Currency Risk Management for International Investors

A thesis presented in fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Finance

at Massey University, Palmerston North,
New Zealand

Zhennan Mao

2025

ABSTRACT

When investors hold assets priced in foreign currencies, they are exposed to foreign exchange (FX) risk. This thesis comprises three independent studies, each exploring a different aspect of currency risk management. For investors in the US market, while FX volatility increases the risk of unhedged international investment, its covariance with the portfolio reduces investment risk for most short-term holdings, providing a natural hedge. For Australian, Canadian, UK, and South Korean investors, the net risk contribution from FX risk reduces short-term investment risk without currency hedging, providing a full natural hedge. In many cases, the additional risk reduction from adopting the optimal hedge is not statistically significant relative to the zero hedge when investment-implied foreign currency exposure provides protection, except for long-term investments. The existence of a natural hedge removes practical barriers associated with currency risk for international investors by mitigating the need for costly hedging instruments in the short to medium term. In addition, our findings show that CIP violations do not affect the results of forward contracts and money market hedges; investors can choose whichever suits them.

Adopting the dynamic conditional correlation generalised autoregressive conditional heteroskedasticity (DCC–GARCH) framework improves overall currency risk management performance compared to simple hedging and static optimal hedging strategies. Notably, when the currency return involves the British pound (GBP), the return series consistently requires a GARCH model with an asymmetric term. To accurately estimate conditional variances, investors should select a univariate model aligned with each asset's risk profile. Across the seven univariate models considered, four were selected as optimal for different return series. This finding underscores the pitfall of relying on any single model. Instead, investors should

identify candidate models based on data characteristics, then select the best-performing model for each series. The DCC model adequately describes the dynamic correlations among assets for the asset, currency, and sample period chosen in this study, without the need for the ADCC model. The performance of the dynamic model shows that it minimises investment risk, requires less currency exposure, and improves hedged returns compared with the static model, especially for Canadian investors.

Currency risk management is also effective for home-biased investors whose domestic assets comprise a large part of their portfolios. For investors in Canada, the European Union (EU), the United States (US), the United Kingdom (UK), Australia and South Korea, optimal currency exposures are similar regardless of whether a home-biased or diversified portfolio is adopted. In contrast, optimal currency exposures shift noticeably between the two portfolio comparisons for investors in Japan, Brazil, Indonesia, and South Africa. Currency hedging is effective at a similar level for Canadian, EU, UK, US, and Australian investors in terms of risk reduction. This finding carries a significant implication: for Canadian, EU, UK, and US investors, the choice between a home-biased and a diversified portfolio becomes irrelevant when currency risk is actively managed. In addition, we investigate the role of gold and bitcoin as alternative assets in improving the optimal hedge and protecting against the uncertainty of traditional safe havens. Adding gold futures contracts to the currency hedging strategy results in a positive optimal demand for gold among diversified investors, but it does little to reduce US dollar (USD) exposure or overall risk. However, it does improve hedged returns across selected countries. Conversely, the optimal demand for bitcoin remains small for currency risk management.

ACKNOWLEDGEMENTS

Globalisation has been challenged in many ways in recent years. Although trade and international cooperation increase the average person’s utility, decoupling and trade conflicts frequently appear in news headlines around the world. I hope that the study of currency risk management can offer investors who are still willing to invest in foreign markets a means of protecting themselves from foreign exchange volatility until current conflicts are resolved and a new framework of global cooperation is established.

I want to express my sincere thanks to my supervisors. Your support and guidance are valuable to me. Dr Naylor and Dr Chen were my research supervisors since I was working on my master's degree at Massey University. Dr Naylor always let me try out any ideas I came up with so I could explore things I am genuinely interested in. I am so grateful for all the long meetings Dr Chen has held. In those meetings, we spent a lot of time finalising my research, and he taught me a great deal about conducting sound research. Also, I want to thank Dr Chen for resolving unexpected issues with finding examiners and for taking everything into account. I feel lucky to have him as my research supervisor. Dr Smith joined our team at the end of my study, and I want to thank him for his contributions to the editing of the research.

I would also like to thank Zhu, Xiaorui and Mao, Fangyuan, for your companionship. I hope Fangyuan can also study something you find interesting and achieve a PhD degree in that subject, as it is fun. Last but not least, a special thank you goes to my parents for their unwavering support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE INTRODUCTION

This chapter provides an overview and background of this thesis, which comprises three studies. In particular, the chapter presents the motivations, objectives, methods, and contributions of each of the three studies and concludes with an overview of the overall thesis structure.

1.1. Introduction

After decades of globalisation, the dramatic growth in cross-border investments has become a characteristic trend in today's financial market.[1] When investors hold international investments denominated in foreign currencies, they hold foreign assets and implicitly hold foreign currencies equal to the value of the investment. As a result, fluctuations in foreign exchange (FX) rates can have either a positive or negative impact on the return and risk of unhedged international investments.

The direct consequence of FX risk is that investors will reduce their willingness to diversify globally, leading to home bias – the empirical tendency for investors to favour domestic assets relative to their global market weight. Fidora et al. (2007) found that higher exchange rate volatility encourages a preference for domestic assets, and this bias is more pronounced for asset classes with low inherent volatility. Their results show that if monthly exchange rate volatility were hypothetically reduced to zero, equity and bond home bias would drop by about 20 and 60 percentage points on average, indicating that currency risk is a barrier to foreign investment. Therefore, international investors should develop strategies to manage foreign exchange risk.

However, investors are limited in their ability to mitigate foreign exchange risk through currency diversification. The empirical results of Eun and Resnick (1988) indicate that correlations are significantly higher among exchange rate changes than among local stock market returns, suggesting that while local stock market risk can be largely diversified away, much of the exchange rate risk remains non-diversifiable. Alternatively, Dumas and Solnik (1995) found that FX risk premia are a significant component of securities returns in

[1] Gross international capital flows (the sum of cross-border inflows or outflows worldwide) rose from about 10% of world GDP in 2000 to roughly 22% of global GDP in 2007, reflecting the trend of financial globalisation. After the global financial crisis in 2008, the level is between 5% to 10% of world GDP (Davis & Van Wincoop, 2021).

international financial markets. This means that, all else equal, equities with greater exposure to FX risk tend to offer higher expected returns, implying that currency risk is systematic and not fully diversifiable globally. Therefore, investors should use foreign exchange derivatives to manage their currency exposure.

When a foreign portfolio is fully hedged, the unknown exchange rate is entirely replaced by the forward exchange rate, which is known at the beginning of the investment. A complete hedge, however, is not always optimal for investors. If the foreign currency is negatively correlated with the foreign asset, holding a long position in the foreign currency can reduce portfolio risk. For example, Campbell et al. (2010) found that for Canadian investors, a fully hedged investment carries a higher risk than an investment with currency risk that is either unhedged or half-hedged. These findings depict a scenario in which investors from countries with weaker domestic currencies invest in foreign markets with stronger currencies. Capital markets tend to correlate with the strength of their respective currencies – for example, the European Union (EU), Japanese, and United States (US) capital markets are considered major markets with safe-haven currencies. As a result, investors from other countries are naturally hedged against foreign currency risk exposure when investing in these markets. The effectiveness of natural hedging remains to be further studied. Thus, the principle of currency risk management seems simple – the key to effective hedging centres on a thorough analysis of asset–currency variance and covariance.

The mean–variance framework provides international investors with an optimal hedging strategy as an alternative to choosing between the simple strategies of zero, half, and full hedging. The international asset pricing model (IAPM), developed by Solnik (1974), predicts that investors will adjust their portfolios in response to both global market factors and currency factors. The risk-minimising hedge policy has arisen in response to the high volatility of foreign exchange markets and their low returns. This approach minimises investment risk by varying the weight of foreign currencies through the use of FX derivatives. Our three independent studies build on risk-minimising hedging and provide implications for international investors based on empirical findings.

The static mean–variance framework provides investors with long-term optimal average currency positions, as demonstrated by Schmittmann (2010) and Campbell et al. (2010). However, the correlation between foreign assets and foreign exchange rate returns is unstable over time (Schmittmann, 2010). Therefore, with the static model, the possibility of sign reversion and changes in optimal currency positions cannot be accounted for. Conversely, the dynamic model – for example, the DCC–GARCH framework developed by Engle (2002) – accounts for the conditional variance and covariance between assets and foreign exchange; the resulting optimal currency positions reflect the most current market information. The DCC–GARCH framework enables investors to select univariate and multivariate models based on asset risk characteristics. Thus, the potential of the framework warrants further examination.

Regardless of the model that investors choose, the general strategy is to expose them to currencies that are negatively correlated with foreign asset returns and to reduce exposure to those that are positively correlated with foreign asset returns. The euro (EUR), Japanese yen (JPY), Swiss franc (CHF),[2] and US dollar (USD)[3] are typical safe-haven currencies. Although positive exposure to these currencies may help reduce investment risk, depending solely on them may not be optimal, as they may not be available or a significant premium may be

[2] Ranaldo and Söderlind (2010) demonstrate that the JPY, CHF, and EUR tend to appreciate against the USD during risk-off episodes.
[3] Campbell et al. (2010) found that investors require positive exposure to USD to minimise international investment risk.

required when markets perceive upcoming risks. Consequently, investors should seek alternatives beyond the currencies mentioned above.

Foreign exchange fluctuations introduce an additional layer of risk for international investors, potentially discouraging diversification into assets listed in foreign markets and priced in foreign currencies. This thesis aims to provide international investors with strategies that optimise foreign currency exposures and minimise the risk of international investments, drawing on the findings of three interconnected studies. Study One lays the foundation by investigating how variance and covariance influence the overall risk arising from foreign currency exposures. It also examines the distinction between hedging with forward contracts and hedging with borrowing and lending, and establishes the fundamental mechanics of currency risk management.

Building on this, Study Two compares the performance and benefits of static and dynamic mean–variance models. Furthermore, while Study One establishes whether and how hedging works, Study Two addresses which approach is more effective over time, recognising that correlations and volatilities are not constant.

Finally, Study Three extends the analysis to practical considerations: it introduces alternative hedging assets (gold and bitcoin) to address situations where traditional safe havens like the USD may fail, and it compares optimal currency exposure and hedging performance for diversified versus home-biased investors. This completes the thesis by moving from general principles (Study One) through methodological refinement (Study Two) to investor-specific applications (Study Three).

1.2. Study 1: The natural hedge effect and optimal hedging with the violation of CIP

International investors encounter foreign exchange risk when they hold assets denominated in foreign currencies. Although the foreign exchange rate variance always adds risk to the investment, its covariance with foreign assets may not bring additional risk. Investors whose domestic/foreign currency positively/negatively correlates with the local currency asset return may experience some risk reduction through negative foreign exchange-asset covariance.

Campbell et al. (2010) found that full currency hedging increases the risk for unhedged Canadian investors, implying that investors whose domestic currency tends to depreciate against exposed foreign currencies benefit from the 'natural hedge'. The unhedged investment being less risky than a fully hedged one also indicates that the natural hedge effect could be larger than the FX variance and already reduces investment risk without currency risk management. However, Campbell et al. (2010) did not adequately quantify the level of the natural hedge, as their study was not designed to address this issue. The first study contributes to the literature by identifying and quantifying the natural hedge effect using the variance decomposition method, as shown by Schmittmann (2010).

To capture the natural hedge effect, this study is conducted in a scenario in which investors invest in a foreign market with a strong currency that will appreciate against their domestic currency when market returns decline. Following the optimal hedging strategy proposed by Campbell et al. (2010), safe-haven currencies tend to exhibit negative correlations with the global market, making their corresponding markets suitable investment destinations. Considering that the US market is the most developed capital market, with a full array of stock and currency products, this study assumes that investors hold the US country index.

We conduct the research from the perspective of G20 countries to cover the major economies. After excluding countries with insufficient data, this research includes Canada, Australia, the United Kingdom (UK), and the EU, as well as investors from emerging markets such as South Africa, Turkey, and South Korea. The primary explanation lies in the inverse relationship between exchange rate movements against the USD and US equity returns for these countries, which functions as a natural hedge. As the natural hedge effect reduces the overall risk contribution from foreign currency exposure, it is necessary to update optimal hedge policies[4] and test the performance of the optimal hedge for international investors. The result answers whether active hedging is required when the natural hedge is present.

Investors can implement risk-minimising hedging strategies via options, forward and futures contracts, and borrowing and lending. Campbell et al. (2010) and Schmittmann (2010) show that forward contracts and borrowing/lending are equivalent as long as the covered interest rate parity (CIP) holds. This implies that although their research uses forward exchange rates implied by interest rate differentials, the hedging strategy should yield the same results when using forward contracts directly. Recent studies, however, support the violation of CIP (Du et al., 2018), which can lead to deviations between forward contracts and borrowing/lending hedging. Nonetheless, studies assessing its impact on optimal currency hedging are scarce, prompting an update of the literature by considering both hedging vehicles and their potential differences.

Finally, this study provides results for investors with long-term investment horizons. Schmittmann (2010) documents that optimal hedge ratios change across investment horizons. The finding implies that assets' variance and covariance vary with investors' holding periods.

[4] Following Schmittmann (2010) and Campbell et al. (2010), the optimal hedge policy is the risk-minimising hedge that utilises currency positions to minimise the risk of the international equity portfolio.

Thus, the natural hedge effect observed in the short term may not be sustained for investors who want to utilise it to counter long-term cycles. Hence, this study considers investments with horizons ranging from 1 to 36 months.

This study contributes to the literature by quantifying the level of the natural hedge effect and comparing it with the performance of the optimal risk-minimising hedge. The CIP violation is considered, and the differences between hedging with forward contracts and borrowing and lending are compared. This study also accounts for the variability of correlation and covariance structures over time by providing empirical results for investors with investment horizons of up to three years. With the above examination, informed investors and practitioners can make better choices in selecting a hedging strategy and hedging vehicle and adjust accordingly based on their investment horizons.

1.3. Study 2: Dynamic currency risk management for international investors

Study One focuses on long-term average variance and correlations among assets. A key limitation, however, is that correlations between foreign assets and exchange rate returns vary over time. Although the static model reliably estimates long-term average optimal currency positions, it fails to account for potential shifts in these positions. To incorporate the most current market information, investors need dynamic models. Study Two addresses this need by introducing a time-varying framework.

The DCC–GARCH model developed by Engle (2002) enables investors to estimate the required parameters dynamically. Some studies on FX risk management have applied this model to mitigate investment risk (e.g., Cho et al., 2020; Chang et al., 2013; Filipozzi & Harkmann, 2020). However, different assets exhibit distinct risk characteristics. Thus, for an international investment involving assets and currencies across several countries, investors should not rely on a single model to estimate the variance and covariance of returns across such diverse portfolios. The DCC–GARCH framework is flexible, as it allows investors to vary univariate and multivariate models to suit the characteristics of their asset returns. This study leverages the flexibility of the DCC–GARCH framework to account for asymmetric volatility and correlation, which are often overlooked in studies on currency risk management.

The asymmetric volatility of asset returns refers to the phenomenon in which volatility increases more sharply following a negative shock than after a positive shock of the same magnitude. If the asymmetry effect is ignored, the conditional variance after a positive/negative shock may be over-/underestimated, which can distort the optimal currency positions obtained. Previous studies have often employed a uniform univariate model to fit all asset returns, as seen in Cho et al. (2020). The first innovation of this research is that it accounts for asymmetric volatility and selects the optimal univariate model for each asset series from a set of seven models, with and without an asymmetry term. The proposed methodology serves a dual purpose: (1) empirically validating asymmetric volatility responses in asset returns, and (2) identifying asset-specific optimal model specifications via the Bayesian Information Criterion (BIC).

For any given currency pair, exchange rate returns exhibit a reciprocal relationship: investors holding the base currency experience returns that are inversely proportional to those observed by investors holding the counter currency. As asymmetrical univariate models are introduced, the sign of the asset return may affect the variance equation, as some asymmetry models control the error term by its sign. The second innovation is that this study fits the univariate model from the perspective of investors on both sides of the currency pair. While Wang and Yang (2009) show that the asymmetric effect of foreign exchange is currency-specific, our approach provides further insights into the asymmetric effect between currency pairs.

Asymmetric correlation refers to the situation in which assets tend to move together more closely during market declines than during market gains. As in the case of asymmetric volatility, failure to account for asymmetric correlation results in biased estimates of conditional correlations—overestimation after positive shocks and underestimation after negative shocks. The third contribution of this study is its explicit accounting for asymmetric correlation by estimating the ADCC model developed by Cappiello et al. (2006).

