency (currencies) is (are) not included in the hedging strategies. The performance of hedging can be evaluated by the hedged portfolio risk which is expressed as a percentage of the unhedged portfolio risk. The risk of the portfolio with 'no hedge' is 100% regardless of the currency (currencies) being excluded from hedging. To demonstrate how to interpret the result, in testing the marginal effect of AUD, we assign a hedge ratio of 0 for AUD. The orange line shows that the risk (standard deviation) of the conditionally hedged portfolio (without hedging the AUD risk) is about 88% of the unhedged portfolio risk. Similarly, the purple line depicts that the risk of the unconditionally hedged portfolio (with a hedge ratio of 0 for AUD) is about 91% of the unhedged portfolio risk. Also, the conditional hedging strategy performs the best for this 'marginal currency' portfolio as it results in the smallest portfolio risk.

[19] The result of hedging the seven-asset portfolio with all six currencies is documented in section 5.1, Table 5.6. The same hedging result is used here as a starting point for comparison with the result of the marginal effect test.

We also tested the statistical significance of:

i) the difference between the conditional hedging strategy and every other strategy (e.g. no hedge, half hedge etc) for every marginal currency portfolio indicated on the horizontal-axis of the graph; and of

ii) the difference between each marginal currency portfolio and the 'original' portfolio under each hedging strategy. The test results will be described as we proceed through this section.

From Figure 1, it seems that for single currencies, imposing a zero hedge ratio for AUD and CAD has the biggest negative impact on the hedging performance of all hedging strategies as the hedged portfolio risk now represents a bigger percentage of the unhedged portfolio risk compared to the original. On the other hand, imposing a zero hedge ratio for CHF and EUR has positive impact on the hedging performance of the full hedge and half hedge. The hedged portfolio risk represents a smaller percentage of the unhedged risk relative to the original, and this is especially evident for the full hedge. However, the difference between the risk of the portfolio hedged with five currencies and that of its original counterpart is not statistically significant at the 5% level.

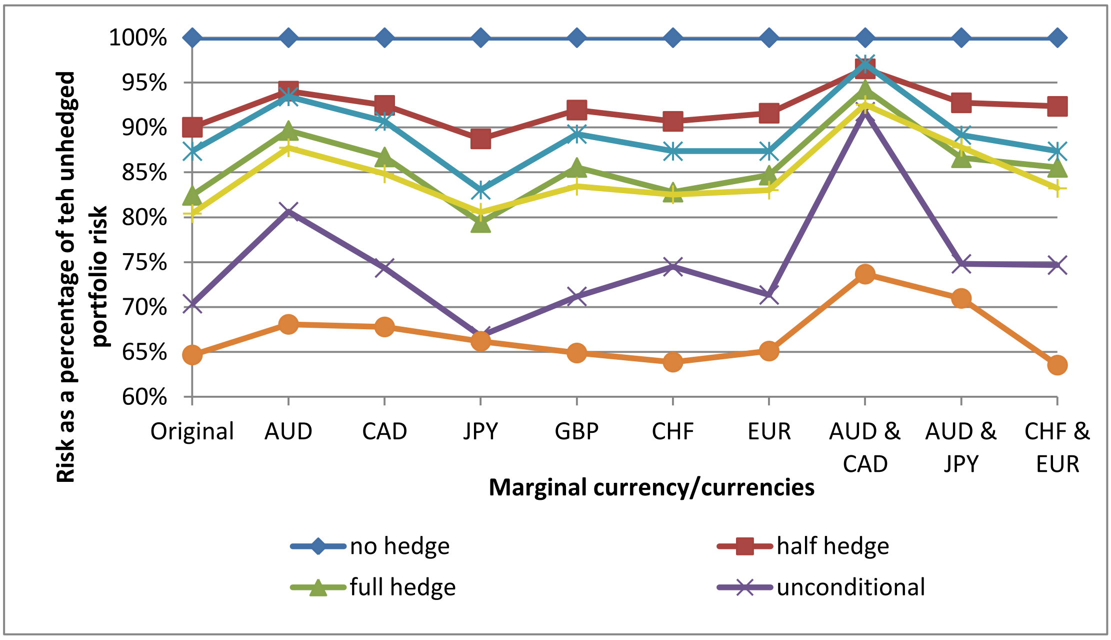
For currency pairs, excluding AUD and CAD from hedging clearly reduces the performance of all hedging strategies, with unconditional hedge and conditional hedge being affected the most. For these strategies, the difference between the risk of the portfolio hedged with four currencies and the risk of the portfolio hedged with all six currencies (original) under the same hedging strategy is as high as 8%, and the difference is statistically significant at the 5% level. But as in the case of the 'original' portfolio, the difference between the conditional and unconditional hedging strategies for the marginal currency portfolio (AUD-CAD) is not statistically significant. Imposing a zero hedge ratio on AUD and JPY also has a negative impact on the performance of all hedging strategies, though the impact is smaller compared to that of the first currency pair. The marginal effect of CHF and EUR on hedging performance differs across strategies. Removing the two currencies from hedging enhances the performance of the full hedge but lowers the performance of the conditional and unconditional hedge. However, the marginal effect of the last two currency pairs is not statistically significant, as the risk of the marginal portfolio is not significantly different from the risk of the 'original' portfolio under any hedging strategy.

Figure 2 demonstrates the marginal effect of hedging for the out-of-sample period of Jan

2006-Apr 2010. The result for this period resembles the result for the in-sample period in the sense that for the single currencies, imposing a zero hedge ratio for AUD and CAD has a clear adverse effect on the performance of all hedging strategies, whilst removing other currencies has a less significant impact on hedging performance. Moreover, when AUD is excluded from hedging, the risk of the marginal portfolio is statistically significantly different from the risk of the 'original' portfolio under all hedging strategies except for the half hedge and conditional hedge. For currency pairs, excluding AUD-CAD from hedging significantly reduces the performance of all hedging strategies. This is especially true for unconditional hedging where the hedged risk is more than 20% higher than that of its 'original' counterparts. The other two pairs of currencies have limited impact on hedging performance.

Figure 2 Marginal effects for out-of-sample period (Jan 2006-Apr 2010)

This figure illustrates the marginal effect of currency/currencies on hedging performance for an equally-weighted seven-asset portfolio over the period January 2006 to April 2010. The vertical-axis shows the hedged portfolio risk as a percentage of the unhedged portfolio risk. The horizontal-axis shows which currency or currency pair has been excluded from hedging. The 'original' portfolio employs all six currencies for hedging. The seven strategies considered for this test are (as previously defined): no hedge, half hedge, full hedge, unconditional hedge, constrained unconditional hedge, conditional hedge and constrained conditional hedge.



It appears that all hedging strategies are more effective at reducing portfolio risk during the out-of-sample period, for example, the risk of the 'original' unconditionally hedged portfolio represents 88% of the unhedged portfolio risk for the in-sample period, whereas the corresponding figure is about 70% for the out-of-sample period. Also, the performance of the full hedge has improved significantly relative to other strategies when compared to the in-sample period. Instead of being the worst performing strategy as in the in-sample period, the full hedge is dominated only by the conditional and unconditional hedge during this period.

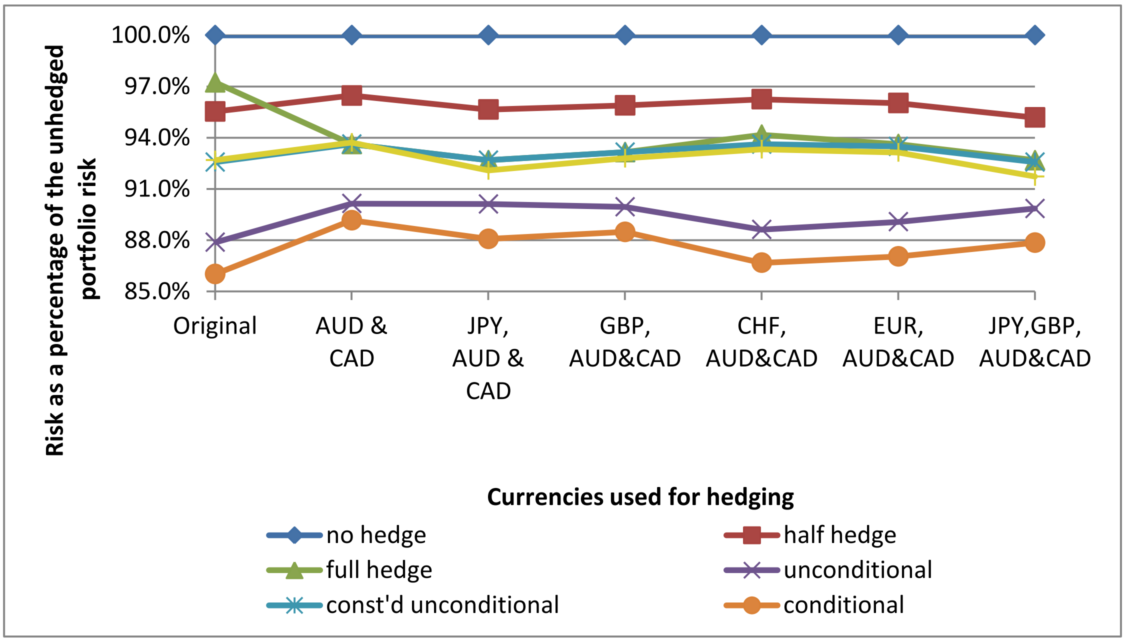
One unique result for this period is that when JPY is excluded from hedging, the performance of all hedging strategies except for conditional hedging improves relative to the ‘original’ scenario and all the other scenarios that have been considered, though the improvement is not statistically significant. As has been documented in section 3, JPY had a negative correlation with all stock markets except for the Japanese market during the period covering the GFC, despite the fact that most of the corresponding correlations are positive in the in-sample period. This suggests that JPY could to some degree hedge against a decline in the world stock market during the GFC. JPY also had low or negative correlation with most currencies considered. So with hindsight, exposure to the yen should be considered as a natural hedge for the position in stocks and other currencies and ought to be left unhedged during the GFC. Indeed in the out-of-sample analysis of hedging performance in section 4, we note that all hedging strategies except for conditional hedging increase the risk of the two-asset portfolio consisting of Japan and the U.S. over the period covering the GFC, although all strategies help reduce portfolio risk for the portfolio invested in all stock markets.

The role of JPY as a safe haven currency during financial crises has been well documented (see Kohler, 2010; Ranaldo & Soderlind; 2010; Habib & Stracca, 2011 among others). However, every crisis is different. The safe haven status of a currency depends on a country’s net foreign asset position, market size, stability of the financial system and liquidity. The yen might lose its ability to hedge against a decline in the world equity market during the next crisis if it loses its safe haven status. In other words, the low or negative correlations between JPY and the world stock markets are not guaranteed. This is precisely why conditional hedging is more desirable than static or unconditional hedging strategies. Conditional hedging constantly updates the hedge ratios based on the forecasts for correlations and volatilities made by the DCC-GARCH model as new data becomes available. This enables conditional hedging to adapt to changes in market conditions especially when the market is in turmoil.

To sum up, the marginal effect of a single currency on hedging performance is not immediately obvious except for that of AUD and CAD. In addition, the combination of AUD and CAD has a statistically significant impact on the performance of all hedging strategies both in-sample and out-of-sample. This poses the question of whether the currency exposure of a diversified portfolio can be effectively cross hedged. That is, whether hedging the portfolio's exposure with less than six currencies, especially AUD and CAD, can achieve more or less the same outcome as hedging with all six currencies. The marginal effect test serves this purpose in the sense that excluding one currency (two currencies) from hedging is equivalent to hedging with the remaining five (four) currencies. We have already identified AUD and CAD as the main driver of the hedging result in terms of portfolio risk reduction. Next we will examine how effective AUD and CAD are at reducing portfolio risk, compared to using all six currencies for hedging as in the 'original' scenario. We will also look at whether adding other currency (currencies) to the pair will improve hedging performance. This test considers hedging with 6 groups of currencies: AUD-CAD, AUD-CAD-JPY, AUD-CAD-GBP, AUD-CAD-CHF, AUD-CAD-EUR and AUD-CAD-JPY-GBP. The performance of the seven hedging strategies we consider in this study will be recorded for each group of currencies both in sample and out of sample. The in-sample results are displayed in Figure 3.