This study aims to equip international investors with accurate and dynamic currency risk management strategies through the flexible DCC–GARCH framework. The methodology involves selecting the optimal univariate model for conditional variance estimation and the optimal multivariate model for conditional covariance estimation. By capturing asymmetric volatility and asymmetric correlation, the framework accounts for these effects and delivers more precise estimates under varying market conditions. Consequently, the adoption of dynamic models significantly enhances the effectiveness of currency risk management.

1.4. Study 3: Currency risk management for diversified and home-biased investors and the effectiveness of gold and bitcoin

Having demonstrated that currency risk may not increase portfolio risk (Study One) and that it can be dynamically managed when it does (Study Two), this thesis now turns to a pervasive reality of international investing: home bias. Most investors hold a significant portion of their wealth in domestic assets, yet the currency-hedging implications of this behaviour remain underexplored. Study Three, therefore, investigates how home-biased investors can optimally hedge currency exposure, extending the analysis to portfolios that reflect actual investor behaviour. Although such investors still hold foreign assets, their weights are significantly lower than those of internationally diversified portfolios.

Practitioners may expect the optimal currency position to differ between diversified and home-biased portfolios when applying a risk-minimising hedge, as these portfolios have distinct underlying risk exposures. Nevertheless, Campbell et al. (2010) demonstrate that optimal currency risk management policy remains stable even when the weight of investors' portfolios changes. The stability of their optimal currency demands indicates that changes in investment-implied foreign currency exposure do not affect the optimal currency exposure for minimising investment risk.

Despite their contributions, the findings of Campbell et al. (2010) leave certain gaps that offer valuable opportunities for extension. First, the home-biased portfolios in their study are hypothetical portfolios with 75% of investments in the domestic market. Although these hypothetical portfolios confirm the cross-portfolio stability of optimal currency positions, this insight offers limited practical guidance for hedging policies. The reason is that the degree of home bias[5], which directly influences optimal hedging, varies significantly across countries. This study constructs home-biased portfolios that represent the average preferences of investors.

Second, Campbell et al. (2010) claim that optimal currency positions are 'qualitatively and quantitatively similar' across different portfolios. However, their findings lack statistical tests to demonstrate that the optimal currency positions are equal across portfolios. The present study contributes by subjecting this assertion to formal hypothesis testing. Specifically, it employs the z test of Clogg et al. (1995) to compare optimal currency demand across diversified and home-biased portfolios.

One implication of Study One is that exposure to the USD provides a natural hedge, which in turn may strengthen demand for both the US market and the currency itself. In this research, a

[5] Sercu and Vanpee (2012) found that investors from different regions tend to demonstrate home bias and allocate their total investments in their respective domestic markets differently.

key finding emerges: demand for USD dominates as the primary hedging instrument. While holding a long USD position is a sound strategy for risk-minimising investors, relying solely on it is suboptimal. As Study Two reveals, the USD does not always function as a safe haven—during the Global Financial Crisis, for example, its hedging properties diminished. Investors should therefore explore alternatives to improve diversification and optimise currency exposure.

One approach is to include safe-haven assets that either behave similarly to the USD or protect against USD depreciation. Numerous studies have documented gold's role as a hedge against USD weakness (e.g., Reboredo & Rivera-Castro, 2014; Reboredo, 2013; Joy, 2011). More recently, Kang et al. (2020) demonstrate that bitcoin may serve as an effective safe haven, mitigating downside risk in portfolio management. Accordingly, this study incorporates gold and bitcoin as alternative assets to enhance the optimal hedge and provide protection against uncertainty in traditional safe havens.

This study contributes to the literature by statistically testing whether differing portfolio weights lead to differences in optimal currency positions. In addition, although many studies have examined the safe-haven characteristics of gold and bitcoin, there appears to be a lack of research on their ability to improve the diversification of optimal currency positions by reducing the weight of the USD. The empirical results of this study provide both diversified and home-biased investors with currency risk management strategies. Furthermore, this study aims to expand the range of safe-haven assets for investors with hedging needs to prevent unsuccessful hedging due to high premiums or a lack of counterparty when market uncertainty is expected to be high.

1.5. Thesis structure

The overall structure of this PhD thesis is as follows: Chapter 2 examines the natural hedge effect and optimal hedging when CIP is violated (Study 1). Chapter 3 investigates dynamic hedging by adopting the DCC–GARCH framework, which incorporates asymmetry effects (Study 2). Chapter 4 considers the differences in currency risk management for diversified and home-biased investors and explores how gold and bitcoin perform as optional safe-haven assets (Study 3). Finally, Chapter 5 presents the conclusion, summarises the main findings and policy implications, and examines the limitations and offers suggestions for future research.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Zhennan Mao
Name and title of main supervisor:	Jianguo Chen, Doctor
In which chapter is the manuscript/published work?	Chapter two

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Chapter Two includes Study One - The Natural Hedge Effect and Optimal Hedging with the Violation of CIP.
Zhennan Mao is primarily resposible for the research design, data collection, empirical analysis, and manuscript writing.

Please select one of the following three options:

○ **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

○ **The manuscript is currently under review for publication**

Please provide the name of the journal:

◉ **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Zhennan Mao — Digitally signed by Zhennan Mao Date: 2025.07.25 14:10:27 +12'00'	Main supervisor's signature:	Jianguo Chen — Digitally signed by Jianguo Chen DN: cn=Jianguo Chen, c=NZ, o=Massey University, ou=School of Economics and Finance, email=j.g.chen@massey.ac.nz Date: 2025.07.25 15:24:34 +12'00'

This form should be placed at the beginning of each relevant thesis chapter.

[1] Refer to the Massey University Publishing and Authorship guidelines (OneMassey for staff, Stream for students) and/ or Contributor Roles Taxonomy (CRediT) guidelines for guidance.

CHAPTER TWO STUDY ONE
THE NATURAL HEDGE EFFECT AND OPTIMAL HEDGING WITH THE VIOLATION OF CIP

This study considers investors from Canada, Australia, the UK, the EU, South Africa, Turkey, and South Korea who are fully invested in the US market index and use both the US dollar and their domestic currency to manage risk. It examines three key aspects: the strength of the natural hedge effect arising from negative covariance between assets and foreign exchange, the performance of optimal static hedging, and the difference between adopting forward contracts versus borrowing and lending, while accounting for violations of covered interest rate parity (CIP). The empirical results show that negative covariance between the portfolio and foreign exchange reduces short-term investment risk for Australian, Canadian, UK, and South Korean investors without additional currency hedging. For these investors, the performance of the optimal hedge is not statistically different from the zero-hedge when negative covariance is present, except for Turkish and South African investors. However, in the long term, as the natural hedge effect dissipates, the optimal hedge significantly outperforms the unhedged position. Furthermore, violations of CIP do not create significant differences in optimal hedge ratios between borrowing/lending and forward contracts; consequently, the risk and return of optimally hedged investments remain similar in most cases.

Keywords: currency risk management, natural hedge, CIP violation

2.1. Introduction

For international investors, holding assets priced in foreign currencies is inevitable. Thus, international investment is a combination of assets and the implicitly held foreign currencies that equal the value of the investment. The literature has highlighted that foreign currency exposure introduces foreign exchange (FX) risk, ultimately affecting the returns and risks of investments when estimated in investors' home currencies.

International investors concerned about FX risk can manage it by shorting foreign currency and going long on their domestic currency using today's highly developed FX derivatives market. Following Campbell et al. (2010) and Schmittmann (2010), this study assumes that investors hold the US country index and utilise the currency position to minimise investment risk. We consider investors from Canada, Australia, the UK, the EU, South Africa, Turkey, and South Korea who fully invest in the US market index and only utilise the USD and their own domestic currency to manage risk. This study primarily focuses on three key areas. First, it examines FX risk and currency hedging for investors who benefit from negative FX and asset correlations.[6] Second, it examines whether the violation of CIP leads to a difference between the forward contract and the borrowing/lending hedge.[7] Third, it reveals the long-term relationship of risk components for foreign investments.[8]

Campbell et al. (2010) examined currency hedging with seven currencies: the Australian dollar (AUD), Canadian dollar (CAD), euro (EUR), Japanese yen (JPY), British pound (GBP), US

[6] In this case, the negative covariance between FX return and asset return already reduces FX risk without hedging. Although the literature has extensively explored FX risk management, we have not seen dedicated studies on this topic.
[7] FX risk management relies on the validity of CIP to calculate the interest rate-implied forward exchange rate. The impact of CIP violations on FX risk management has not been thoroughly examined in the literature and warrants an update.
[8] This study provides results for investments with a horizon of up to three years. This study, however, adopts the discrete model to provide empirical results for all investment horizons, where Schmittmann (2010) adopted a continuous equation for long-term investments due to the ease of calculation.

dollar (USD), and Swiss franc (CHF). They suggest that some currencies, such as the USD and CHF, tend to correlate negatively with the global market and are known as ‘safe-haven currencies’. Proper exposure to these currencies can help reduce the overall risk of foreign investment. In contrast, other currencies, such as the AUD and CAD, tend to correlate positively with the global market. A hedging strategy often involves shorting/going long a certain amount of currencies that positively/negatively correlate with asset returns measured in the pricing currency.

Under the above hedging strategy, foreign currency exposure may not always increase the risk of an unhedged investment. For international investors whose domestic/foreign currencies are positively/negatively correlated with asset return in pricing currency, although exposure to foreign currency introduces FX variance, it may also provide some risk reduction through the negative FX–asset correlation. Campbell et al. (2010) found that full currency hedging may increase risk for unhedged Canadian investors. Their findings imply that as the full hedge reduces currency exposure, it reduces FX variance from EUR, AUD, JPY, USD, CHF, and GBP, while sacrificing some risk-reduction effects arising from the negative FX–asset correlation of some of the exposed foreign currencies. Their results show that foreign currency exposure to a stronger currency that tends to appreciate against the domestic currency when the market declines provides some ‘natural hedge’. In addition, the unhedged investment being less volatile than a fully hedged investment also indicates that the natural hedge effect could be larger than the FX variance and already reduces investment risk without currency risk management.

Campbell et al.’s (2010) study was broader in scope and thus did not elaborate on the above findings. However, their findings provide a new direction in currency hedging that is worth further inquiry. First, the natural hedge effect should be identified and quantified utilising variance decomposition, following the approach by Schmittmann (2010). Campbell et al. (2010) demonstrate the natural hedge effect through a comparison of unhedged and fully hedged investment risk. The risk levels of FX variance and FX–asset covariance, as well as their contribution to the unhedged investment, remain unknown. Investors may fully benefit from the natural hedge effect when the unhedged investment is less risky than a fully hedged one. Conversely, if the natural hedge only partially offsets risk, the unhedged investment remains riskier than the fully hedged alternative. In such cases, the natural hedge effect cannot be identified without variance decomposition. For instance, Campbell et al. (2010) note that risk reduction from a full hedge is relatively small for Australian investors. However, without studying the individual risk components, it is not possible to conclude whether these investors also benefit from the natural hedge effect. Thus, this study includes variance decomposition to comprehensively examine the presence and extent of the natural hedge effect.

Second, the study of the natural hedge effect should be conducted in a more suitable context. When Campbell et al. (2010) conducted their global currency hedging study, they included investors from seven countries and utilised all relevant currencies in their analysis. Alternatively, this study focuses on the currencies and investments that provide a natural hedge against fluctuations in the market. If it adopts the same framework as Campbell et al. (2010), in many cases, the exposed currency may not provide any natural hedge effect, especially for investors from the US, Japan, and Switzerland. Thus, this study is conducted in a context in which investors invest in a foreign market with a strong currency, and the foreign currency tends to appreciate against the investors' domestic currency when market returns decline.

As this research is conducted for investors who benefit from the natural hedge effect, the unhedged investments should be less risky than those held by investors who do not benefit from it. The lower risk of unhedged investments would make it harder to achieve statistically significant risk reduction through active hedging. To answer whether active hedging is necessary for such investors, it is necessary to update optimal hedge policies and test their performance for international investors.

Investors can implement risk-minimising hedging strategies via options, forward and futures contracts, and borrowing and lending. In terms of currency hedging, research exploring the use of options is scarce; instead, it is commonly assumed that investors use forwards or borrowing and lending to hedge currency risk. Furthermore, Campbell et al. (2010) and Schmittmann (2010) show that forward contracts and borrowing/lending are equivalent as long as CIP holds, implying that, although their research utilises interest rate–implied forward rates, the hedging strategy is effectively the same as that using forward contracts.

Recent studies, however, have supported the violation of CIP (Du et al., 2018), which can lead to deviations between forward contracts and borrowing/lending hedging. Nonetheless, to our knowledge, no studies have assessed its impact on optimal currency hedging, prompting us to consider the two hedging instruments and their potential differences. Our primary focus is to investigate whether CIP violation results in different optimal hedge ratios and the hedging performance of the optimal hedge when employing these two hedge instruments.

Finally, this study provides results for investors with various investment horizons. Although Campbell et al. (2010) covered investment horizons ranging from 1 to 12 months, these holding periods primarily focus on investors with short-term horizons. Schmittmann (2010) considered investments with a horizon from 1 quarter to 5 years. The empirical result indicates that optimal hedge ratios can vary across investment horizons, implying that the relevant variables' variances and correlations change as holding periods change. The natural hedge effect observed in the short term may not be sustained for investors who want to utilise it to counter long-term cycles. In the case of the optimal hedge, we also lack information on the long-term strategy and performance. Thus, this study considers investments with horizons ranging from 1 to 36 months, considering the smaller sample size compared with Schmittmann (2010).

Although this study imposes many restrictions on the construction of international investments, the assumed scenario is not uncommon. Given the unique role of the USD and the significant weight of US capital markets in the global market, we believe this research offers valuable implications for many investors, especially those seeking to gain exposure to the US market and considering the choice between unhedged ETFs (exchange-traded funds) and currency-hedged ETFs.

This research contributes to the literature in various respects. Initially, it quantifies the level of natural hedge; thus, investors can identify investments that partially benefit from it. Secondly, it examines the usefulness of active currency risk management when the natural hedge is present, allowing investors to choose between the natural and active hedge. Lastly, it updates the literature by testing whether forward contracts and borrowing/lending are equivalent under the CIP deviation. The information is valuable to investors with limited access to hedging vehicles.

In the following sections, we present the existing literature and the data sources. Then, we measure the natural hedge effect using the variance decomposition to quantify the level of variance, covariance, and initial currency risk. After that, we estimate optimal hedge ratios and examine performance using borrowing/lending to determine whether active hedging is useful for investors. Lastly, we address the CIP violation by employing forward contract hedging to compare market-based and theoretical hedges, and conclude.

2.2. Literature review

Following Campbell et al. (2010), this research is conducted to address risk management demand arising from estimating the optimal hedge ratio that minimises investors' investment risk. Therefore, the analysis focuses on the variances and correlations of the relevant variables. Since the related variances always increase investment risk, the correlation between equity and the FX market becomes the core, as it not only determines the unhedged investment risk but also the optimal hedging methodology.

2.2.1. The connection between equity and FX market

A substantial body of literature has documented the correlation between equity and currency markets. Diermeier and Solnik (2001) analysed a broad cross-section of security prices from firms in eight developed countries and concluded that currency factors have a significant influence on asset returns. Similarly, Ajayi et al. (1998) examined the relationship between stock and currency markets across seven advanced and eight emerging economies. Their findings indicate that the two markets are well integrated in six of the advanced economies studied, with exchange rates responding to innovations in stock markets. In contrast, the evidence for the eight emerging economies is mixed, suggesting weaker or inconsistent causal linkages.

Cho et al. (2016) further explored foreign exchange–equity correlations, attributing the positive correlation in emerging markets and negative correlation in developed markets to capital flows. In addition, Katechos (2011) provided further evidence on the interaction between equity markets and exchange rates, showing that currencies with higher (lower) interest rates are positively (negatively) correlated with global equity returns. Together, these studies highlight the connection between exchange rate dynamics and fluctuations in the equity market. They explained factors that connect the equity and FX markets; however, the direction of their comovement is more important for investors when making hedging decisions.

2.2.2. Optimal hedging strategy and the natural hedge effect

By estimating optimal hedge ratios, scholars have identified the optimal strategy for reducing investment risk. Campbell et al. (2010) utilised up-to-date international market data to determine the risk-minimising optimal currency exposure of an exogenous portfolio. They conclude that holding short positions in AUD, CAD, JPY, and GBP while holding long positions in USD, EUR, and CHF can efficiently reduce the risk of international equity investments. Similarly, from a Latin American perspective, Walker (2008) concludes that exposure to the USD could be used to counter negative stock returns. The results reveal that the returns of some currencies tend to move in tandem with the capital market – for example, commodity currencies such as the AUD, GBP, and CAD (Campbell et al., 2010). Alternatively, some currencies are negatively correlated with the broader market and tend to appreciate during market crises, making them safe-haven currencies.

Aftab et al. (2015) employed the DCC–GARCH model to analyse the dynamic correlation between equity and currency markets for Chinese investors. Their empirical findings reveal a negative relationship between exchange rates and stock prices. Campbell et al. (2010) note that the USD and CHF are safe-haven currencies. Min et al. (2016) found that the USD, JPY, and CHF have negative dynamic correlations with equity returns. Ranaldo and Söderlind (2010) reached similar results with high-frequency data and showed that the CHF and JPY are safe-haven currencies, as they appreciate when the US stock market declines. These studies suggest that investors can control investment risk by actively exposing themselves to certain currencies, with USD, JPY, and CHF among the most commonly recognised. These results raise the question: What if international investors hold assets priced by one of the safe-haven currencies?

Cho et al. (2016) suggest that hedging currency risks may undo the natural hedge and increase the total return volatility under negative correlation. Campbell et al. (2010) investigated currency hedging with seven currencies (e.g., AUD, CAD, EUR, JPY, GBP, USD, and CHF). They found that full currency hedging increases the risk for unhedged Canadian investors under such conditions. Their findings imply that by reducing foreign exchange risk with a full hedge, the FX variance from the EUR, AUD, JPY, USD, CHF, and GBP is reduced, along with some risk reduction effects emerging from the negative FX–asset correlation that comes from some of the exposed foreign currencies. The unhedged investment being less risky than a fully hedged investment also indicates that the natural hedge effect emerging from the negative FX–asset covariance could be larger than the FX variance, thereby reducing investment risk without currency risk management.

International investors commonly perceive FX risk as an additional risk. Campbell et al. (2010) and Cho et al. (2016) show that if investors' foreign currency exposure appreciates against their domestic currency when the foreign investment return declines, the unhedged foreign currency exposure may entirely or partially offset the total FX variance of the unhedged international investment. While they provide a crucial foundation for studying the natural hedge effect, there is a distinct lack of discussion about its magnitude. This paper will therefore focus on quantifying the level of the natural hedge using the variance decomposition suggested by Schmittmann (2010), aiming to fill the research gap and deepen the understanding of the subject.

2.2.3. The mean–variance framework

The natural hedge effect raises another question: as the natural hedge reduces unhedged investment risk, will an optimal hedge provide a statistically significant risk reduction for international investors? To answer this question, we first need to derive the optimal hedge, and the literature offers various approaches to solving the problem. This study chose the static mean–variance framework for two reasons.

Firstly, though many indicator strategies have been studied and proven effective, the theory underlying these strategies sometimes yields conflicting opinions. The effectiveness of fundamental economic indicators[9] examined by Morey and Simpson (2001), Simpson (2004), and Simpson and Dania (2006), such as PPP, supports the efficient markets hypothesis. At the same time, technical analysis[10], as examined by scholars such as VanderLinden et al. (2002), Levich and Thomas (1993), Neely (1997) and Neely et al. (1997), generates risk-adjusted excess returns that appear to violate the efficient market hypothesis. The above studies suggest that the usefulness of indicators is sensitive to investors' currency and investment.

Secondly, some research that combines indicators with the mean–variance framework also shows conflict results. Glen and Jorion (1993) included a conditional strategy that depends on interest rate differentials. The improvement in stock and bond portfolio performance is significant both in sample and out of sample, and the hedged portfolio return increases without an increase in risk. Campbell et al. (2010) investigated the usefulness of interest rate differences within the mean–variance framework. Nonetheless, they found that the indicator did not provide significant additional risk reduction beyond that of an optimally hedged portfolio within the sample. The results further demonstrate that investors should be prudent when applying findings derived from these indicators.

Thus, following existing studies, we derive the equation to estimate optimal hedge ratios using the static mean–variance framework, as in Glen and Jorion (1993), Campbell et al. (2010), and

---

[9] The indicators are not limited to PPP, Hazuka and Huberts (1994) and Simpson and Dania (2006) also discussed fundamental economic indicators based on the domestic real interest rate and foreign real interest rate.

[10] Additional technical analysis include the forward hedge rule (FHR), which was developed from the random walk hypothesis and suggests that one should hedge whenever the forward (futures) rate is at a premium (e.g., Morey & Simpson, 2001; Simpson, 2004; Simpson & Dania, 2006; Hamza et al., 2007).

Schmittmann (2010). Though the method ignores dynamic correlation, it answers whether an optimal hedge is a better choice for investors who benefit from natural hedging. Thus, the result provides a baseline for international investors.

2.2.4. Optimal hedge and CIP violation

Currency risk management can be conducted through many hedge vehicles. Although some studies consider options (e.g., Attfield et al., 2001; Kasikov, 2012), the majority of the literature tends to suggest that investors apply the mean–variance framework using FX forward contracts or borrowing/lending strategies. The equation used in the studies by Schmittmann (2010) and Campbell et al. (2010) shows that if CIP holds, hedging with forward contracts and borrowing and lending are essentially the same.

Thornton (1989) argues that covered interest parity holds on average, suggesting that interest rates and exchange rates respond to economic news in a manner consistent with the CIP. Using high-frequency data, Taylor (1987) examined the validity of CIP and found evidence supporting the market efficiency hypothesis. Balke and Wohar (1998), employing daily UK/US exchange and interest rate data, reported that the CIP condition occasionally exceeded the transaction cost band, implying the existence of arbitrage opportunities. Similarly, Akram et al. (2008) utilised tick quotes for three major US dollar exchange rates—EUR, GBP, and JPY—and documented short-lived but profitable deviations from CIP. Skinner and Mason (2011) investigated CIP in emerging markets and found that it holds only for short-term maturities, while longer-term horizons exhibit frequent and substantial violations, indicating that CIP does not hold consistently across all time horizons. While these studies offer differing views on CIP violations, most do not find strong evidence of persistent deviations.

In contrast, Baba and Packer (2009) focused on the violation of CIP from 2007 to 2008 and found sharp and persistent deviations from the CIP condition. Du et al. (2018) found that deviations from CIP, both short-term and long-term, were substantial during the global financial crisis and persisted afterwards. A more recent study by Kwas et al. (2024) shows that since the crisis, CIP has served only as a rough approximation. Although numerous studies have provided explanations for these deviations, the findings raise critical questions about the substitutability of forward contracts and borrowing/lending as hedging instruments. Schmittmann (2010) and Campbell et al. (2010) used the forward exchange rates implied by CIP in their studies. The violation of CIP leads to differences in the implied forward premium and the actual forward premium calculated using FX forward contracts. If this violation results in significant differences in hedge ratios and the consequent hedge performance, then the conclusion drawn by adopting borrowing/lending cannot apply to investors using forward contracts and vice versa.

Therefore, this study considers the violation of CIP. To determine whether forward hedging and borrowing/lending can be considered equivalent, this research employs forward contracts and borrowing/lending to examine whether the violation of CIP causes noticeable variations in hedge ratios and hedged returns and risk. More importantly, we use the F test to check whether the optimally hedged investment displays different risks when employing these two hedge vehicles.

2.2.5. The dynamics of the optimal hedging strategy

The optimal hedge ratio varies across different subperiods and investment horizons. Schmittmann (2010) found that the correlation between exchange rates and asset returns is unstable over time, based on their chosen data, especially from 2007 to 2009. Lee et al. (2011) employed the Smooth Transition Conditional Correlation–Generalised Autoregressive Conditional Heteroscedasticity (STCC–GARCH) model and discovered that the correlation between stock and foreign exchange markets increases when stock market volatility rises in

Asian emerging markets. Zhao (2010) adopted monthly data from January 1991 to June 2009, claiming that there is no stable long-term equilibrium relationship between the Chinese yuan (RMB) real effective exchange rate and stock price. These findings reveal the limitations of this study, which adopts a static model.

On the other hand, the optimal hedge ratios also vary across different investment horizons. Froot (2019) demonstrated that the risk reduction potential of currency hedging decreases almost monotonically with an investor's time horizon, implying a decreasing optimal hedge ratio as the investment horizon increases. On the contrary, Schmittmann (2010) also compared short- and long-term optimal hedge ratios and did not find the effect described by Froot (2019). Although whether optimal hedge ratios vary with investment horizons is not the focus of this study, the above findings show that optimal hedge ratios differ across investors with different horizons. To provide robust recommendations to international investors, this research considers investment horizons ranging from 1 month to 36 months to detect potential variations for long-term investors.

The development of currency hedging literature shows that exposure to foreign currencies should no longer be considered a risk. It is an asset that has been neglected and should be optimised to improve overall investment. Thus, this study utilises the mean–variance framework and explores how currency hedging performs for international investors.

2.3. Data and summary statistics

This study tests hedge performance, assuming investors hold equity portfolios. We focus on investors with a non-safe-haven domestic currency who hold assets priced by safe-haven currencies. Additionally, we are interested in the performance of the optimal hedge using different hedge vehicles, including borrowing and lending and forward contracts. Thus, we base our analysis on a scenario in which investors outside the US invest in the US stock market, as it is the most developed capital market, offering a full array of stock and currency products.

Following the optimal hedging framework of Campbell et al. (2010), safe-haven currencies typically exhibit negative correlations with global equity markets, making countries with such currencies attractive investment destinations. Conversely, investors from countries with non-safe-haven currencies tend to experience positive correlations between their FX returns and USD-denominated asset returns. Accordingly, this study assumes that international investors held the US country index from January 2000 to December 2020, and considers investors from G20 countries[11] for which spot and forward exchange rates are available. Our sample includes investors from Canada, Australia, the UK, and the EU—economies whose currencies generally lack safe-haven status—as well as investors from emerging markets (South Africa, Turkey, and South Korea), where the natural hedge effect may be more pronounced than in developed economies. This yields a total of nine currencies: the AUD, CAD, EUR, JPY, South African rand (ZAR), South Korean won (KRW), Turkish lira (TRY), USD, and GBP. We selected this sample period to incorporate the most extensive time-series data available and to avoid using simulated exchange rates for EU investors, as described in Campbell et al. (2010). Although the period spans several distinct economic regimes, the results serve as a long-term average reference for investors.

The exchange rate is quoted in the base currency per unit of USD. We use investment horizons of 1 month, 3 months, 6 months, 12 months, 24 months, and 36 months, and obtain monthly data for FX spot rates and forward contracts from DataStream. The interest rates[12] are obtained

[11] We chose the G20 countries to cover the major economies in international investment.
[12] This study uses the official cash rate (OCR) for three reasons. Firstly, LIBOR (London InterBank Offered Rate) have stopped publishing new data. Secondly, the Reserve Bank of New Zealand suggest using OCR as the fall-back benchmark interest rate (Reserve Bank of New Zealand, 2020). Thirdly, the position of LIBOR is shaken after the systematic manipulation of LIBOR rates in 2012 (Kendall, 2017).

from the International Monetary Fund database, and the country index is obtained from the Morgan Stanley Country Index.

Table 2.1 presents asset and currency returns, standard deviations, and correlations. The annualised asset returns are presented in Panel A and are the same for investors with the same investment horizons; the differences across horizons are minor. On the other hand, the differences in currency returns are significant for investors from different countries. Across all investment horizons, South African and Turkish investors benefit most from holding US dollars. For Turkish investors, returns from currency exposure could reach 15.64%, more than double the asset return.

For Australian, Canadian, EU, UK, Japanese, and South Korean investors, the currency returns are smaller in absolute value. For Australian, Canadian, and EU investors, they would expect negative returns from holding the US dollar in most cases. On the other hand, Japanese and South Korean investors would expect positive returns by shorting their domestic currencies against the US dollar. For UK investors, though the currency returns are small compared with those of South African and Turkish investors, they are all above 1%, which might impact the hedged return if currency risk management is applied. Finally, for all investors except those in South Africa and Turkey, currency standard deviation is consistently lower than the standard deviation of underlying asset returns, as reported in Panel B of Table 2.1.

Panel C of Table 2.1 presents the asset–exchange correlation for holding periods ranging from 1 to 36 months, with currencies listed across the top and investment horizons displayed to the left of each row. There are two apparent patterns. The first pattern relates to the correlation across different currencies. We can categorise the nine currencies into two groups based on the sign of their correlations. The first group tends to negatively correlate with the assets: AUD, CAD, EUR, GBP, ZAR, TRY, and KRW. The second group consistently shows a positive average correlation with assets, particularly JPY.

The second pattern relates to the investment horizon. As the investment horizon increases, the average correlation tends to move in a positive direction for investors whose domestic currency is AUD, CAD, EUR, GBP, ZAR, TRY, or JPY. For example, the correlation between investment and the EUR/USD exchange rate is −0.30 at a 1-month investment horizon but increases to 0.35 at a 36-month horizon. The KRW deviates from this trend, with the investment and exchange rate correlations remaining relatively stable as the investment horizon increases.

Table 2.1
Summary statistics

This table presents summary statistics for asset and currency returns. The exchange rate is quoted as the base currency per unit of foreign currency. All returns and standard deviations are annualised and reported in percentage points. Panel A reports the asset and currency returns. Panel B reports the annualised volatility (standard deviation) of the asset and currency returns. Panel C reports the correlation between asset and currency returns. For holding periods longer than one month, correlations are calculated using overlapping monthly observations. The results are presented for holding periods ranging from 1 to 36 months. In this table, the currencies are listed at the top of each column, and the investment horizon is shown on the left of each row.

Panel A: Returns on assets and exchange rates									
Horizon	AUD	CAD	EUR	GBP	ZAR	TRY	JPY	KRW	Asset
1 month	-0.05	-0.15	-0.48	1.27	5.73	14.98	0.46	0.30	5.77
3 months	0.11	-0.12	-0.45	1.38	5.93	15.64	0.34	0.38	5.76
6 months	0.04	-0.13	-0.56	1.40	5.99	15.54	0.39	0.62	5.72
12 months	-0.04	-0.13	-0.59	1.30	5.90	15.29	0.42	0.78	5.48
24 months	-0.49	-0.30	-0.72	1.18	5.25	13.19	0.27	0.32	6.00
36 months	-0.76	-0.41	-0.85	1.11	4.20	11.74	0.15	0.01	6.33
Panel B: Standard deviation of returns									
1 month	12.23	9.02	9.80	8.77	17.19	18.43	8.94	10.47	15.31
3 months	13.20	8.69	9.99	9.51	17.52	21.03	9.48	10.22	15.36
6 months	13.80	8.81	10.10	10.44	17.59	23.03	9.78	10.79	15.97
12 months	12.94	8.60	9.78	9.95	17.27	26.16	9.83	11.33	16.28
24 months	11.91	8.50	9.06	9.53	17.80	26.76	10.88	10.19	17.16
36 months	11.59	8.96	8.34	8.73	16.12	25.39	11.41	8.68	16.64

Table 2.1 Continued

Panel C: Correlation between asset and exchange rate return								
Horizon	AUD	CAD	EUR	GBP	ZAR	TRY	JPY	KRW
1 month	−0.54	−0.57	−0.30	−0.32	−0.42	−0.38	0.08	−0.47
3 months	−0.56	−0.57	−0.26	−0.45	−0.44	−0.39	0.21	−0.55
6 months	−0.56	−0.55	−0.30	−0.48	−0.45	−0.43	0.16	−0.63
12 months	−0.45	−0.46	−0.19	−0.49	−0.42	−0.45	0.15	−0.68
24 months	−0.12	−0.19	0.01	−0.41	−0.26	−0.38	0.28	−0.67
36 months	0.23	0.13	0.35	−0.20	0.14	−0.15	0.49	−0.60

2.4. The natural hedge effect

2.4.1. Asset–exchange rate correlation

Campbell et al. (2010) suggest that certain currencies, such as USD and CHF, tend to exhibit negative correlations with the global market. In contrast, most non-safe-haven currencies tend to correlate positively with the global market (e.g., the AUD and CAD). In this study, for investors whose domestic currency is one of AUD, CAD, EUR, GBP, ZAR, TRY, and KRW, the exchange rate return – representing a position of going long on the USD and short on the relevant domestic currency – negatively correlates with the asset return in its pricing currency. Thus, without hedge policies, asset and exchange rate covariances mitigate overall FX risk. The negative correlation between FX assets makes a natural hedge possible. Nevertheless, the level of the natural hedge effect also depends on the risk level of all the related risk components.

2.4.2. Variance decomposition of unhedged returns

The variance decomposition of returns illustrates the extent to which each risk component contributes to the overall risk of foreign investment. Following the approach by Schmittmann (2010), we find that the variance of the unhedged international portfolio is:

$$var(r_{U,t}) \approx var(r_t) + var(e_t) + 2cov(r_t, e_t) \tag{2.1}$$

In Equation (2.1), r_t is the return on equity in its pricing currency and e_t is the exchange gain/loss in the base currency per unit of foreign currency over the same period.