Figure 3 Cross hedging for in-sample period (Jan 2002-Dec 2005)

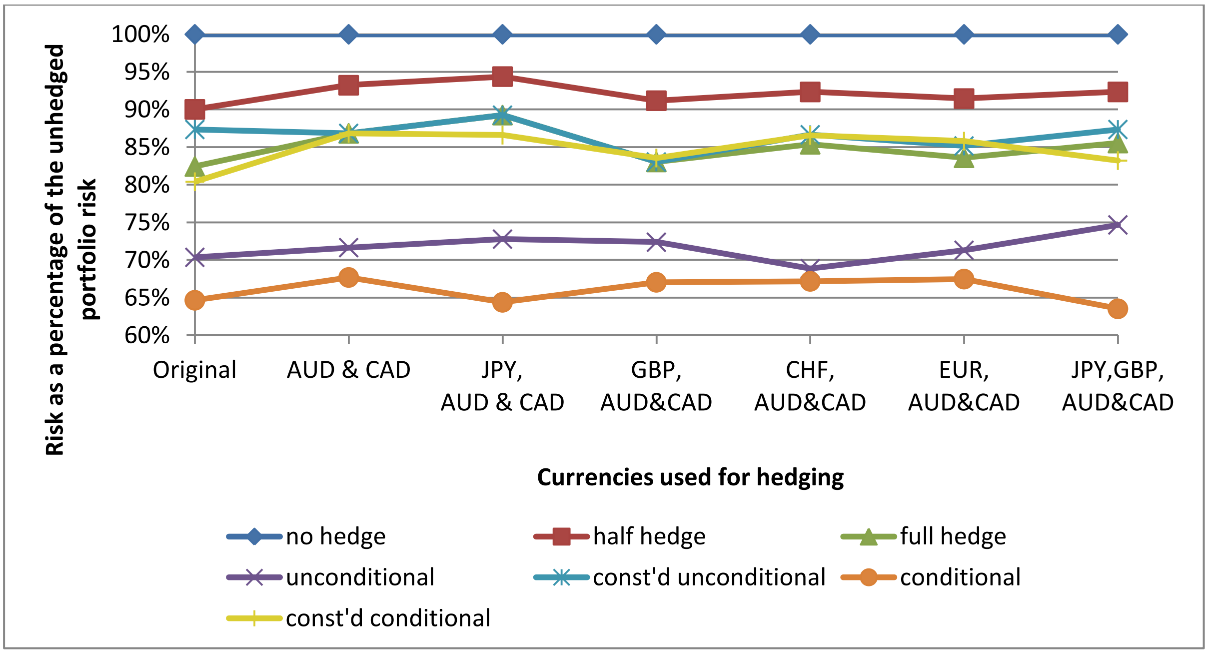
This figure illustrates the effectiveness of cross hedging currency risk for an equally-weighted seven-asset portfolio over the period January 2002 to December 2005. The vertical-axis shows the hedged portfolio risk as a percentage of the unhedged portfolio risk. The horizontal-axis shows which currencies are <u>used</u> for hedging. The 'original' portfolio employs all six currencies for hedging. The seven strategies considered for this test are (as previously defined): no hedge, half hedge, full hedge, unconditional hedge, constrained unconditional hedge, conditional hedge and constrained conditional hedge.



The figure shows that hedging with AUD and CAD achieves sizable risk reduction under all hedging strategies. The risk reduction realized by fully hedging the exposure to AUD and CAD is noticeably larger than that realized by fully hedging all six currencies. As for other hedging strategies, the risk reduction resulting from hedging these two currencies is only slightly lower than that of their counterparts in the 'original' scenario. We find that hedging with only AUD and CAD is not statistically significantly different (at the 5% level) from hedging with all six currencies under any hedging strategy. The same can be said for the other groups of currencies, which also prove to be effective at reducing portfolio risk.

Figure 4 Cross hedging for out-of-sample period (Jan 2006-Apr 2010)

This figure illustrates the effectiveness of cross hedging currency risk for an equally-weighted seven-asset portfolio over the period January 2006 to April 2010. The vertical-axis shows the hedged portfolio risk as a percentage of the unhedged portfolio risk. The horizontal-axis shows which currencies are used for hedging. The 'original' portfolio employs all six currencies for hedging. The seven strategies considered for this test are (as previously defined): no hedge, half hedge, full hedge, unconditional hedge, constrained unconditional hedge, conditional hedge and constrained conditional hedge.



The same conclusion can be reached for the out-of-sample period of January 2006 to April 2010. From Figure 4, it is clear that the majority of the risk reduction achieved in the 'original' scenario by hedging with all six currencies can be realized by hedging with AUD and CAD only. This is true for all hedging strategies, especially the half and unconditional hedge. Similar to the results for the in-sample period, the difference between hedging with AUD and CAD and hedging with all six currencies is not statistically significant under any hedging strategy. Adding JPY to AUD and CAD for hedging significantly worsens the performance of the full hedge relative to the 'original' scenario, whilst adding other currencies to the pair for hedging does not have significant impact on the hedging performance under any hedging strategy.

The results for the analysis on cross hedging confirm our finding from the analysis on the marginal effect of hedging. The analysis identifies AUD and CAD as the main drivers of the risk reduction achieved by all the hedging strategies for the seven-asset portfolio over both the in-sample and out-of-sample periods. The effectiveness of using AUD and CAD to reduce portfolio risk is especially high during the recent GFC. It is interesting to note that the banking system of Australia and Canada also fared well during the GFC and came out mostly unscathed (Stevens, 2009).

The analyses conducted in this section, though simple, have important implication for cross hedging a well-diversified international equity portfolio with fewer currencies than the portfolio has exposure to. Many international equity funds manage equity portfolios invested in 20 to 30 currencies. Hedging the exposure to every single currency can be time consuming and hard to implement/maintain over time, especially when the hedge requires frequent rebalancing, not to mention the transaction costs involved, and the difficulty in hedging the less liquid currencies. Cross hedging allows a fund manager to focus on a few liquid currencies to hedge the exposure of the entire portfolio, reducing transaction costs and providing ease for managing the hedge over time. The challenge lies in the choice of currencies for cross hedging. With a portfolio of seven stock markets, we show that AUD and CAD can effectively cross hedge the exposure of the entire portfolio for a US investor. Further research on cross hedging a more diversified international portfolio potentially including emerging markets looks promising.