Table 2.2 presents the variance decomposition of foreign investment returns for investors with investment horizons ranging from 1 to 36 months. Investors' domestic currencies are presented at the top of each column and each risk component's risk and contribution to the overall investment are reported in each row. For example, the second cell in the first column of the table, which corresponds to the annualised foreign investment risk in its pricing currency, has a value of 0.024. As we assume that all investors hold the same foreign portfolio, the value is identical for all investors.

Table 2.2
Variance decomposition of unhedged investment returns

Data coverage ranges from January 2000 to December 2020. The domestic currencies are presented at the top of each column and the level and weight of each component are reported at the left of each row, where $var(e_t)$ is the variance of the FX rate, $var(r_{U,t})$ is the unhedged risk in investors' domestic currency, $var(r_t)$ is the investment risk in USD, and $cov(r_t,e_t)$ is the covariance of the asset and exchange rate. We report the level and risk contribution of each component for the investment horizon ranging from 1 to 36 months. The weights are reported as percentage points.

	AUD	CAD	EUR	GBP	ZAR	TRY	JPY	KRW
	1 month							
(1) $var(r_{U,t})$	0.018	0.0156	0.024	0.0228	0.0312	0.036	0.0336	0.0192
(2) $var(r_t)$	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240
(3) $var(e_t)$	0.0144	0.0084	0.0096	0.0072	0.0300	0.0336	0.0084	0.0108
(4) $2*cov(r_t,e_t)$	−0.0204	−0.0156	−0.0084	−0.0084	−0.0216	−0.0216	0.0024	−0.0144
(2)/(1)	128%	145%	97%	104%	75%	65%	70%	120%
(3)/(1)	82%	50%	40%	34%	94%	94%	24%	56%
(4)/(1)	−110%	−97%	−37%	−38%	−70%	−60%	7%	−76%
	3 months							
(1) $var(r_{U,t})$	0.0184	0.0168	0.0256	0.0200	0.0320	0.0432	0.0376	0.0172
(2) $var(r_t)$	0.0236	0.0236	0.0236	0.0236	0.0236	0.0236	0.0236	0.0236
(3) $var(e_t)$	0.0176	0.0076	0.0100	0.0092	0.0308	0.0444	0.0088	0.0104
(4) $2*cov(r_t,e_t)$	−0.0228	−0.0152	−0.008	−0.0132	−0.0236	−0.0256	0.006	−0.0172
(2)/(1)	128%	142%	93%	118%	74%	55%	63%	139%
(3)/(1)	95%	45%	39%	45%	96%	103%	24%	61%
(4)/(1)	−123%	−91%	−31%	−65%	−74%	−59%	16%	−101%

Table 2.2 Continued

	AUD	CAD	EUR	GBP	ZAR	TRY	JPY	KRW
	6 months							
(1) $var(r_{U,t})$	0.0202	0.0190	0.0264	0.0212	0.0326	0.0486	0.0388	0.0160
(2) $var(r_t)$	0.0256	0.0256	0.0256	0.0256	0.0256	0.0256	0.0256	0.0256
(3) $var(e_t)$	0.0190	0.0078	0.0102	0.0110	0.0310	0.0530	0.0096	0.0116
(4) $2*cov(r_t,e_t)$	−0.0248	−0.0156	−0.0096	−0.0160	−0.0252	−0.0318	0.0052	−0.0216
(2)/(1)	126%	135%	97%	120%	78%	53%	66%	160%
(3)/(1)	94%	41%	39%	51%	95%	109%	25%	73%
(4)/(1)	−123%	−82%	−36%	−75%	−77%	−66%	13%	−136%
	12 months							
(1) $var(r_{U,t})$	0.0266	0.0225	0.0304	0.0217	0.0364	0.0553	0.0412	0.0149
(2) $var(r_t)$	0.0265	0.0265	0.0265	0.0265	0.0265	0.0265	0.0265	0.0265
(3) $var(e_t)$	0.0167	0.0074	0.0096	0.0099	0.0298	0.0684	0.0097	0.0128
(4) $2*cov(r_t,e_t)$	−0.0189	−0.013	−0.006	−0.016	−0.0235	−0.0382	0.0049	−0.0249
(2)/(1)	100%	118%	87%	122%	73%	48%	64%	178%
(3)/(1)	63%	33%	32%	46%	82%	124%	23%	86%
(4)/(1)	−71%	−57%	−20%	−74%	−65%	−69%	12%	−168%
	24 months							
(1) $var(r_{U,t})$	0.0440	0.0340	0.0372	0.0266	0.0590	0.0731	0.0574	0.0173
(2) $var(r_t)$	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295
(3) $var(e_t)$	0.0142	0.0073	0.0082	0.0091	0.0317	0.0717	0.0119	0.0104
(4) $2*cov(r_t,e_t)$	−0.0049	−0.0056	0.0003	−0.0133	−0.0158	−0.0350	0.0106	−0.0234
(2)/(1)	67%	87%	79%	111%	50%	40%	51%	170%
(3)/(1)	32%	21%	22%	34%	54%	98%	21%	60%
(4)/(1)	−11%	−16%	1%	−50%	−27%	−48%	18%	−135%
	36 months							
(1) $var(r_{U,t})$	0.0592	0.0457	0.0459	0.0322	0.0898	0.1178	0.0728	0.0191
(2) $var(r_t)$	0.0277	0.0277	0.0277	0.0277	0.0277	0.0277	0.0277	0.0277
(3) $var(e_t)$	0.0134	0.0080	0.0069	0.0076	0.0260	0.0644	0.0130	0.0075
(4) $2*cov(r_t,e_t)$	0.0090	0.0040	0.0098	−0.0059	0.0078	−0.0129	0.0186	−0.0173
(2)/(1)	47%	61%	60%	86%	31%	24%	38%	145%
(3)/(1)	23%	18%	15%	24%	29%	55%	18%	40%
(4)/(1)	15%	9%	21%	−18%	9%	−11%	26%	−91%

Table 2.2 shows that the variance of the foreign portfolio is relatively stable across different investment horizons, ranging from 0.0236 to 0.0295. Across all investor currencies, the foreign portfolio contributes between 48% (TRY) and 178% (KRW) of the total risk to unhedged investments for those with a horizon of 12 months or less. As the investment horizon increases, foreign portfolio risk becomes a smaller share of overall investment risk. The range is 40% (TRY) to 170% (KRW) for a 24-month investment and 24% (TRY) to 145% (KRW) for a 36-month investment.

The foreign exchange variance is smaller than the investment variance in most cases, except for investors from South Africa and Turkey. For Canadian, EU, UK, Japanese, and South Korean investors, the FX variance is less than 50% of the foreign portfolio risk in USD. However, it still accounts for a significant part of the total unhedged investment risk. For investments with a horizon of 12 months or less, the FX variance weight on unhedged investment variance ranges from 23% (JPY) to 124% (TRY). As the investment horizon increases, FX variance accounts for a smaller share of overall investment risk. The range is between 21% (JPY) and 98% (TRY) for a 24-month investment and between 15% (EUR) and 55% (TRY) for a 36-month investment.

Alternatively, in many cases, the covariance between the asset and foreign exchange can reduce the contribution of FX volatility to the overall investment risk, providing a natural hedge effect without the need for currency risk management. For investments with holding periods of 1 to 12 months, the covariance is negative, except for Japanese investors. As the investment horizon reaches 24 months, Canadian investors also experience positive FX–asset covariance. When the investment horizon reaches 36 months, all investors except those in the UK, Turkey and South Korea experience a positive FX–asset covariance. Compared to the variance decomposition shown by Schmittmann (2010), the covariance between the asset and FX returns in this study contributes more substantially to overall investment risk in most scenarios.

Taking both the FX risk ($var(e_t)$) and FX and investment covariance ($cov(r_t, e_t)$) into account, these results indicate that introducing a foreign exchange rate to foreign investment does not necessarily bring additional risk as the net influence from foreign exchange depends on the level of both risk components. Table 2.3 displays the net influence ($var(e_t) + cov(r_t, e_t)$) of foreign exchange rates risk for investors with several domestic currencies. The first cell in the first column of the tables, which corresponds to the net risk contribution of foreign exchange from the Australian investors' perspective, has a value of −28%, which means that for investors from Australia, foreign currency exposure helps reduce the overall risk of their foreign investments in the US market.

Table 2.3
Net influence from foreign exchange

Data coverage ranges from January 2000 to December 2020. The domestic currencies are presented at the top of each column and the investment horizon is reported at the left of each row. Net risk contribution is the sum of the contributions from var(e_t) and cov(r_t,e_t). We report the net risk contribution of each domestic currency for investment horizons ranging from 1 to 36 months. The net weights are reported as percentage points.

Horizon	AUD	CAD	EUR	GBP	ZAR	TRY	JPY	KRW
1 month	−28%	−47%	3%	−4%	24%	34%	31%	−20%
3 months	−28%	−46%	8%	−20%	22%	44%	40%	−40%
6 months	−29%	−41%	3%	−24%	18%	43%	38%	−63%
12 months	−8%	−24%	12%	−28%	17%	55%	35%	−82%
24 months	21%	5%	23%	−16%	27%	50%	39%	−75%
36 months	38%	27%	36%	6%	38%	44%	44%	−51%

Table 2.3 shows that investors whose domestic currency is AUD, CAD, GBP, or KRW tend to fully benefit from foreign currency exposure in the short term, as the sum of risk contributions from FX variance and FX–asset covariance is negative. Meanwhile, EU, South African, and Turkish investors partially benefit from exposure to foreign currencies. Although the currency's short-term covariance with the asset is negative, the net risk contribution remains positive, as the negative covariance is insufficient to offset the risk contribution from foreign exchange variance. As the investment horizon shifts to 24 months, only UK and South Korean investors fully benefit from foreign currency exposure. When the investment horizon reaches 36 months, only South Korean investors can fully benefit from foreign currency exposure without hedging.

To conclude, the USD serves as a safe haven for our selected currencies, as it tends to appreciate or depreciate against most currencies when investment returns rise or fall, except against the JPY. Thus, from the international investors' perspective, although entering the US market brings potential foreign currency uncertainty, for investors whose domestic currency is AUD, CAD, GBP, and KRW, the foreign exchange has a sizeable negative risk contribution to their foreign investment in most cases in the short term, leading to higher risk if the foreign currency exposure is fully hedged. Thus, the natural hedge effect fully protects these investors. Alternatively, although foreign currency exposure still adds short-term risk to unhedged investments for EU, South African, and Turkish investors, the overall risk level is reduced due to the negative covariance between foreign exchange and assets. Thus, we claim that the natural hedge effect partially protects these investors. In the long term, however, only South Korean investors can fully benefit from the natural hedge effect. The results prompt investors to consider whether the optimal hedge strategy provides a statistically meaningful risk reduction for investments that fully or partially benefit from the natural hedge effect, especially compared with unhedged investments. Meanwhile, the evolution of the FX–asset covariance suggests that the benefit of exposure to a safe-haven currency holds only for short-term investments, not for long-term ones.

2.5. Risk-minimising optimal hedge

An optimal hedge is formed for international investors who want to estimate currency hedging demand, thereby minimising the stock portfolio risk in the US market. In Solnik's (1974a) international capital pricing model (IAPM), mean–variance optimised investors hold a combination of the domestic risk-free asset and a portfolio of all assets, including forward contracts on foreign currencies. Based on the approach by Schmittmann (2010), we develop our equations.

The unhedged return from time $t-1$ to t for international investors who spot their local currency for a foreign currency and invest in the foreign market is:

$$r_{U,t} = (1 + e_t)(1 + r_t) - 1 \tag{2.2}$$

In Equation (2.2), r_t is the return on equity in foreign currency and e_t is the exchange gain/loss in the base currency per unit of foreign currency over the same period. Equation (2.2) can be rewritten as:

$$r_{U,t} = r_t + e_t + r_t e_t \tag{2.3}$$

Since $r_t e_t$ is small in magnitude, $r_{U,t}$ can be approximated by:

$$r_{U,t} \approx r_t + e_t \tag{2.4}$$

For an international investment, its return $r_{U,t}$ is subject to the return on the investment itself r_t and the gain/loss on the exchange rate e_t. If investors worry about exchange rate volatility, they could take a hedged position (shorting foreign currency and buying their home currency) of Φ with FX forward or futures contracts. The variable $E(r_t)$ is the portfolio expected return and f_t is the forward premium/discount, which denotes the hedged return as follows:

$$\begin{aligned} r_{H,t} = \Phi_t[1 + E(r_t)](1 + f_t) + (1 - \Phi_t)[1 + E(r_t)](1 + e_t) \\ +[\, r_t - E(r_t)](1 + e_t) - 1 \end{aligned} \tag{2.5}$$

In Equation (2.5), $\Phi_t[1 + E(r_t)](1 + f_t)$ represents the expected value hedged by the forward contracts, $(1 - \Phi_t)[1 + E(r_t)](1 + e_t)$ is the part of the expected value left unhedged, and $[\, r_t - E(r_t)](1 + e_t)$ is the unhedged unexpected value. As it is impossible to obtain the exact value of $E(r_t)$ ahead, we can hedge the beginning of the period value by setting $E(r_t)$ equal zero. Equation (2.5) can then be further simplified as:

$$r_{H,t} = r_t + e_t + e_t r_t + \Phi(f_t - e_t) \tag{2.6}$$

We are interested in the hedge ratio Φ that minimises the variance of portfolio return:

$$\min_{\Phi} Var[r_{H,t}] \tag{2.7}$$

Thus, following Equation (2.3), Equation (2.7) can be rewritten as:

$$\min_{\Phi} Var\big[r_{U,t} + \Phi(f_t - e_t)\big] \tag{2.8}$$

By expanding this equation, we arrive at Equation (2.9) as follows:

$$\min_{\Phi} \big[Var(r_{U,t}) + \Phi^2 Var(f_t - e_t) + 2\Phi\text{Cov}(r_{U,t}, f_t - e_t)\big] \tag{2.9}$$

Following Whaley (2006), we take the derivative of Equation (2.9) with respect to Φ and set it equal to zero:

$$dVar(r_{H,t})/d\Phi = 2\Phi Var(f_t - e_t) + 2\ \text{Cov}(r_{U,t}, f_t - e_t) = 0$$

Thus, we find that the risk-minimising hedge is as follows:

$$\Phi = -\ \text{Cov}(r_{U,t}, f_t - e_t)/Var(f_t - e_t) \tag{2.10}$$

Using Equation (2.10), we can collect data and estimate variance and correlation parameters to compute the risk-minimising hedge. Following Schmittmann (2010), the optimal static hedge ratio can also be developed by performing the OLS estimation where the estimate of β is the optimal static hedge:

$$r_{U,t} = \alpha + \beta[e_t - f_t] + \varepsilon_t \tag{2.11}$$

Meanwhile, the optimal hedge can also be achieved by hedging through borrowing and lending. Utilising the money market, under the assumption that CIP holds, the performance of adopting borrowing/lending and forward contracts should be the same (Schmittmann, 2010). Following Schmittmann (2010), Equation (2.12) links the interest rate and the forward premium:

$$f_t - 1 = 1 + i_{d,t-1}/1 + i_{f,t-1} \tag{2.12}$$

In Equation (2.12), $i_{d,t-1}$ and $i_{f,t-1}$ are the domestic and foreign interest rates.

Although CIP was well maintained in the past, the situation has changed, and many researchers have documented CIP violations (e.g., Kwas et al., 2023; Du et al., 2018). Thus, this study examines the violation of CIP and presents the hedging results for adopting borrowing and lending and forward contracts.

2.6. Optimal hedge for investment with the natural hedge effect

Thus far, we have developed the equations for the optimal hedge. Investors can subsequently utilise the mean–variance framework to actively adjust optimal foreign currency exposure in order to minimise investment risk. We estimate the optimal hedge ratios for two purposes. First, we aim to determine how currency risk management performs on currency pairs that provide a natural hedge effect. Accordingly, we use the interest rate–implied forward rate in Equation (2.12) to estimate optimal hedge ratios and test performance, following Campbell et al. (2010) and Schmittmann (2010). Second, we aim to determine whether the violation of CIP will cause differences when hedging with forward contracts and borrowing/lending. We use the actual forward contract to estimate the optimal hedge ratio and test whether the hedged risk and return differ from the borrowing/lending hedge.

2.6.1. Optimal hedge ratio

Table 2.4 presents the optimal hedge ratios estimated using Equation (2.11) for international investors with money market (borrowing/lending) hedging. The investment horizons are reported at the left of each row and the domestic currencies are reported at the top of each column. To facilitate explanation, we use an example to discuss in detail. For instance, Australian investors with a one-month holding period show a value of 0.31. This means that a risk-minimising Australian investor fully invested in the US equity market should, on average, purchase FX forward contracts that short the USD and go long 0.31 AUD for every Australian dollar invested in US equities. The value indicates that the risk-minimising Australian investor should partially hedge the USD exposure held implicitly in the investment, suggesting that the USD appreciates against the AUD when the stock market declines.

Table 2.4
Optimal hedge ratios for money market hedges

This table reports the optimal hedge ratios for each domestic currency. The investment horizons are reported at the left of each row and the domestic currencies are reported at the top of each column. We report the results for investments with horizons of 1 to 36 months. For TRY, we report the results for investments with horizons of 1 to 24 months. Standard errors are corrected for autocorrelation if overlapping intervals are adopted using the Newey–West procedure. We mark coefficients with one, two, or three asterisks, indicating rejection of the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. The optimal hedge ratios are estimated using Equation (2.11) for international investors with money market (borrowing/lending) hedging.

Horizon	AUD	CAD	EUR	GBP	TRY	ZAR	KRW
1 month	0.31***	0.03	0.52***	0.43***	0.65***	0.62***	0.30***
	(0.07)	(0.09)	(0.09)	(0.11)	(0.05)	(0.05)	(0.08)
3 months	0.31**	−0.03	0.59**	0.26	0.71***	0.60***	0.11
	(0.15)	(0.26)	(0.26)	(0.32)	(0.16)	(0.15)	(0.19)
6 months	0.28	−0.04	0.52	0.19	0.71***	0.58***	−0.09
	(0.31)	(0.46)	(0.44)	(0.52)	(0.24)	(0.17)	(0.23)
12 months	0.43	0.10	0.72	0.14	0.74***	0.61**	−0.18
	(0.49)	(0.75)	(0.46)	(0.93)	(0.17)	(0.25)	(0.19)
24 months	0.94**	0.80	1.10**	0.33	1.29***	1.00***	−0.55***
	(0.38)	(0.55)	(0.44)	(0.79)	(0.24)	(0.36)	(0.13)
36 months	1.45***	1.68**	1.84***	0.77	-	1.68***	−0.70**
	(0.33)	(0.65)	(0.30)	(0.88)	-	(0.27)	(0.31)

Table 2.4 shows that the one-month optimal hedge ratios are statistically significant at the 1% level for all investors except those from Canada. Obtaining statistically meaningful hedge ratios and robust standard errors becomes more challenging as the investment horizon increases due to the limited number of data points and issues with autocorrelation. The estimation quality deteriorates as the investment horizon moves from 3 to 12 months. Most observations can achieve statistically significant estimations when the investment horizon approaches 24 and 36 months.

All risk-minimising investors have a hedge ratio of less than one for investments with a horizon of less than 12 months, indicating that investors benefit from their exposure to the USD in the short term. For Canadian and South Korean investors, the risk-minimising portfolio, in some cases, has an optimal hedge ratio below zero, suggesting that optimally hedged investments should seek additional exposure to the USD over the implicit exposure of the investment. In line with Campbell et al. (2010), the general strategy suggests that investors should maintain a positive/negative exposure to currencies that negatively/positively correlate with the investment returns in the pricing currency.

Although positive USD exposure is optimal for all investors in the short term, the level varies significantly among different investors. For Canadian investors, the optimal strategy leans towards a no-hedge policy. Their estimated hedge ratio is close to zero, and the hypothesis of an estimated hedge ratio of zero cannot be rejected in all cases. Australian, UK, and South Korean investors tend to favour a hedge ratio of less than 0.5, and it is optimal to have only a small portion of foreign currency exposure protected. EU, Turkish, and South African investors tend to favour a larger position in shorting foreign currency and going long on domestic currencies.

As the investment horizon reaches 24 and 36 months, the optimal hedge ratio tends to shift from partial hedge to over-hedge, except for UK and South Korean investors. This indicates the diminishing of negative FX–asset covariance in the long term. For UK investors, the partial hedge is optimal throughout all investment horizons. Alternatively, South Korean investors are observed to seek more exposure to the USD for long-term investments.

Although short-term optimal strategies tend to suggest a positive exposure to currencies that negatively correlate with the investment, as seen by Schmittmann (2010) and Campbell et al. (2010), the optimal strategy for long-term investment is quite the opposite. Our results extend these studies' findings and indicate that investors should over-hedge their USD exposure, as it correlates positively with long-term investment returns.

2.6.2. Optimal hedge performance

Based on the estimation of the optimal hedge ratios for investors' foreign investments, we examine the quantity of risk reduction. Following Campbell et al. (2010), we choose zero, half, and full hedge as benchmarks. The zero- or full-hedge strategy refers to the condition where investors choose a hedge ratio of zero or one. The half-hedge strategy indicates a hedge ratio of 0.5, a strategy that reduces investors' regret. We employ the *F* statistic to assess the statistical significance of the risk reduction achieved by the optimal hedge in comparison to the benchmark strategies (Campbell et al., 2010).

Table 2.5
Benchmark and optimally hedged risk with borrowing/lending

This table displays the in-sample results for risk reduction from the optimal hedge. The domestic currencies are reported at the top of each column and the risks under different hedging strategies are reported in each row. Below the risk section, we also present the *F* statistics and mark coefficients with one, two, or three asterisks, indicating that the benchmark hedged risk is larger than the optimally hedged risk at the 10%, 5%, and 1% significance levels, respectively. The benchmark strategies adopted are zero hedge, half hedge, and full hedge. We provide results for investment horizons ranging from 1 to 36 months. For TRY, we report the results for investments with horizons of 1 to 24 months.

	AUD	CAD	EUR	GBP	TRY	ZAR	KRW
				1 month			
Zero hedge	13.52	12.71	15.51	15.04	18.96	17.73	13.98
Half hedge	13.19	13.41	14.65	14.56	14.87	14.30	13.79
Full hedge	15.50	15.45	15.39	15.37	15.94	15.60	15.47
Optimal hedge	12.98	12.71	14.65	14.55	14.59	14.15	13.63
				Comparison			
Zero vs optimal	1.09	1.00	1.12	1.07	1.69***	1.57***	1.05
Half vs optimal	1.03	1.11	1.00	1.00	1.04	1.02	1.02
Full vs optimal	1.43***	1.48***	1.10	1.12	1.19	1.22*	1.29**
				3 months			
Zero hedge	13.57	12.90	15.96	14.17	20.75	17.88	13.01
Half hedge	13.19	13.68	14.86	14.15	15.82	14.47	13.57
Full hedge	15.87	15.67	15.40	15.64	16.36	16.02	15.89
Optimal hedge	12.94	12.90	14.83	13.96	15.28	14.36	12.96
				Comparison			
Zero vs optimal	1.10	1.00	1.16	1.03	1.84***	1.55***	1.01
Half vs optimal	1.04	1.12	1.00	1.03	1.07	1.02	1.10
Full vs optimal	1.50***	1.47***	1.08	1.26**	1.15	1.24**	1.50***
				6 months			
Zero hedge	14.21	13.75	16.23	14.56	22.03	18.08	12.10
Half hedge	14.01	14.54	15.33	14.77	16.89	14.81	13.62
Full hedge	16.94	16.49	16.08	16.69	17.45	16.56	16.81
Optimal hedge	13.67	13.74	15.33	14.42	16.33	14.73	12.06
				Comparison			
Zero vs optimal	1.08	1.00	1.12	1.02	1.82***	1.51***	1.01
Half vs optimal	1.05	1.12	1.00	1.05	1.07	1.01	1.28**
Full vs optimal	1.54***	1.44***	1.10	1.34**	1.14	1.26**	1.94***

Table 2.5 Continued

	AUD	CAD	EUR	GBP	TRY	ZAR	KRW
				12 months			
Zero hedge	16.31	15.01	17.43	14.74	23.51	19.07	10.18
Half hedge	15.31	15.37	16.04	15.10	17.31	15.64	12.60
Full hedge	17.06	16.83	16.12	17.00	17.50	17.02	16.66
Optimal hedge	15.28	14.99	15.89	14.67	16.44	15.50	9.97
				Comparison			
Zero vs optimal	1.14	1.00	1.20**	1.01	2.04***	1.51***	1.04
Half vs optimal	1.00	1.05	1.02	1.06	1.11	1.02	1.60***
Full vs optimal	1.25**	1.26**	1.03	1.34**	1.13	1.21*	2.79***
				24 months			
Zero hedge	20.96	18.42	19.29	16.30	27.58	21.87	10.07
Half hedge	18.09	17.32	17.29	16.06	21.16	18.11	14.00
Full hedge	17.22	17.22	16.39	17.30	16.90	16.67	18.71
Optimal hedge	17.20	17.13	16.37	15.97	16.14	16.67	8.12
				Comparison			
Zero vs optimal	1.48***	1.16	1.39***	1.04	2.92***	1.72***	1.54***
Half vs optimal	1.11	1.02	1.12	1.01	1.72***	1.18	2.97***
Full vs optimal	1.00	1.01	1.00	1.17	1.10	1.00	5.31***
				36 months			
Zero hedge	24.34	20.87	21.42	17.93	-	28.94	10.15
Half hedge	20.04	18.85	18.56	16.56	-	22.25	12.44
Full hedge	17.05	17.42	16.31	16.51	-	16.51	15.29
Optimal hedge	16.09	16.66	14.67	16.36	-	12.75	8.72
				Comparison			
Zero vs optimal	2.29***	1.57***	2.13***	1.20*	-	5.15***	1.35**
Half vs optimal	1.55***	1.28*	1.60***	1.02	-	3.04***	2.04***
Full vs optimal	1.12	1.09	1.24*	1.02	-	1.68***	3.08***

Table 2.5 shows the annualised standard deviation of benchmark strategies and the optimal strategy estimated using Equation (2.11). The investors' domestic currencies are listed at the top of each column, while the corresponding rows present the standard deviations and performance comparisons for each hedging strategy. We report the results for investments with horizons from 1 to 36 months. For example, the first four cells in the first column of the table, which correspond to the annualised standard deviation for Australian investors investing in the US equity market and adopting the zero, half, full, and optimal hedging strategies, have values of 13.52, 13.19, 15.50, and 12.98, respectively. The following numbers represent the F statistics used to test whether investments adopting benchmark strategies have higher risk than optimally hedged investments. We mark with one, two, or three asterisks the coefficients for which

benchmark hedged risk is larger than optimally hedged risk at 10%, 5%, and 1% significance levels, respectively.

The asset-exchange rate covariance can reduce the risk of investments that are negatively correlated with the exchange rate return. Similar to Campbell et al. (2010), we find that full hedging increases the risk for Canadian investors compared to unhedged investments. However, Table 2.5 shows that this effect is not limited to Canadian investors with a three-month investment horizon, as noted by Campbell et al. (2010). For example, unhedged investments carry lower risk than fully hedged ones for Australian and Canadian investors with a 1- to 12-month horizon, UK investors with a 1- to 24-month horizon and South Korean investors with a 1- to 36-month horizon. More importantly, as the investment horizon increases, the FX–asset covariance becomes positive, and some investments have a higher unhedged risk than fully hedged ones. For example, Australian and Canadian investors face a higher level of unhedged risk than fully hedged investments when the investment horizon exceeds 24 months, while for UK investors this is the case for 36-month investments.

For EU, Turkish and South African investors, holding USD has a negative correlation with investment returns in the US market. In most cases, however, the negative FX–asset covariance is insufficient to offset the variance in exchange rates. Thus, domestic and foreign currency pairs sometimes increase the overall investment risk. For example, as the natural hedge effect is similar to the FX variance for investors from the EU, the unhedged and fully hedged investments are at a similar risk level for short-term investments, as shown by the difference ranging from 0.12 to 0.15 for investments of 1 to 6 months in Table 2.5. For Turkish and South African investors, unhedged investments are always riskier than fully hedged ones.

Next, we assess the performance of the optimal hedge. Due to the nature of the in-sample analysis, the optimally hedged investments have the lowest annualised standard deviation. In some cases, however, the lower risk is not statistically significant compared to benchmark strategies.

The natural hedge effect is strong for Australian and Canadian investors in the short term. Unless investors take a full hedge and eliminate the natural hedge effect, the *F* test for an optimal hedge in relation to a zero or half hedge cannot be considered statistically significant. Conversely, the natural hedge effect is the lowest for EU investors; however, they also have a low FX variance. Thus, for their 1- to 6-month investments, they are in FX risk neutral conditions as the FX variance and natural hedge effects are similar, which means optimal currency exposure has minimal impact on investment risk. The conditions for UK investors are mixed: their 1-month investments are more similar to those of EU investors, while their 3- to 12-month investments are more comparable to those of Australian and Canadian investors. While Turkish and South African investors also exhibit a strong natural hedge effect in the short term, their FX variance is the highest among all investors, making the natural hedge effect insufficient to cover it. Thus, although adopting a high hedge ratio sacrifices the natural hedge effect, it reduces risk from FX variance, making the optimal hedge statistically preferable to a zero hedge. The natural hedge effect of the above investors either diminishes or disappears when the investment horizon reaches 36 months, at which point the optimal hedge outperforms the zero-hedge strategy statistically for all investors.

South Korean investors are the only group that consistently benefits from a strong natural hedge effect across all investment horizons. The optimal hedge performs similarly to Australian and Canadian investors for the 1- and 3-month investments. When the investment horizon increases, however, they tend to demand more USD exposure to reduce investment risk. The zero hedge is outperformed statistically by the optimal hedge when the investment horizon reaches 24 months.

Thus, the performance of optimal hedging shows that, for Australian, Canadian, UK, and South Korean investors, the strong natural hedge effect results in only minor risk reduction relative to unhedged investments in the short term. As a result, foreign currency exposure does not create a significant additional barrier for these international investors – in fact, unhedged foreign investments may even carry less risk than those measured in USD. For these investors, currency hedging becomes beneficial once the investment horizon reaches 24 months. In contrast, currency hedging is optimal from the outset for Turkish and South African investors, given their significantly higher FX risk. EU investors do not benefit from optimal short-term hedging but should consider adopting currency hedging once their investment horizon reaches 12 months.

Campbell et al. (2010) achieved a significant reduction in risk using the optimal hedge. However, the optimal hedge cannot significantly outperform an unhedged investment when foreign currency exposure offers substantial protection against FX variance. Our results suggest that investors who already benefit from a strong natural hedge effect see limited additional risk reduction from applying the optimal hedge, unless their domestic currency is highly volatile and requires further FX exposure to mitigate investment risk. Conversely, when the natural hedge effect disappears, implementing the optimal hedge is advisable, as it can statistically reduce investment risk compared to remaining unhedged.

2.7. Differences between hedge vehicles

2.7.1. Differences in full-sample hedge ratios

Many researchers have reported violations of CIP (e.g., Kwas et al., 2023; Du et al., 2018). However, Schmittmann (2010) and Campbell et al. (2010) proved that the equivalent of the borrowing/lending hedge and the forward derivative hedge relies on the validation of CIP. Thus, hedging with borrowing and lending, as well as with forward derivatives, should yield different optimal currency demands. Table 2.6 provides the estimated optimal hedge ratios calculated using Equation (2.11) and forward exchange contracts in the derivative market.

Table 2.6
Optimal hedge ratios for forward contract hedges

This table reports the optimal hedge ratios calculated using Equation (2.11) and forward exchange contracts in the derivative market for each domestic currency. The investment horizons are listed in the leftmost column and the domestic currencies are reported at the top of each column. We report the results for investments with horizons of 1 to 36 months. For TRY, we report the results for investments with horizons of 1 to 24 months. Standard errors are corrected for autocorrelation if overlapping intervals are adopted using the Newey–West procedure. We mark coefficients with one, two, or three asterisks, indicating rejection of the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively.

Horizon	AUD	CAD	EUR	GBP	TRY	ZAR	KRW
1 month	0.26***	0.02	0.49***	0.43***	0.18***	0.47***	0.25***
	(0.07)	(0.09)	(0.10)	(0.11)	(0.03)	(0.05)	(0.09)
3 months	−0.12*	−0.04	0.60**	0.27	0.38**	0.58***	0.08
	(0.07)	(0.26)	(0.25)	(0.30)	(0.19)	(0.15)	(0.21)
6 months	0.27	−0.05	0.54	0.20	0.48***	0.29***	−0.10
	(0.30)	(0.47)	(0.43)	(0.52)	(0.18)	(0.11)	(0.24)
12 months	0.41	0.07	0.72	0.12	0.48***	0.25	−0.18
	(0.50)	(0.74)	(0.45)	(0.88)	(0.12)	(0.16)	(0.19)
24 months	0.90**	0.73	1.04***	0.24	1.13***	0.90**	−0.60***
	(0.45)	(0.68)	(0.40)	(0.80)	(0.23)	(0.42)	(0.11)
36 months	1.48***	1.72***	1.76***	0.64	-	1.59***	−0.85***
	(0.31)	(0.65)	(0.34)	(1.08)	-	(0.23)	(0.17)

A comparison of Tables 2.4 and 2.6 reveals that the choice of hedge vehicle generally has little impact on optimal hedge ratios across most scenarios, with notable exceptions of investors from Turkey and South Africa. For Canadian, EU, UK, and South Korean investors, the average differences in optimal hedge ratios between borrowing/lending and forward contracts strategies are minimal – typically within five basis points. The most considerable difference observed among these groups is 15 basis points in the case of South Korean investors with a three-year investment horizon. The position is similar for Australian investors, though they experience a 43-basis-point deviation for a three-month investment horizon. In contrast, the average hedge ratio differences for Turkish and South African investors are approximately 29 and 17 basis points, respectively. The most significant variation (a 47-basis-point difference) appears at the 1-month investment horizon for Turkish investors.