6. AUD as the base currency

The analyses we have done so far assume a US perspective. It is natural to ask if the findings apply to other base currencies as well. The last section demonstrates that AUD has the highest marginal effect on hedging the seven-asset portfolio from the perspective of a US investor. In this section, we take the perspective of an Australian investor, and carry out the same analyses as performed section 4 to see if our results agree with that from the US perspective. To avoid repetition, we will only report the results for the seven-asset portfolio over the in-sample and out-of-sample periods.[20]

Table 11 reports the unconditional and the average conditional hedge ratios, as well as their constrained counterparts, for the six currencies including USD (which replaces AUD). The unconditional hedge ratios for the five currencies other than USD are exactly the same as those estimated from a US perspective (as can be seen from Appendix A). This is expected as it has been shown by Campbell et al. (2010) that the variance-minimizing hedge ratios are the same for a given international portfolio regardless of the base currency. The average conditional hedge ratios are also very close to those which have been estimated from a US perspective.

Table 11 Hedge ratios for seven-asset portfolios (2002-2005)

This table presents both unconditional and conditional hedge ratios for equally-weighted seven-asset portfolios from an Australian perspective over the sample period January 2002 to December 2005. Unconditional hedge ratios are generated by regressing the unhedged portfolio return (in AUD) onto the currency forward returns. Daily conditional hedge ratios are computed using equation (2.8), with the conditional covariance matrix estimated from the DCC-GARCH model.

Panel A: Unconditional hedge ratios						
	USD	CAD	JPY	GBP	CHF	EUR
unconstrained	2.06	2.47	1.13	0.68	-3.47	1.17
constrained	1.00	1.00	1.00	0.45	0.00	1.00
Panel B: Average conditional hedge ratios						
unconstrained	2.48	1.99	1.29	0.79	-2.29	0.94
std dev	*1.13*	*1.26*	*0.44*	*0.46*	*1.13*	*0.97*
constrained	1.00	0.98	0.94	0.71	0.00	0.67
std dev	*0.01*	*0.06*	*0.14*	*0.28*	*0.00*	*0.41*

Table 12 illustrates the hedging performance of the seven strategies during the in-sample period of January 2002 to December 2005 from an Australian perspective. The results are comparable to those generated from a US perspective over the same period. The percentage risk reduction of the hedging strategies is very similar albeit slightly higher than that of their counterparts documented for US investors in Table 8. The ranking of the strategies is the same as that from the US perspective; the conditional hedge dominates the unconditional hedge which in turn dominates the static hedges and constrained hedges, but the difference between the conditional and unconditional hedge is not statistically significant. Also, the risk reduction achieved by the unconditional and conditional hedging strategies as well as their constrained counterparts is statistically highly significant.

[20] Full result of the analysis is available on request.

Although the level of risk as measured by portfolio standard deviation is in general very close to that from the US perspective, the mean portfolio return tends to be significantly lower. The unhedged mean return for an Australian investor holding the equally-weighted seven-asset portfolio is 0.019% (as in Table 12), whereas the mean return for a US investor holding the same portfolio is 0.054% as reported in Table 8. This is understandable given that the USD depreciated against all major currencies during the in-sample period whereas AUD appreciated against all the currencies. Therefore without hedging, the same portfolio would have generated on average much smaller return for an Australian investor than for a US investor. Hedging not only lowers portfolio risk but also enhances portfolio return on average.

Table 12 Hedging results comparison for seven-asset portfolio (2002-2005)

This table presents mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression), constrained unconditional hedge, conditional hedge (hedge ratio based on dynamic conditional covariance matrix) and constrained conditional hedge. All constrained hedge ratios are bounded by 0 and 1. The portfolio contains all seven stock indices. All calculations are done from an Australian perspective based on daily observations over the period January 2002 to December 2005. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging strategy	Aus-Can-Jap-UK-Swit-Ger-US		
	mean	stdev	% down
no hedge	0.019	0.814***	0.0
half hedge	0.020	0.773***	5.0*
full hedge	0.021	0.790***	2.9
unconditional	0.026	0.713	12.3***
const'd uncon	0.022	0.746	8.4***
conditional	0.032	**0.709**	12.8***
const'd con	0.024	0.749***	7.9***

The appreciation of AUD over the in-sample period is illustrated in Figure 5 which plots the spot exchange rate of the six foreign currencies in terms of AUD over the period January 2002 to April 2010. The adverse effect of AUD's rise in value on the return of foreign investments for an Australian investor is evident in Table 13 which reports the summary statistics of returns on stock markets both in local currency and in Australian dollar. The average return of all stock markets is shown to be lower in terms of AUD than in their own currencies in Panel A of the table. The most noticeable is the US stock market which generates an average return of 0.019% in USD, but the return is a disappointing -0.013%

when measured in AUD, owing to the sharp decline of USD against AUD during this period. This pattern in mean return persists in the out-of-sample period, as AUD experienced a sharp but temporary decline in value during the height of the crisis in 2008 and quickly gained value against the other currencies soon after that. This can be seen very clearly from Figure 5.

Figure 5 Spot exchange rates

The figure plots daily spot exchange rates of AUD against six currencies: USD, CAD, JPY, GBP, CHF and EUR over January 2002 - April 2010. All exchange rates are quoted in terms of AUD.

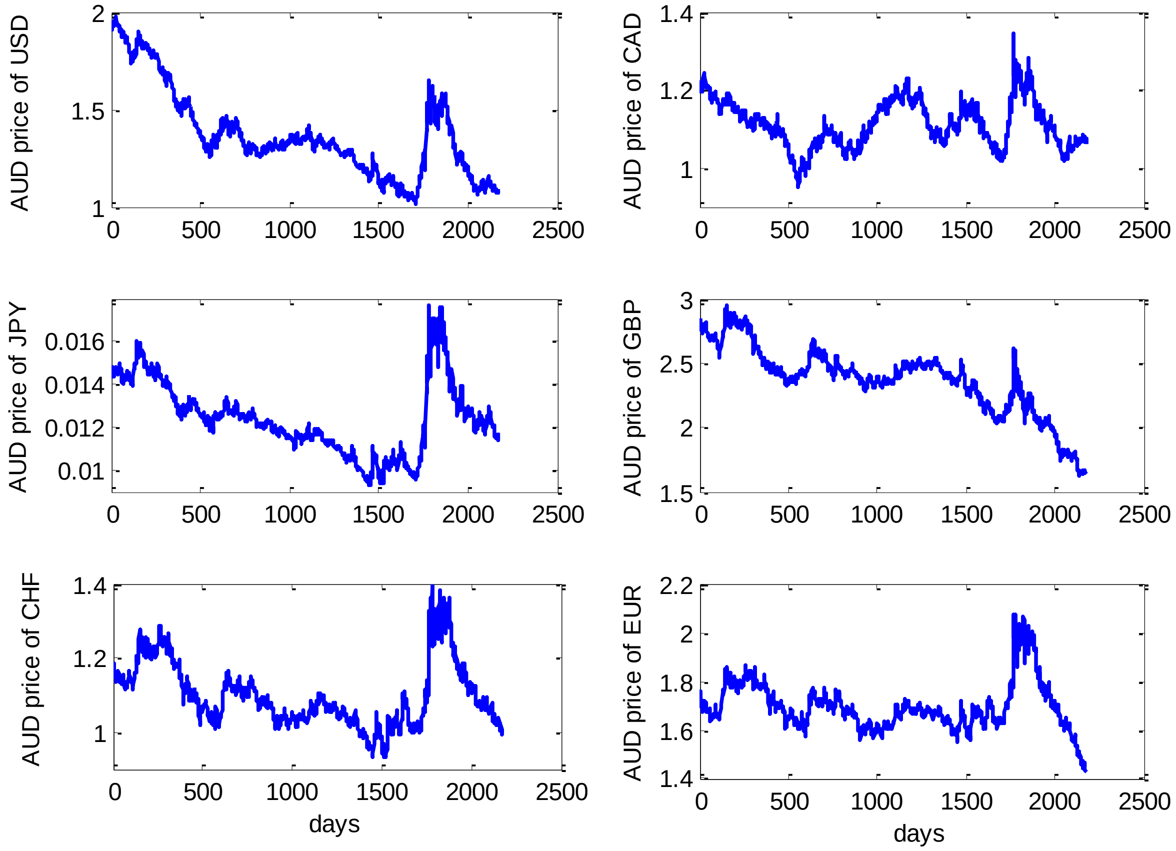


Table 13 Summary statistics (Australian perspective)

The table reports descriptive statistics of stock market returns and forward currency hedge returns for the periods: January 2002-December 2005 and January 2006-April 2010. Mean stock return (local currency) is the average daily stock market return measured in local currency. Mean stock return (AUD) is the average daily unhedged stock market return measured in AUD. Mean currency forward return is the average daily return on a long position in a one-day currency forward contract measured in AUD. Daily data on MSCI country stock indices, spot exchange rates and one-day forward exchange rates are obtained from DataStream. Mean and standard deviation are in percentage terms.

	US	Canada	Japan	UK	Switzerland	Germany	Australia
%	Panel A: January 2002-December 2005						
mean stock return (local currency)	0.019	0.045	0.051	0.025	0.031	0.019	0.044
standard deviation	1.082	0.827	1.144	1.104	1.207	1.650	0.645
mean currency forward return	-0.019	0.006	0.000	-0.013	0.008	0.005	-
standard deviation	0.664	0.582	0.660	0.569	0.625	0.563	-
mean stock return (AUD)	-0.013	0.042	0.029	0.007	0.018	0.011	0.044
standard deviation	1.277	0.991	1.286	1.120	1.163	1.576	0.645
	Panel B: January 2006-April 2010						
mean stock return (local currency)	0.014	0.030	-0.022	0.024	0.004	0.016	0.026
standard deviation	1.586	1.588	1.717	1.481	1.350	1.577	1.420
mean currency forward return	-0.004	0.007	0.032	-0.019	0.020	0.005	-
standard deviation	1.108	0.839	1.493	0.884	1.054	0.860	-
mean stock return (AUD)	-0.005	0.022	-0.025	-0.010	-0.002	0.003	0.026
standard deviation	1.677	1.644	1.642	1.324	1.123	1.388	1.420

The out-of-sample performance of the hedging strategies for the year 2006 is reported in Table 14. As in the case of the US perspective, all hedging strategies result in lower portfolio risk. However, the risk reduction lacks statistic significance which is in contrast to the result documented in Table 9 for a US investor. From Table 9, the conditional hedge generates a risk reduction of 22.2% at 1% significance level. The other hedging strategies also have sizable risk reductions which are not statistically significantly different from that of the conditional hedge. But when we take a closer look at the two sets of results, the unhedged portfolio risk from the Australian perspective is only 0.627% for the period, much lower than the risk of 0.728% from a US perspective. The risk of the conditionally hedged portfolio is 0.579% for an Australian investor, slightly higher than the risk of 0.566% of the corresponding portfolio for a US investor. For the other strategies, the hedged portfolio risk from an Australian perspective is either the same or a little lower than its counterparts from a US perspective. Therefore, even though the hedging strategies do not seem to provide much benefit for an Australian investor in year 2006, the hedged portfolio risk is largely comparable to that from a US perspective, and the reason for the relatively poorer performance of the hedging strategies from an Australian perspective is because the unhedged portfolio risk is lower in AUD than USD to start with.

Table 14 Hedging results comparison for seven-asset portfolio (2006)

This table presents mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression within-sample), constrained unconditional hedge, conditional hedge (hedge ratio estimated with forecasts of dynamic conditional covariance matrix based on in-sample VAR-DCC-GARCH parameters) and constrained conditional hedge. The constrained hedge ratios are bounded by 0 and 1. The portfolio contains all seven stock indices. All calculations are done from an Australian perspective based on daily observations over the period January 2006 to December 2006. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging	Aus-Can-Jap-UK-Swit-Ger-US		
strategy	mean	stdev	% down
no hedge	0.056	0.627	0.0
half hedge	0.054	0.592	5.5
full hedge	0.052	0.603	3.8
unconditional	0.073	0.608	3.0
const'd uncon	0.061	0.588	6.2
conditional	0.064	**0.579**	7.7
const'd con	0.055	0.587	6.3

For the entire out-of-sample period that covers the recent GFC, all hedging strategies except for conditional hedging increase the risk of the unhedged portfolio as shown in Table 15, and the increase in risk is generally statistically significant. This result might seem shocking at first, especially when all hedging strategies helped reduce portfolio risk for a US investor over the same period, with the top performing strategy shedding more than 35% portfolio risk. However, this result can be explained in the same way as we did for the result of year 2006. The unhedged portfolio risk is lower in AUD than USD in the first place. Compared with the result documented in Table 10, the unhedged portfolio risk is 1.378% for a US investor, but only 0.902% for an Australian investor (from Table 15). For all hedging strategies, the risk of the hedged portfolios, though not lower than the risk of the unhedged portfolio, is generally comparable to and even slightly lower than its counterpart from the US perspective. It can be concluded that an Australian investor who holds the same international equity portfolio as a US investor will receive more or less the same hedging result in terms of hedged portfolio risk for all hedging strategies both in-sample and out-of-sample. However, hedging might not be beneficial for the Australian investor during certain time periods such as the recent GFC.