While different investors face different conditions, hedging with borrowing and lending typically requires more positions in domestic currencies than hedging with forward contracts. In 35 of the 41 scenarios, the hedge ratios are higher for the borrowing/lending hedge than for the forward contracts hedge. In addition, the optimal hedge ratios across all the investment horizons are more consistent for the borrowing/lending hedge than for the forward contracts hedge. This means there are fewer jumps in optimal hedge ratios among investments with similar investment horizons, especially for investors from Australia, Turkey, and South Africa. Moreover, sizeable differences in optimal hedge ratios tend to emerge when investments have short horizons (e.g., 1- to 12-month holding periods), reaching up to 47 basis points. For 24- and 36-month investments, the largest difference between hedge ratios is only 16 basis points.

2.7.2. Stability check of the subsample hedge ratios

Kwas et al. (2024) demonstrate that CIP was maintained until the global financial crisis (GFC) in 2008, and the relationship expressed by CIP thereafter became a rough approximation. The full sample period for which we have analysed optimal hedge ratios using Equation (2.11) includes an early period of CIP held closely, followed by another subperiod with noticeable violations of CIP. This study divides the entire sample into two subsamples: one from January 2000 to December 2008 and another from January 2009 to December 2020. We examine the impact of CIP violations on optimal hedge ratios, as well as the shifts in optimal hedge positions before and after the GFC. Due to data availability, we focus on investments with a horizon of 1 month to 12 months.

Table 2.7 shows that differences in the adoption of different hedge vehicles are similar across the two subsamples, with the notable exceptions of Turkish and South African investors. For the first subsample – excluding the sharp increase at the three-month horizon for Australian investors and the results for Turkish and South African investors – the average difference in hedge ratios across all investment horizons is within four basis points for most investors. In the second subsample, under the same conditions, this average difference decreases to approximately two basis points. These findings suggest that, contrary to expectations in the literature, which anticipate a widening gap between hedge vehicles after the GFC, there is no substantial difference in hedge ratios between the two hedge vehicles across the subsamples for most investors. However, the differences in hedge ratios between borrowing/lending and forward contract hedging are considerable for Turkish and South African investors across the two subsamples. In the first subsample, the average differences are relatively large – 34 and 26.5 basis points, respectively. In the second subsample, these differences shrink to 2 and 8 basis points, respectively. One possible explanation for these findings is that the choice of hedge vehicle affects optimal hedge ratio estimation only when the forward premium variance is considerable relative to the FX variance.

Table 2.7
Subperiod optimal hedge ratios

This table reports the optimal hedge ratios using Equation (2.11) for each domestic currency. The investment horizons are reported in the leftmost column and the domestic currencies are reported at the top of each column. We report the results for investments with horizons of 1 to 12 months. Parts A and B display the results before and after the GFC, respectively. Standard errors are corrected for autocorrelation if overlapping intervals are adopted using the Newey–West procedure. We mark coefficients with one, two, or three asterisks, for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively.

Part A: Pre-GFC (January 2000 to December 2008)							
Horizon	AUD	CAD	EUR	GBP	TRY	ZAR	KRW
	Money market hedge						
1 month	0.41***	0.07	0.76***	0.70***	0.57***	0.74***	0.49***
	(0.10)	(0.14)	(0.14)	(0.17)	(0.06)	(0.08)	(0.12)
3 months	0.28	−0.11	0.65	0.19	0.57	0.64**	0.17
	(0.18)	(0.38)	(0.40)	(0.57)	(0.36)	(0.26)	(0.28)
6 months	0.24	−0.06	0.60	0.20	0.70	0.66***	0.07
	(0.28)	(0.52)	(0.74)	(0.75)	(0.65)	(0.22)	(0.46)
12 months	0.15	−0.44	0.61	−0.03	0.72	0.52*	−0.06
	(0.60)	(0.39)	(0.76)	(0.80)	(0.87)	(0.27)	(0.28)
	Forward contract hedge						
1 month	0.35***	0.05	0.76***	0.77***	0.14***	0.48***	0.43**
	(0.11)	(0.15)	(0.15)	(0.18)	(0.03)	(0.07)	(0.13)
3 months	0.02	−0.13	0.65*	0.18	0.28	0.64**	0.16
	(0.06)	(0.38)	(0.38)	(0.57)	(0.19)	(0.26)	(0.29)
6 months	0.22	−0.08	0.59	0.18	0.40	0.24*	0.05
	(0.25)	(0.52)	(0.73)	(0.73)	(0.25)	(0.13)	(0.41)
12 months	0.10	−0.48	0.52	−0.08	0.38*	0.14	−0.07
	(0.56)	(0.33)	(0.80)	(0.61)	(0.22)	(0.13)	(0.23)
Part B: Post-GFC (January 2009 to December 2020)							
	Money market hedge						
1 month	0.22**	−0.03	0.25**	0.21	0.76***	0.51***	0.13
	(0.09)	(0.11)	(0.12)	(0.13)	(0.08)	(0.07)	(0.11)
3 months	0.37***	0.01	0.42***	0.37**	0.87***	0.55***	0.11
	(0.13)	(0.21)	(0.15)	(0.16)	(0.16)	(0.09)	(0.15)
6 months	0.51***	0.08	0.47**	0.48**	0.87***	0.58***	0.08
	(0.17)	(0.27)	(0.20)	(0.22)	(0.15)	(0.10)	(0.18)
12 months	0.70***	0.40*	0.60***	0.42*	0.93***	0.69***	0.05
	(0.17)	(0.23)	(0.17)	(0.24)	(0.16)	(0.14)	(0.12)
	Forward contract hedge						
1 month	0.19**	−0.04	0.22*	0.19	0.74***	0.45***	0.08**
	(0.08)	(0.11)	(0.12)	(0.13)	(0.08)	(0.07)	(0.11)
3 months	0.08	0.01	0.42***	0.37**	0.87***	0.53***	0.12
	(0.15)	(0.21)	(0.16)	(0.16)	(0.16)	(0.10)	(0.15)
6 months	0.51***	0.08	0.48**	0.51**	0.85***	0.45***	0.08
	(0.16)	(0.27)	(0.20)	(0.22)	(0.14)	(0.09)	(0.19)
12 months	0.72***	0.36	0.62***	0.43*	0.89***	0.58***	0.05
	(0.17)	(0.23)	(0.18)	(0.24)	(0.16)	(0.13)	(0.12)

Equation (2.8) shows that borrowing and lending, as well as forward contracts, affect optimal hedge ratio estimation through the channel of the forward premium. Thus, if the risk of forward premium is small relative to the exchange rate return, it cannot influence the estimation of optimal hedge ratios. Table 2.8 presents the ratio of the variance between the forward premium and the exchange rate return, indicating the relative influence that hedge vehicles can have on the estimation of optimal hedge ratios. For example, the first four cells in the first column have a value of 0.16, representing the variance of the forward premium calculated using Equation (2.12) and interest rates, accounting for 0.16% of the exchange rate risk. As the forward premium variance is minimal relative to the exchange rate variance, it does not effectively drive the estimation of the optimal hedge. The results in Table 2.8 closely match those in Tables 2.4 and 2.6; the difference between borrowing/lending and forward contract optimal hedge ratios is strictly related to the sharp increases in forward premium variance relative to the variance of the exchange rate.

As shown in Table 2.8, using different hedge vehicles results in differences in the forward premium. When the forward premium variance is notably smaller than the variance of the foreign exchange rate return, CIP violations are unlikely to cause noticeable differences in the estimated optimal hedge ratios. Thus, in terms of optimal currency hedging, changes in hedge vehicles do not necessarily lead to shifts in hedging positions unless large forward or interest rate jumps occur. However, to conclude that borrowing/lending and forward contracts are equivalent, we must examine whether adopting these hedging vehicles results in significant differences in risk and return.

Table 2.8
Ratio of forward premium variance to exchange rate return variance

This table displays the ratio of forward premium variance to the variance of exchange rate returns in percentage terms. The forward premium used in Panel A is calculated using Equation (2.12) with interest rates. The forward premium used in Panel B is calculated using real forward contract data. Data coverage spans January 2000 to December 2020. The domestic currencies are presented at the top of each column and the investment horizon is reported at the left of each row. We report the results for investment horizons ranging from 1 to 36 months. The ratios are reported as percentage points.

Horizon	AUD	CAD	EUR	GBP	ZAR	TRY	KRW
Panel A: Money market hedge							
1 month	0.16	0.06	0.14	0.16	0.12	6.76	0.14
3 months	0.40	0.18	0.41	0.40	0.35	14.22	0.40
6 months	0.73	0.33	0.78	0.67	0.69	25.74	0.73
12 months	1.57	0.64	1.52	1.40	1.42	47.98	1.28
24 months	3.08	1.01	2.77	2.58	2.44	9.73	2.16
36 months	3.92	0.94	3.60	3.74	1.63	-	6.78
Panel B: Forward contract hedge							
1 month	7.81	4.05	6.15	9.83	27.49	288.27	14.05
3 months	111.91	1.64	2.41	3.24	2.71	73.74	3.53
6 months	1.73	1.07	1.85	1.91	122.62	38.07	2.30
12 months	2.17	2.71	2.28	2.19	143.36	34.59	1.94
24 months	3.55	1.63	3.47	2.90	3.15	15.03	2.33
36 months	4.40	2.14	3.97	3.18	2.50	-	10.39

Schmittmann (2010) and Campbell et al. (2010) found optimal hedge ratios with interest rate–implied forward rates. Our results show that even if CIP is violated, the equivalence between the two hedging vehicles generally holds for the developed economies examined in this study. In contrast, for emerging economies, breaches of CIP typically cause greater variations in estimated optimal hedge ratios.

2.7.3. Performance of the forward contract hedge

To assess whether borrowing/lending and forward contract hedging are equivalent, we compare the optimal hedge performance of forward hedging using the F test to determine whether it performs differently in relation to benchmark strategies. We also apply the F test to examine whether the risk profiles of the benchmark and optimal hedge differ between borrowing/lending and forward hedging. As the estimated optimal hedge ratios are similar for both methods, their performance is comparable in most cases. Therefore, this section focuses on the differences between the two hedge vehicles.

The results of the money market hedge support the notion that the unhedged investment has a lower/higher risk than the fully hedged investment for those with a negative/positive net FX risk contribution. Equation (2.8) shows that when investors apply currency hedging, the forward premium is introduced into the hedged return equation, which may create a distorted relationship between unhedged and fully hedged investment risk, as observed in the variance decomposition. As the level of forward premium implied by CIP is relatively minor compared to that calculated with forward contracts, this effect is more prominent when hedging with forward contracts. For example, one would expect the one-month unhedged investment for EU investors to have higher risk than the fully hedged investment, based on the natural hedge effect (see Section 2.4.2). However, the opposite results are found, as shown in Table 2.9.

When comparing the benchmark and optimal hedged risk, between borrowing/lending and forward contract hedging, we find that the differences are minimal for Canadian, EU, and UK investors. In all these cases, the differences are not statistically significant, even at the 10% level. Conversely, Turkish and South African investors exhibit the most considerable differences, which in some cases[13] are not only quantitatively substantial but also statistically significant. Australian and South Korean investors are in the middle: For Australian investors, the differences are statistically significant in three cases[14] (at least at the 10% level) and for South Korean investors, they are significant in one case.[15]

[13] For Turkish investors, these are half-, full-, and optimal hedging strategies with 1- and 3-month horizons, as well as the full hedge with 6- and 12-month horizons and the optimal hedge with a 12-month horizon. For South African investors, these cases include full hedge with a 1-month horizon, half and full hedge with a 6-month horizon, half, full, and optimal hedge with a 12-month horizon, and optimal hedge with a 36-month horizon.

[14] The three cases involve 3-month investments with half and full hedging, as well as the 36-month investment with an optimal hedge.

[15] The one case is the 36-month investment with an optimal hedge.

Table 2.9

Benchmark and optimally hedged risk with forward contracts

This table displays the in-sample results for risk reduction from the optimal hedge. The domestic currencies are reported at the top of each column and the risks under different hedging strategies are reported on the left of each row. Below the risk section, we also present the *F* statistics and mark coefficients with one, two or three asterisks, indicating that the benchmark hedged risk is larger than the optimally hedged risk at the 10%, 5% and 1% significance levels, respectively. The benchmark strategies adopted are no hedge, half hedge and full hedge. We provide results for investment horizons ranging from 1 to 36 months. For TRY, we report the results for investments with horizons of 1 to 24 months.

	AUD	CAD	EUR	GBP	TRY	ZAR	KRW
				1 month			
Zero hedge	13.52	12.71	15.51	15.04	18.96	17.73	13.98
Half hedge	13.49	13.40	14.79	14.60	21.42	15.03	13.98
Full hedge	15.92	15.38	15.57	15.35	35.54	18.29	15.72
Optimal hedge	13.17	12.71	14.79	14.59	17.72	15.02	13.75
				Comparison			
Zero vs optimal	1.05	1.00	1.10	1.06	1.15	1.39***	1.03
Half vs optimal	1.05	1.11	1.00	1.00	1.46***	1.00	1.03
Full vs optimal	1.46***	1.47***	1.11	1.11	4.02***	1.48	1.31**
				3 months			
Zero hedge	13.57	12.90	15.96	14.17	20.75	17.88	13.01
Half hedge	17.06	13.70	14.86	14.12	17.96	14.81	13.67
Full hedge	23.28	15.67	15.34	15.52	25.03	16.43	16.03
Optimal hedge	13.40	12.90	14.82	13.96	17.64	14.74	12.98
				Comparison			
Zero vs optimal	1.02	1.00	1.16	1.03	1.38***	1.47***	1.00
Half vs optimal	1.62***	1.13	1.00	1.02	1.04	1.01	1.11
Full vs optimal	3.01***	1.48***	1.07	1.24**	2.01***	1.24**	1.52***
				6 months			
Zero hedge	14.21	13.75	16.23	14.56	22.03	18.08	12.10
Half hedge	14.08	14.55	15.31	14.74	17.66	17.08	13.67
Full hedge	16.96	16.49	15.99	16.60	22.67	26.60	16.89
Optimal hedge	13.72	13.74	15.30	14.41	17.65	15.86	12.05
				Comparison			
Zero vs optimal	1.07	1.00	1.12	1.02	1.56***	1.30**	1.01
Half vs optimal	1.05	1.12	1.00	1.05	1.00	1.16	1.29**
Full vs optimal	1.53***	1.44***	1.09	1.33**	1.65***	2.81***	1.97***
				12 months			
Zero hedge	16.31	15.01	17.43	14.74	23.51	19.07	10.18
Half hedge	15.45	15.44	16.09	15.16	18.12	19.10	12.70
Full hedge	17.22	16.99	16.19	17.07	24.41	28.76	16.88
Optimal hedge	15.41	15.00	15.95	14.69	18.10	17.51	9.96
				Comparison			
Zero vs optimal	1.12	1.00	1.19*	1.00	1.69***	1.19*	1.04
Half vs optimal	1.00	1.06	1.02	1.06	1.00	1.19*	1.62***
Full vs optimal	1.25**	1.28**	1.03	1.35**	1.82***	2.70***	2.87***

Table 2.9 Continued

	AUD	CAD	EUR	GBP	TRY	ZAR	KRW
				24 months			
Zero hedge	20.96	18.42	19.29	16.30	27.58	21.87	10.07
Half hedge	18.54	17.48	17.53	16.33	21.27	18.54	14.13
Full hedge	17.94	17.53	16.84	17.73	17.86	17.66	18.87
Optimal hedge	17.90	17.38	16.83	16.14	17.68	17.61	7.75
				Comparison			
Zero vs optimal	1.37***	1.12	1.31**	1.02	2.43***	1.54***	1.69***
Half vs optimal	1.07	1.01	1.08	1.02	1.45***	1.11	3.33***
Full vs optimal	1.00	1.02	1.00	1.21*	1.02	1.01	5.94***
				36 months			
Zero hedge	24.34	20.87	21.42	17.93	-	28.94	10.15
Half hedge	20.83	19.07	18.94	17.03	-	22.85	12.82
Full hedge	18.43	17.79	17.08	17.29	-	18.02	15.92
Optimal hedge	17.60	17.06	15.92	16.98	-	15.58	7.90
				Comparison			
Zero vs optimal	1.91***	1.50***	1.81***	1.12	-	3.45***	1.65***
Half vs optimal	1.40***	1.25*	1.42***	1.01	-	2.15***	2.63***
Full vs optimal	1.10	1.09	1.15	1.04	-	1.34**	4.06***

The performance of the optimal hedge in relation to benchmarks also differs when investors adopt different hedge vehicles. Among all investors, the differences are the smallest for Canadian, UK, and South Korean investors. The optimal hedge performs almost identically whether implemented via a forward contract or a money market hedge, not only in terms of risk reduction but also in terms of the F test. In contrast, Turkish and South African investors experience the largest differences, primarily due to the disparity in hedge ratios and forward premiums. The large difference, however, shrinks as the investment horizon increases. Australian and EU investors are in the middle, and the differences apply only to Australian investors for 3-month investments and to EU investors for 36-month investments.