The current literature on currency hedging lacks evidence on the relationship between the base currency and the benefit of currency hedging. More studies in this area are needed to determine how the benefit of hedging the same global asset portfolio is affected by the investor's base currency, and how this effect changes over time as we go through different economic conditions.

Table 15 Hedging results comparison for seven-asset portfolio (2006-2010)

This table presents mean and standard deviation of hedged portfolio returns under different hedging strategies: No hedge (h=0), half hedge (h=0.5), full hedge (h=1), unconditional hedge (hedge ratio generated by OLS regression within-sample), constrained unconditional hedge, conditional hedge (hedge ratio estimated with forecasts of dynamic conditional covariance matrix based on in-sample VAR-DCC-GARCH parameters) and constrained conditional hedge. The constrained hedge ratios are bounded by 0 and 1. The portfolio contains all seven stock indices. All calculations are done from an Australian perspective based on daily observations over the period January 2006 to April 2010. Mean and standard deviation are in percentage terms. An F-test of equal variance (standard deviation) is performed for the conditional hedge against every other hedge. In the "stdev" column, ***, ** and * respectively represent 1%, 5% and 10% significance levels at which the null of equal variance can be rejected. The best performing hedge with the lowest standard deviation is in bold. %down = percentage change in standard deviation relative to no hedge. The statistical difference between no hedge and every other hedge is shown by the significance indicators (*** etc) in the "%down" column.

hedging	Aus-Can-Jap-UK-Swit-Ger-US		
strategy	mean	stdev	% down
no hedge	0.001	0.902	0.0
half hedge	-0.001	0.946**	-5.0*
full hedge	-0.004	1.140***	-26.5***
unconditional	0.006	0.968***	-7.3**
const'd uncon	-0.002	0.983***	-9.0***
conditional	0.000	**0.884**	1.9
const'd con	0.000	0.937*	-3.9

It is then natural to ask why is hedging unwarranted during the out-of-sample period for an Australian investor, and why is the unhedged portfolio risk so much lower than that from the US perspective. To answer these questions, we turn our attention back to Table 13 which reports the risk of each stock market in both local currency and the Australian dollar. During the in-sample period, (from Panel A) the stock market risk measured in AUD is generally higher than that in local currency except for Switzerland and Germany, the same is documented from the US perspective. However, during the out-of-sample period, (from Panel B) the stock market risk measured in AUD is lower than that in local currency for four countries other than the U.S. and Canada. In contrast, from the US perspective, Japan is the only stock market that has a lower risk when measured in USD than in local currency JPY. From the Australian perspective, the lower stock market risk in AUD for four out of six foreign markets certainly contributes positively to the lower overall risk of the portfolio.

Obviously the riskiness of each stock market is not the only determinant of the overall portfolio risk, and we need to also look at how the stock markets tend to co-move over time.

The stock market correlations reported in Table 2 suggest that from the US perspective, the stock markets tend to co-move more during the crisis period. This is consistent with previous studies documenting increased correlations between international stock markets in market downturns (see Lin, Engle & Ito, 1994; Longin & Solnik, 2001 for example). Table 16 reports the correlation of stock market returns measured in AUD during both the in-sample and the out-of-sample period. In contrast, many correlations in Panel B for the period covering the GFC are actually lower than their counterparts in Panel A for the in-sample period, and no single correlation has increased by more than 0.05 in the out-of-sample period. This is another reason why the risk of the unhedged portfolio return measured in AUD is much lower than that in USD. It should be noted that the reason why the correlations between stock market returns are different for different base currency is because the returns are measured in the base currency and are affected by the changes in exchange rates. The correlations will be the same regardless of the base currency if stock market returns are measured in local currencies instead.

Table 16 AUD stock market return correlations

The table reports unconditional correlations among unhedged daily country stock market returns measured in AUD for the period January 2002 to April 2010 and two sub-periods. All correlations are statistically significant at the 5% level.

	US	Canada	Japan	UK	Switzerland	Germany	Australia
	Panel A: January 2002-December 2005						
US	1.00						
Canada	0.69	1.00					
Japan	0.20	0.22	1.00				
UK	0.52	0.49	0.21	1.00			
Switzerland	0.48	0.45	0.22	0.76	1.00		
Germany	0.63	0.56	0.17	0.73	0.72	1.00	
Australia	0.00	0.08	0.30	0.17	0.15	0.10	1.00
	Panel B: January 2006-April 2010						
US	1.00						
Canada	0.65	1.00					
Japan	0.02	0.02	1.00				
UK	0.39	0.51	-0.05	1.00			
Switzerland	0.41	0.41	0.09	0.71	1.00		
Germany	0.45	0.47	-0.05	0.78	0.71	1.00	
Australia	-0.17	0.06	0.35	0.19	0.08	0.14	1.00

Lastly, to explain why almost all hedging strategies added risk to the portfolio during the out-of-sample period, we will look at the correlations among currency forward returns and the cross correlations between currencies forward returns and stock market returns. The former are documented in Appendix B. The correlations in the out-of-sample period are generally higher than the corresponding correlations in the in-sample period, reducing the degree of natural hedges among currencies resulting from multi-currency diversification. The latter are reported in Table 17, the correlations in Panel B (for the out-of-sample period) are in many cases significantly lower than the corresponding correlations in Panel A (for the in-sample period). The most noticeable result from the table is that the Australian stock market had a negative correlation with all currencies during the in-sample period, and those correlations became much more negative during the period covering the GFC. The correlations between the British stock market and the currency forwards also reduced significantly during the out-of-sample period with four out of six turning negative. The negative correlations imply that exposure to foreign currencies to some extent serves as a natural hedge to the equity risks facing an Australian investor, and hedging simply removes this natural hedge. This issue together with the other factors we have identified earlier are likely to have contributed to the low unhedged portfolio risk facing an Australian investor and the poor hedging performance out of sample.

Table 17 AUD stock-market-return and currency-forward-return correlations

The table reports unconditional correlations between unhedged stock market returns and currency forward returns for the period January 2002 to April 2010 and two sub-periods. All returns are measured in Australian dollar and are on daily basis. The underlined correlation coefficients are not significant at the 5% level.

	US	Canada	Japan	UK	Switzerland	Germany	Australia
	Panel B: January 2002-December 2005						
USD	0.53	0.35	0.23	0.33	0.31	0.23	-0.12
CAD	0.38	0.55	0.20	0.26	0.28	0.21	-0.05
JPY	0.29	0.21	0.46	0.13	0.20	0.09	-0.14
GBP	0.28	0.22	0.15	0.28	0.21	0.10	-0.19
CHF	0.12	0.13	0.10	0.04	0.20	-0.01	-0.21
EUR	0.17	0.16	0.13	0.09	0.21	0.05	-0.19
	Panel C: January 2006-April 2010						
USD	0.41	0.01	0.31	-0.14	0.11	-0.12	-0.42
CAD	0.39	0.32	0.21	0.09	0.28	0.11	-0.27
JPY	0.26	-0.06	0.40	-0.25	0.08	-0.18	-0.39
GBP	0.34	0.11	0.27	0.14	0.23	0.04	-0.32
CHF	0.22	-0.03	0.28	-0.17	0.23	-0.04	-0.40
EUR	0.30	0.05	0.30	-0.06	0.28	0.07	-0.37

In summary, hedging is equally beneficial to an Australian investor and a US investor within sample. However out of sample, the Australian investor fares poorly with hedging, and all hedging strategies except for conditional hedging end up adding risk to the portfolio. Closer examination reveals that the hedging outcome, in terms of hedged portfolio risk, from the Australian perspective is comparable to that from the US perspective. The poor performance of the hedging strategies relative to no hedge for the Australian investor is due to the fact that the unhedged portfolio risk is much smaller in AUD than in USD. This finding highlights the fact that even if the hedging outcome in terms of hedged portfolio risk is the same across different base currencies, the practice of hedging might be more beneficial for certain base currencies than others depending on market conditions. The result calls for further research on the benefit and timing of hedging for different base currencies.

7. Conclusion

This paper investigates the practice of currency hedging for international stock portfolios for the purpose of risk-minimization. The performance of various hedging strategies are examined for a number of portfolio compositions both in-sample and out-of-sample. It has been shown by Brown et al. (2012) that the conditional hedging strategy is better at achieving a hedger's objective compared to unconditional hedging and static strategies both in sample and out of sample. We document that all hedging strategies tend to perform better for the most diversified seven-asset portfolio than for less diversified portfolios both in and out of sample. By testing the marginal effect of each currency and a number of currency pairs on hedging performance, we identify AUD and CAD as the most effective at reducing the overall risk of the seven-asset portfolio. Hedging with only AUD and CAD is found to differ little from hedging with all currencies, and the ability of these two currencies in cross hedging the seven-asset portfolio is especially visible for the period covering the GFC. Cross hedging is useful in practice when an international portfolio has exposure to a large number of currencies, and hedging the exposure to every single currency becomes costly and inefficient. Our result has positive implications for further research in this direction, and the focus of future research should be on how to identify the currencies that are most effective for cross hedging international portfolios.

When comparing the performance of various hedging strategies for the seven-asset portfolio from an Australian perspective, the in-sample result for hedging is almost identical to that from the US perspective. However out of sample, an Australian investor is found to be better off not hedging the currency exposure as all hedging strategies except for the conditional hedging strategy add risk to the portfolio, despite the hedged portfolio risk being comparable to its counterpart for a US investor under each hedging strategy. This is because the unhedged risk of the seven-asset portfolio is significantly smaller from the Australian perspective than from the US perspective during the out-of-sample period covering the recent GFC. This is an interesting result, as we show that even if hedging leads to the same portfolio risk for all base currencies, the decision in implementing the hedge is not universal and should be made individually for each base currency.

Finally, we summarize below the limitations of the current study and their implications for future research:

1) The DCC model restricts all correlation processes to have the same dynamic structure, which is undesirable for large systems. Various generalizations of the DCC model can be used to allow for more flexible correlation structure, but this is usually at the cost of lower estimation efficiency.
2) The out-of-sample forecasts of mean, variances and covariance are based on fixed parameters estimated within sample. Updating (re-estimating) the model parameters during the out-of-sample period as new data become available could produce more relevant results for the period.
3) The analyses done in the thesis assume daily rebalancing of hedging positions and no transactions costs. Although incorporating transactions costs will not affect our conclusions, future study on conditional hedging relative to less costly hedging strategies could do so for a more accurate comparison.
4) The study examines only seven developed countries for portfolio diversification and hedging. These countries are all in a relatively mature stage of their economic development, their economies are highly co-integrated and are likely to be affected in a similar way by common shocks to the global economy. Future study can include in the investment set emerging markets, whose economies are less correlated with that of the developed markets, and such investments will provide benefit in diversification and possibly in hedging performance.

References:

Black, F., 1989, Universal hedging: optimizing currency risk and reward in international equity portfolios, *Financial Analysts Journal* 45, 16-22.

Black, F., 1990, Equilibrium exchange rate hedging, *Journal of Finance* 45, 899-907.

Bolleslev, T., R. Chou, and K. Kroner, 1992, ARCH modeling in finance: A review of the theory and empirical evidence, *Journal of Econometrics* 52, 5-59.

Brown, C., J. Dark, and W. Zhang, 2012, Dynamic currency hedging for international stock portfolios, working paper.

Brunnermeier, M.K., 2009, Deciphering the liquidity and credit crunch 2007-2008, *Journal of Economic Perspectives* 23, 77-100.

Caballero, R. J., and P. D. Kurlat, 2009, The 'surprising' origin and nature of financial crises: A macroeconomic policy proposal, MIT Department of Economics working paper No. 09-24.

Campbell, J., K. de Medeiros, and L. Viceira, 2010, Global currency hedging, *Journal of Finance* LXV, 87-122.