2.8. Conclusion

This study examined foreign currency risk management from the perspectives of Australian, Canadian, British, EU, Turkish, South African, and South Korean equity investors based on the assumption that investors from these countries held assets in the US market index. We found that many currency pairs – such as AUD/USD, CAD/USD, KRW/USD, ZAR/USD, TRY/USD, EUR/USD, and GBP/USD – negatively correlate with the US stock market in the short term and positively correlate with the US stock market in the long term. Thus, when investors are exposed to the USD in the short term, the covariance between the investment and the FX return is negative, exhibiting the natural hedge effect that reduces FX risk without requiring currency risk management.

Our variance decomposition extends the work of Schmittmann (2010). While Schmittmann (2010) claims that the FX–asset covariance is significantly smaller than the FX variance, our results show that the covariance is prominent in many cases and can sometimes offset the FX variance entirely. Although FX variance increases the risk of unhedged international investment, its covariance with the portfolio reduces the investment risk for almost all short-term investments. The net risk contribution from the FX risk is negative and even reduces short-term investment risk for Australian, Canadian, UK and South Korean investors without currency hedging. Nevertheless, the negative portfolio return-exchange rate return covariance disappears in the long term. Both FX variance and covariance with asset return reinforce the volatility of foreign investments for investors with a holding period of 36 months, except for those from South Korea.

Campbell et al. (2010) found that the optimal hedge can statistically and significantly reduce risk for Canadian investors, whose unhedged foreign currency exposure mitigates investment risk. The results of this study suggest that when investors benefit from the natural hedge effect, the risk reduction from adopting the optimal hedge is not statistically significant compared to the zero-hedge strategy, except for Turkish and South African investors. However, when the natural hedge effect diminishes over the long term, the optimal hedge statistically outperforms the unhedged investment.

We considered the violation of CIP and estimated the optimal hedge ratios using borrowing and lending, as well as forward contracts. The estimated optimal hedge ratio implies that most investors should maintain positive exposure to USD in the short term and short USD in the long term, except for UK and South Korean investors, who are better off maintaining a positive exposure to USD for investments of 1 to 36 months. Aside from UK and South Korean investors, the hedging policy of maintaining positive exposure to a safe-haven currency is effective only in the short-term. Furthermore, all investors, except those from South Korea, tended to adopt higher optimal hedge ratios as their investment horizons increased, which contradicts Froot's (2019) claim that long-term investment requires zero hedging.

In most scenarios, the difference in optimal hedge ratios between the forward contracts and borrowing/lending hedge strategies is minor. The sizeable differences are commonly observed in the investments of Turkish and South African investors. The violation of CIP results in discrepancies between the forward premium implied by interest rates and the actual forward premium. However, the risk levels of both forward premiums are small relative to the FX variance, leading to no significant variation in the estimated optimal hedge ratios. Only when the forward premium risk level is similar to or larger than the FX variance does the difference between the forward and borrowing/lending hedge become noticeable. With the same explanation, the hedge ratio difference across subperiods (see section 2.7.2) also showed slight variation when the forward premiums of different hedge vehicles are small.

To determine whether borrowing/lending and forward contracts are equivalent, we examined the changes in hedged risk resulting from the two hedge vehicles. When comparing the benchmark and optimal hedged risk for borrowing/lending with that of the forward contract, we found that the differences for Canadian, EU, and UK investors are not statistically significant at the 10% level. Conversely, Turkish and South African investors often experience significant statistical differences. Australian investors experience three cases in which the difference is significant, at least at the 10% level, whereas South Korean investors experience one case. Campbell et al. (2010) and Schmittmann (2010) claim that borrowing/lending and forward hedges are equivalent under the assumption that CIP is held. Our results show that it still holds roughly for developed economies, even with the violation of CIP.

Lastly, optimal hedge ratios varied across subperiods. Practitioners interested in applying active currency hedging should exercise caution when selecting the optimal hedge ratios for future investments. Although this study imposes many restrictions on the construction of international investments, the assumed scenario is not uncommon. Given the unique role of the USD and the weight of the US capital markets in the global market, we believe this research will have helpful implications for many investors.

However, the analysis of this paper could be extended in several ways. We acknowledge that the dynamics of asset returns and the covariances between assets and FX rates are vital variables for estimating optimal hedge ratios. Thus, further studies could adopt the DCC–GARCH model introduced by Engle (2002) to estimate the optimal hedge ratio and examine whether it outperforms the static model. Future research should also extend this analysis to out-of-sample settings to determine whether the natural hedge effect persists beyond the sample period examined in this thesis.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Zhennan Mao
Name and title of main supervisor:	Jianguo Chen, Doctor
In which chapter is the manuscript/published work?	Chapter three

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Chapter Three includes Study Two - Dynamic Currency Risk Management for International Investors.
Zhennan Mao is primarily resposible for the research design, data collection, empirical analysis, and manuscript writing.

Please select one of the following three options:

○ **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

○ **The manuscript is currently under review for publication**

Please provide the name of the journal:

◉ **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Zhennan Mao — Digitally signed by Zhennan Mao Date: 2025.07.25 14:12:20 +12'00'	Main supervisor's signature:	Jianguo Chen — Digitally signed by Jianguo Chen DN: cn=Jianguo Chen, c=NZ, o=Massey University, ou=School of Economics and Finance, email=j.g.chen@massey.ac.nz Date: 2025.07.25 15:25:46 +12'00'

This form should be placed at the beginning of each relevant thesis chapter.

[1] Refer to the Massey University Publishing and Authorship guidelines (OneMassey for staff, Stream for students) and/ or Contributor Roles Taxonomy (CRediT) guidelines for guidance.

CHAPTER THREE STUDY TWO
DYNAMIC CURRENCY RISK MANAGEMENT FOR INTERNATIONAL INVESTORS

This study examines currency risk management from the perspectives of Canadian, EU, UK, Japanese, and US investors using a value-weighted international portfolio. Employing both static mean–variance and DCC–GARCH frameworks, we address the role of asymmetric volatility and correlation—features often overlooked in the literature. For each asset, the most appropriate univariate GARCH-family model is selected. The results show that incorporating asymmetric volatility is essential, as significant asymmetry terms are detected across several assets. However, no evidence of asymmetric correlation is found; the DCC model adequately captures dynamic correlations over the sample periods. These findings imply that investors should not rely on a single variance model across all assets, given their heterogeneous risk characteristics.

Keywords: currency risk management, dynamic hedge, asymmetrical variance and correlation, DCC–GARCH, ADCC–GARCH

3.1. Introduction

From an international investor's perspective, foreign currencies are highly volatile and have low average returns. However, correlations between foreign exchange rate returns and financial markets can be used to minimise the variance in international investments: buying currencies that are negatively correlated with investment returns and selling currencies that are positively correlated. Although many studies have examined the effectiveness of currency risk management with a static strategy, dynamic models warrant further research, as they respond to changes in financial markets and provide dynamic hedging ratios.

Following existing studies (e.g., Campbell et al., 2010; Glen & Jorion, 1993), this study examines currency risk management from the perspective of a domestic investor holding stocks listed in foreign markets. It investigates how foreign currency exposure can be managed to minimise investment risk, typically through FX derivatives and short or long positions in both foreign and domestic currencies. This study aims to extend the approach of Campbell et al. (2010) by incorporating the DCC–GARCH framework, offering novel insights for investors seeking to enhance hedging performance.

The estimation of optimal currency positions relies on modelling the asset variances and covariances. The DCC–GARCH model, developed by Engle (2002), allows investors to estimate the required parameters dynamically. Some studies on foreign exchange (FX) risk management have applied this model in currency risk management (e.g., Cho et al., 2020; Chang et al., 2013; Filipozzi & Harkmann, 2020). While these studies demonstrate the usefulness of the DCC–GARCH framework, they exhibit certain limitations that motivate the present research.

First, existing applications typically adopt a single univariate GARCH specification and a multivariate model for all assets, without accounting for the possibility that the optimal model for estimating conditional variance may differ across return series, as noted by Cho et al. (2020). The flexibility of the DCC–GARCH framework lies in its ability to allow investors to estimate conditional variance and correlation in two steps. In the first step, univariate volatility models are fitted for each asset and estimates of variance are obtained. In the second stage, dynamic conditional correlations are estimated using multivariate models that incorporate asset returns, which are transformed using the estimated standard deviations from the first stage. In each step, investors can vary univariate and multivariate models to suit the characteristics of their asset returns. This study leverages the flexibility of the DCC–GARCH framework by selecting the optimal univariate model for each return series to estimate conditional variances and choosing the optimal multivariate model to estimate dynamic correlations.

Second, the currency risk management literature focuses primarily on time-varying variances, while largely overlooking the role of asymmetric volatility. The asymmetric volatility of asset returns refers to the phenomenon in which volatility increases more after a negative shock than after a positive shock of the same magnitude. In some cases, a positive shock may lead to a decrease in asset volatility. If the asymmetry effect is ignored, the conditional variance after a positive/negative shock may be overestimated/underestimated, which would affect the optimal currency positions obtained. We account for asymmetric volatility by including several univariate models that contain symmetric terms. It then selects the best one based on the Bayesian information criterion (BIC), as described by Cappiello et al. (2006), which tests whether the asymmetry effect exists.

For the same currency pair, the currency return is the opposite from the perspective of investors whose domestic currency is on the other side of the exchange rate.[16] The error term obtained

[16] For example, the EUR/USD exchange rate return is identical in absolute terms but opposite from the EU and US investors' perspectives, adopting the equation of Campbell et al. (2010).

from the mean equation is also the opposite for the counterparties. When the standard GARCH model is adopted, the variance equation remains unaffected, as the sign of the mean equation error term does not affect the variance, provided the absolute return remains the same.

As asymmetrical univariate models are introduced, the sign of the asset return may affect the variance equation, as the adoption of the error term is conditional on the sign of the error term. Our third innovation is that we fit the univariate model from the perspective of investors on both sides of the currency pair. Wang and Yang (2009) show that the asymmetry effect of foreign exchange is currency-specific. Our results provide further insight into the asymmetry effect between currency pairs.

Lastly, and most importantly, previous studies have overlooked asymmetry in conditional correlations. Asymmetric correlation refers to the tendency of assets to exhibit stronger co-movement during market downturns than during upturns. Just as neglecting asymmetric volatility distorts variance estimation, ignoring asymmetric correlation leads to systematically biased estimates of conditional correlations—overestimation after positive shocks and underestimation after negative shocks. Consequently, optimal currency positions derived from standard models may be mis-specified, causing investors to under-hedge or over-hedge their foreign exposure.

The final contribution of this study is to address this issue by estimating the Asymmetric DCC (ADCC) model developed by Cappiello et al. (2006), which explicitly captures asymmetric correlation. The estimated parameters are then compared with those from the standard DCC model to determine which specification best describes the relationship between asset and currency returns for the investors, investments, and sample periods under investigation.

While the existing literature tends to study international investment with equal weighting (e.g., Cho et al., 2020; Schmittmann, 2010), this study adopts a more realistic construction for foreign holdings. We assume that investors hold a globally diversified equity portfolio, with weights reflecting each country's market capitalisation in the global market. Specifically, the foreign portfolio comprises 50% US, 25% EU, 15% Japanese, and 5% each for the UK and Canadian markets.

In terms of currency management, a distinct contribution of this study is its selection of hedging instruments. While previous research often employs a broad set of seven major currencies (Campbell et al., 2010), our analysis focuses on five: the Canadian dollar (CAD), euro (EUR), British pound (GBP), Japanese yen (JPY), and US dollar (USD), intentionally excluding the Australian dollar (AUD) and Swiss franc (CHF). This selection is guided by the findings of Campbell et al. (2010), who demonstrate that the EUR and CHF, as well as the AUD and CAD, act as substitutes in risk management. As the optimal positions of CAD and USD are not independent (Campbell et al., 2010), we retain the CAD over AUD. Furthermore, given our interest in the dynamics of the EUR over the entire sample period, we include the EUR and exclude the CHF. Consequently, this study assumes that investors from Canada, the EU, Japan, the UK, and the US hold the same internationally diversified portfolio and utilise their domestic currency alongside four foreign currencies to determine the optimal, risk-minimising currency positions.

In the following sections, we review the relevant literature and present the data and equations for international investment return. We then discuss the methodology and empirical results for the static optimal hedge, followed by the selection of univariate and multivariate models and the empirical results for dynamic optimal hedging. Lastly, we examine the return of hedged investments.

3.2. Literature review

The simplest way to manage currency risk is to fully hedge it, meaning taking a short position in the foreign currency and a long position in the domestic currency equal to the investment's value. However, the currency risk does not always adversely affect the return and risk of the foreign investment. Thus, investors developed methods that selectively hedge the currency exposure. The solution is to create indicators that reasonably predict the direction of currency movement. Then, using those indicators, investors can conditionally choose between hedging and not hedging.

3.2.1. Minimising risk through hedging indicators

Three indicator strategies are typically the focus of research[17]. The first strategy is the forward hedge rule (FHR), which is based on the random walk hypothesis. This suggests that one should hedge whenever the forward (futures) rate is at a premium (e.g., Morey & Simpson, 2001; Simpson, 2004; Simpson & Dania, 2006; Hamza et al., 2007; Chiang et al., 2011). The second strategy, which emerged from relative PPP, has been explored in numerous studies, including those by Morey and Simpson (2001), Simpson (2004) and Simpson and Dania (2006). This strategy requires hedging if the spot rate is above the purchasing power parity (PPP) equilibrium. The third strategy is based on the CIP, also known as the real interest rate rule (RIR), as discussed in Hazuka and Huberts (1994) and Simpson and Dania (2006). It calls for hedging if the domestic real interest rate equals or exceeds the foreign real interest rate.

The indicators based on FX trading styles also show improved investment outcomes. Levich and Thomas (1993) adopted trend-following and filter rules. They found that a simple strategy,

[17] The variation and combination of these basic strategies have also been tested. VanderLinden et al. (2002) introduced a rule that combines FHR and RIR called the real forward hedge rule (RFHR).

which fully hedges investors' portfolios and takes a speculative position in currency markets based on the composite trading rule, performs well when tested on 10-year bonds.

These studies acknowledge the usefulness of economic indicators and foreign exchange trading styles in predicting currency markets. However, the effectiveness of these strategies is subject to debate, as they rest on conflicting theoretical foundations. For instance, fundamental indicators such as PPP imply that the efficient markets hypothesis (EMH) should hold, guiding investors' expectations of future exchange rates. Nevertheless, the trend-following trading rules examined by Levich and Thomas (1993) appear to generate risk-adjusted excess returns, which seemingly contradicts the EMH. This theoretical tension implies that the predictive power of specific indicators is not universal, but rather depends on the investment horizon and currency pair in question. Indeed, a substantial body of research finds that fundamental-based indicators like PPP and UIP have limited ability to forecast exchange rate movements (Engel, 1996, 2000), and therefore investors should not rely solely on indicators.

In addition, managing FX risk by focusing solely on reducing negative impact separates the exchange rate from the overall foreign investment risk and ignores the correlation between the asset and foreign exchange. Thus, the hedge ratios in these studies are often arbitrarily determined, with a binary choice between one and zero. Since the foreign exchange and equity markets are connected[18], investors should manage currency risk by accounting for related variables.