Clarke, R., and M. Kritzman, 1996, Currency management: Concepts and practices, the Research Foundation of the Institute of Chartered Financial Analysts.

Engle, R., and K. Sheppard, 2001, Theoretical and empirical properties of dynamic conditional correlation multivariate GARCH. NBER Working Paper 8554.

Engle, R., 2002, Dynamic conditional correlation: a simple class of multivariate generalized autoregressive conditional heteroskedasticity model. Journal of Business and Economic Statistics 20, 339-350.

Eun, C., and B. Resnick, 1988, Exchange rate uncertainty, forward contracts and international portfolio selection, *Journal of Finance* 43, 197-216.

Froot, K., 1993, Currency hedging over long horizons, NBER Working Paper 4355.

Gagnon, L., T., McCurdy, and G., Lypny, 1998, Hedging foreign currency portfolios, *Journal of Empirical Finance* 5, 197-220.

Galati, G., and M. Melvin, 2004, Why has FX trading surged? Explainning the 2004 triennial survey, *BIS Quarterly Review*, December 67-74.

Gardner, G., and D. Stone, 1995, Estimating currency hedge ratios for international portfolios, *Financial Analysts Journal* 51, 58-64.

Gastineau, G., 1995, The currency hedging decision: A search for synthesis in asset allocation, *Financial Analysis Journal* 51, 8-17.

Glen, J., and P. Jorion, 1993, Currency hedging for international portfolios, *Journal of*

Finance 48, 1865-1886.

Guo, B., 2003, Currency risk hedging with time-varying correlations, SSRN working paper.

Habib, M. M., and L. Stracca, 2011, Getting beyond carry trade, what makes a safe haven currency? European Central Bank working paper 1288.

Hautsch, N., and J. Inkmann, 2003, Optimal hedging of the currency exchange risk exposure of dynamically balanced strategic asset allocations, *Journal of Asset Management* 4, 173-189.

Jorion, P., 1985, International portfolio diversification with estimation risk, *The Journal of Business* 58, 259-278.

Jorion, P., 1994, Mean/variance analysis of currency overlays, *Financial Analysts Journal* 50, 48-56.

Kohler, M., 2010, Exchange rates during financial crisis, *BIS Quarterly Review*, March, 39-50.

Kroner, K., and J. Sultan, 1993, Time-varying distributions and dynamic hedging with foreign currency futures, *The Journal of Financial and Quantitative Analysis* 28, 535-551.

Larsen, G., and B. Resnick, 2000, The optimal construction of internationally diversified equity portfolios hedged against exchange rate uncertainty, *European Financial Management* 6, 479-514.

Lin, W., R. F. Engle, and T. Ito, 1994, Do bulls and bears move across borders? International transmission of returns and volatility, *Review of Financial Studies* 7, 507-538.

Longin, F., and B. Solnik, 1995, Is the correlation in international equity returns constant: 1960-1990? *Journal of International Money and Finance* 14, 3-26.

Longin, F., and B. Solnik, 2001, Extreme correlation of international equity markets, *Journal of Finance* 56, 649-676.

McCauley, R.N., and P. McGuire, 2009,Dollar appreciation in 2008: safe haven, carry trades, dollar shortage and overhedging, *BIS Quarterly Review*, December 85-93.

Mizen, P., 2008, The credit crunch of 2007-2008: A discussion of the background, market reactions and policy responses, *Federal Reserve Bank of St. Louis Review* 90, 531-367.

Perold, A., and E. Schulman, 1988, The free lunch in currency hedging: Implications for investment policy and performance standards, *Financial Analysts Journal* 44, 45-50.

Ranaldo, A., and P. Soderlind, 2010, Safe haven currencies, *Review of Finance* 14, 385-407.

Sheedy, E., 1998, Correlation in currency markets: A risk-adjusted perspective, *Journal of Financial Markets, Institutions and Money* 8, 59-82.

Stevens, G., 2009, Australia and Canada – Comparing notes on recent experience, *Reserve*

Bank of Australia Bulletin, June, 36-44.

Tse, Y., and A. Tsui, 2002, A multivariate generalized autoregressive conditional heteroskedasticity model with time-varying correlations, *Journal of Business and Economics Statistics* 20, 351-362.

Xin, H., 2003, Currency overlay, a practical guide (risk books, Incisive Financial Publishing Ltd)

Appendix A Hedge ratios for seven-asset portfolios (US perspective)

This table presents both unconditional and conditional hedge ratios for equally-weighted seven-asset portfolios over the sample period January 2002 to December 2005. Unconditional hedge ratios are generated by regressing the unhedged portfolio return (in USD) onto the currency forward returns. Daily conditional hedge ratios are computed using equation (3.14), with conditional covariance matrix estimated from the DCC-GARCH model.

	AUD	CAD	JPY	GBP	CHF	EUR
Panel A: Unconditional hedge ratios						
unconstrained	2.95	2.47	1.14	0.67	-3.47	1.19
constrained	1.00	1.00	1.00	0.67	0.00	1.00
Panel B: Average conditional hedge ratios						
unconstrained	2.26	2.18	1.36	1.00	-2.45	1.07
std dev	*0.52*	*1.69*	*0.49*	*0.64*	*1.18*	*1.15*
constrained	1.00	0.99	0.95	0.79	0.00	0.71
std dev	*0.00*	*0.06*	*0.14*	*0.31*	*0.01*	*0.43*

Appendix B AUD currency forward return correlations

The table reports unconditional correlations among daily returns of long forward contracts on various currencies for the period January 2002 to April 2010 and two sub-periods. All correlations are statistically significant at the 5% level.

	USD	CAD	JPY	GBP	CHF	EUR
	Panel A: January 2002-December 2005					
USD	1.00					
CAD	0.67	1.00				
JPY	0.61	0.47	1.00			
GBP	0.66	0.51	0.58	1.00		
CHF	0.49	0.47	0.59	0.73	1.00	
EUR	0.56	0.51	0.59	0.76	0.95	1.00
	Panel B: January 2006-April 2010					
USD	1.00					
CAD	0.72	1.00				
JPY	0.88	0.63	1.00			
GBP	0.75	0.64	0.72	1.00		
CHF	0.79	0.64	0.87	0.75	1.00	
EUR	0.81	0.68	0.84	0.79	0.95	1.00