[18] Diermeier and Solnik (2001) analysed a broad cross-section of security prices from firms in eight developed countries and concluded that currency factors have a significant influence on asset returns. Similarly, Ajayi et al. (1998) examined the relationship between stock and currency markets across seven advanced and eight emerging economies. Their findings indicate that the two markets are well integrated in six of the advanced economies studied. These studies highlight the connection between exchange rate dynamics and fluctuations in the equity market.

3.2.2. Static mean–variance framework

Solnik's (1974a) international asset pricing model proposes that mean-variance-optimising investors should hold a combination of risk-free domestic assets and a globally diversified portfolio of assets, including forward contracts on foreign currencies. The optimal hedge for minimising risk is the minimum variance portfolio, achieved by varying the position in FX derivatives. Some currencies tend to move in line with the capital market; for example, commodity currencies such as the AUD, GBP, and CAD (Campbell et al., 2010). Some currencies are negatively correlated with the capital market and appreciate when the overall market is in crisis[19]. Hence, the rule for reducing investment risk would be to actively increase/decrease exposure to currencies that are negatively/positively correlated with the investment.

The static mean–variance optimal hedge framework focuses on analysing the long-term average variance and correlation of assets. Investors can use the long-term average as a baseline to determine their optimal currency positions. Gastineau (1995) demonstrates this using two hypothetical, equally weighted domestic and foreign bond portfolios, showing that a portfolio with a partially hedged foreign currency position has a higher compound return and lower standard deviation. This implies that a relatively modest amount of foreign currency exposure can improve investment performance.

Glen and Jorion (1993) argue that, for unrestricted portfolios in which investors simultaneously choose asset weights and forward positions, the mean–variance optimisation approach can significantly improve the performance of portfolios that include bonds. Campbell et al. (2010)

[19] Schmittmann (2010) found that, on average, the Deutsche Mark/EUR pair tends to move against the equity market. From a Latin American perspective, Walker (2008) concluded that exposure to the USD could be used to mitigate negative stock returns. Min et al. (2016) found that the USD, JPY, and CHF have negative dynamic correlations between equity and currency returns. Ranaldo and Söderlind (2010) reached similar results with high-frequency data and show that the CHF and JPY are safe-haven currencies because they both appreciate when the US stock market drops.

used more up-to-date, broader international market data to find the risk-minimising optimal currency exposure of an exogenous portfolio. They conclude that taking short positions in the AUD, CAD, JPY, and British pound, and going long on the USD, EUR, and CHF, can efficiently reduce the risk of international equity investments.

However, in practice, investors should use the guidance provided by these research papers prudently, as they are subject to several flaws. Based on their chosen data, Schmittmann (2010) found that the correlation between exchange rates and asset returns was unstable over time, especially from 2007 to 2009. Opie and Riddiough (2020) note that the mean–variance optimisation approach yields poor overall currency hedging performance when applied out of the sample. These findings imply that the correlation between assets and currencies is not stationary. As the development of an optimal hedge depends on a sound model to analyse asset variance and covariance, a static policy might be suboptimal. Researchers have devised two methods to mitigate these issues. Some sought help from indicators, while others abandoned the static model and advocated for the GARCH family models.

3.2.3. Improving the static model with indicators

One solution to unstable correlations is to incorporate economic indicators into the mean–variance framework. Several studies have adopted this approach, using indicators to refine static hedge ratios or to develop dynamic models (Campbell et al., 2010; Kroencke et al., 2014; Bucher, 2020; Opie & Riddiough, 2020).

Opie and Riddiough (2020) exploit the predictability of currency returns arising from a forecastable component in global risk factors. Their empirical results show that a dynamic currency factor hedging strategy yields the highest overall investment performance—measured by the Sharpe ratio—for both equally weighted and GDP-weighted equity and bond portfolios. Bucher (2020) proposes a dynamic conditional currency hedging approach that utilises implied

FX volatility to capture expected future volatility and market risk aversion, offering a forward-looking solution for investors seeking to hedge their portfolios. Kroencke et al. (2014) extend the risk-minimising framework of Campbell et al. (2010) by introducing three FX trading styles—carry trade, momentum, and value strategies. Their conditional optimal hedged benchmark achieves a 28% increase in the Sharpe ratio after incorporating a composite of these strategies across 30 currencies.

Other studies have focused on interest rate differentials as a conditioning variable. Glen and Jorion (1993) find that a conditional strategy based on interest rate differentials significantly improves the performance of stock and bond portfolios, both in-sample and out-of-sample, increasing returns without raising risk. In contrast, Campbell et al. (2010) examine the predictive power of interest rate differentials within a static mean–variance framework and find that this indicator offers no significant additional risk reduction beyond an optimally hedged portfolio in-sample.

These studies acknowledge the usefulness of economic indicators. The results of Glen and Jorion (1993) and Campbell et al. (2010) further elaborate on the issue embedded in indicator-based strategies. These conflicting findings regarding the effectiveness of interest rate differentials—despite similar analytical frameworks—suggest that the predictive power of such indicators is sensitive to multiple factors, including sample period, currency selection, and portfolio composition. Thus, investors should seek models that are inherently designed to capture dynamic changes in variance and covariance.

3.2.4. Dynamic models

To develop a robust hedging policy in practice, scholars have sought methods to enhance the modelling of asset risk characteristics. These models include rolling historical correlations, exponential smoothing, the ARCH model, and the GARCH family models. Thus, investors can adjust the hedge ratio to reflect the most current information set.

Engle (2009) compared the performance of several models[20] in- and out-of-sample using stock data from 1994 to 2004. He utilised dynamic models to construct minimum-variance portfolios and optimal hedges. The in-sample results show that the ARCH–GARCH models outperformed the constant and rolling historical value strategies, except for the factor ARCH model. Although the differences are marginal at 0.2% and 1% for the minimum-variance portfolio and the optimal hedge, respectively, they are not just random chance. On average, for both the minimum variance portfolios and the optimal hedge, the ARCH–GARCH models outperformed the constant and 100-day rolling strategies 75% and 90% of the time, respectively. Among all the ARCH–GARCH models, the best estimators are the DCC and factor DCC. The out-of-sample results confirm the same findings, with DCC being the most effective estimator.

3.2.4.1. The DCC-GARCH framework in FX risk management

Some studies have tested the ARCH-GARCH models in FX risk management. Chang et al. (2013) adopted CCC–GARCH, DCC–GARCH, BEKK–GARCH, and VARMA–AGARCH models to achieve the optimal hedge. Filipozzi and Harkmann (2020) applied the DCC–GARCH model to a portfolio of foreign bonds and found that the full hedge is not optimal for bond investors, as DCC–GARCH has a degree of exposure to a currency carry component, which improves the risk/return profiles of the portfolios. Cho et al. (2020) used an exogenous portfolio of world equities and demonstrated that a dynamic and efficient DCC approach reduces the estimated return variance by approximately 20% compared to the static model by Campbell et al. (2010). Kotkatvuori-Örnberg (2016) employed the copula DCC–EGARCH

[20] These models include the constant, 100-day rolling historical value, DCC–GARCH, factor ARCH, double ARCH, and factor DCC–GARCH models.

model to capture the covariance dynamics between variables, thereby forming efficient hedges in currency markets. The estimation results show that the model produces consistent estimates of the conditional covariance matrix and improves the efficiency of the dynamic hedges.

Although the above studies have contributed to currency risk management literature, they did not fully utilise the flexibility of the DCC–GARCH framework. Cappiello et al. (2006) demonstrated that within the DCC–GARCH framework, various univariate GARCH models can be combined with the DCC or extended to fit the stock and bond returns. Among all the univariate models, they included the standard GARCH model (Bollerslev, 1986), the AVGARCH model (Taylor, 2008), the NARCH model (Higgins & Bera, 1992), the EGARCH model (Nelson, 1991), the ZARCH model (Zakoian, 1994), the GJR-GARCH model (Glosten et al., 1993), the APARCH model (Ding et al., 1993), the AGARCH model and the NAGARCH model (Engle & Ng, 1993). They used BIC to rank and select the best model to combine with the DCC and ADCC models, thereby fitting their data.

In the area of currency risk management, investors utilise various foreign currency exposures to minimise investment risk. For different assets, the model that best describes their risk characteristics may differ. Thus, investors should utilise the DCC–GARCH framework to select the optimal model for each currency and asset; however, we have not seen studies discuss the optimal GARCH model for different asset-currency pairs. Our study utilises the DCC-GARCH framework to estimate optimal hedge ratios; we fill the gap by adopting seven GARCH models to identify the optimal model for each asset and currency pair.

3.2.4.2. Asymmetric variance and correlation

Adopting flexible univariate and multivariate models offers additional benefits, providing investors with the opportunity to examine the asymmetry effect in conditional variance and correlation. Asymmetric volatility has been extensively studied among equity investors.

Christie (1982) examined asymmetric variance and explained it using the leverage effect. Campbell and Hentschel (1992) adopted the quadratic GARCH model and explained the asymmetric variance using the volatility feedback effect. Bekaert and Wu (2000) adopted Nikkei 225 stocks, rejecting Christie's (1982) pure leverage model, and supported the volatility feedback effect. Wu (2001) contributed to the literature by developing an asymmetric volatility model that allows for both the leverage effect and the volatility feedback effect. A recent study by Olbrys and Majewska (2017) used the EGARCH model to analyse the market indices of the UK, France, and Germany. It concluded that a negative asymmetry effect in volatility is found in all markets studied.

Furthermore, numerous studies have examined asymmetric variance in foreign exchange markets. Wang and Yang (2009) studied the asymmetric volatility of the EUR, AUD, GBP, and JPY exchange rates against the USD. They found that the realised volatility of the EUR appears to be symmetric, whereas other currencies exhibit asymmetric volatility. Chkili et al. (2012) used GARCH family models to examine the conditional volatilities of two popular USD exchange rates, revealing strong evidence of asymmetry in the conditional variances across all series considered. Epaphra (2017) used the EGARCH model and suggested that positive Tanzanian shilling/USD exchange rate shocks lead to a higher conditional variance in the next period than negative shocks of the same sign.

Since asymmetric volatility is observed in both equity and foreign exchange markets, investors should consider the asymmetry effect when selecting univariate conditional variance models. However, studies on currency risk management rarely address this issue. Among the currency hedging research that adopts GARCH models, as discussed in section 3.2.4.1, only Chang et al. (2013) and Kotkatvuori-Örnberg (2016) considered asymmetric volatility and tested it with AGARCH and EGARCH models. Though their results are innovative, the limited coverage of asymmetric GARCH models may not fit investors with different domestic and foreign currency exposures. To contribute to the existing body of knowledge, we include six GARCH models that capture asymmetric volatility and offer novel implications for international investors.

Conversely, the asymmetric correlation between currencies has also been addressed by many studies. Patton (2006) examined asymmetric correlation with the Deutsche Mark, JPY and USD. The results show that the Mark/USD and JPY/USD exchange rates are more correlated when they are depreciating against the USD than when they are appreciating. Tamakoshi and Hamori (2014) tested USD exchange rates against EUR, GBP, and CHF with the ADCC–GARCH model and found asymmetric responses in correlations among the three exchange rates.

Kearney and Potì (2006) examined the asymmetric correlation for equity investors in the Eurozone stock market and found mixed results. Toyoshima and Hamori (2013) adopted the asymmetric model developed by Cappiello et al. (2006) and analysed the correlation between the Japanese and Singaporean stock markets. In addition to studies that focus solely on exchange rates or equity markets, Moussa et al. (2021) examined the asymmetric correlation between currency and stock markets. They studied the interdependence of exchange rates and stock prices for Canada, Japan, Denmark, Hong Kong, Singapore, Mexico, and Brazil. They found asymmetric responses in the linkages between stock prices and exchange rates.

Since asymmetric correlation is observed for equity and foreign exchange, investors should consider the asymmetry effect when selecting multivariate models. Among the research that adopts GARCH models to hedge currency risk, as discussed in section 3.2.4.1, none explicitly considered asymmetric correlation. This study seeks to address this critical gap by applying the ADCC-GARCH model to estimate the optimal currency positions. It answers whether assets and currency pairs exhibit asymmetric correlations; if so, how does the model improve the quality of the estimation?

The DCC–GARCH framework is flexible, allowing investors to estimate conditional variance and covariance and to assign univariate or multivariate models to suit the characteristics of their asset returns. Building on the existing literature, our research investigates currency risk management under the assumption that investors hold diversified foreign investments. It follows the method of Cappiello et al. (2006) by selecting the best univariate model for each of the return series. The return series is not limited to a single fixed variance model; instead, tailored models with or without asymmetry terms are selected for each asset's return. Additionally, the asymmetry in asset correlations is addressed by fitting the multivariate ADCC model.

3.3. Data

This study tests hedge performance by assuming that investors from Canada, the EU, the UK, Japan, and the US hold a globally diversified equity portfolio. Our foreign investment assigns a 50% weight to the US market, 25% to the EU market, 15% to the Japanese market and 5% each to both the UK and Canadian markets. Each country's market index can be found on the Morgan Stanley Capital International website.

Our research focuses on five currencies, including CAD, EUR, USD, GBP, and JPY. The exchange and interest rates can be found in the International Monetary Fund's International Financial Statistics database. This study uses the official cash rate (OCR) for three reasons. Firstly, LIBOR (London InterBank Offered Rate) have stopped publishing new data. Secondly, the Reserve Bank of New Zealand suggest using OCR as the fall-back benchmark interest rate (Reserve Bank of New Zealand, 2020). Thirdly, the position of LIBOR is shaken after the systematic manipulation of LIBOR rates in 2012 (Kendall, 2017). In this study, the exchange rates are displayed in the base currency per unit of foreign currency. All data series are available at a monthly frequency, and we report results for investments with a one-month horizon, given the limited observations of asset returns and foreign exchange rate returns. Data coverage spans January 2000 to December 2021.

The optimal hedge is based on estimating risk-minimising currency demands for a stock portfolio in the international market. Our research adopts the equation by Campbell et al. (2010) to calculate the hedged returns of international portfolios:

$$r_{p,t+1}^{h} - i_{1,t} = \sum_{i=1}^{5} \omega_{i,t}\left(r_{i,t+1} - i_{i,t}\right) + \sum_{j=1}^{4} \psi_{j,t}\left(\Delta s_{j,t+1} + i_{j,t} - i_{1,t}\right) \quad (3.1)$$

In Equation (3.1), $\omega_{i,t}$ is the weight of the international portfolio's constituent country index, $r_{i,t+1}$ is the log country index nominal return in its local currency, $\psi_{j,t}$ is the net currency exposure, $\Delta s_{j,t+1}$ is the change in log spot exchange rate, $i_{i,t}$ and $i_{j,t}$ are the log short-term nominal domestic and foreign interest rates, and $i_{1,t}$ is investors' log short-term domestic nominal interest rates.

Following Campbell et al. (2010), $\sum_{i=1}^{5} \omega_{i,t}\left(r_{i,t+1} - i_{i,t}\right)$ represents the excess return of the fully hedged international portfolio that has zero currency exposure. In addition, $\Delta s_{j,t+1} + i_{j,t} - i_{1,t}$ represents the excess return on currency exposure. Thus, $\sum_{j=1}^{4} \psi_{j,t}\left(\Delta s_{j,t+1} + i_{j,t} - i_{1,t}\right)$ represents the pure excess return on all currency exposures given by $\psi_{j,t}$. Equation (3.1) can be simplified as follows:

$$X_{p,t+1}^{h} = X_{0,t+1} + \sum_{j=1}^{4} \Psi_{j,t+1} X_{j,t+1} \quad (3.2)$$

In Equation (3.2), $X_{p,t+1}^{h} = r_{p,t+1}^{h} - i_{1,t}$ is the excess return of the hedged portfolio return, $X_{0,t+1} = \sum_{i=1}^{5} \omega_{i,t}\left(r_{i,t+1} - i_{i,t}\right)$ is the excess return of the fully hedged international portfolio and $X_{j,t+1} = \Delta s_{j,t+1} + i_{j,t} - i_{1,t}$ is the excess return on currency exposure.

Table 3.1 displays the averages, standard deviations, and distributions of excess returns from unhedged international investments, including both excess investment return ($X_{0,t+1}$) and excess currency returns from shorting domestic currency and going long on foreign currencies ($X_{j,t+1}$), as displayed in Equation (3.2). The investment and foreign currencies are displayed at the top of each column, and the average, standard deviation, skewness, and kurtosis are reported in the corresponding rows. The unhedged international investment is the same for all investors, yielding an annualised excess return of 1.79 percentage points with a standard deviation of 14.24 percentage points. It is left-skewed, and the fat tails signal a tendency towards large negative outliers.

Table 3.1
Summary statistics of excess portfolio and currency returns

Data coverage spans January 2000 to December 2021. The investment and foreign currencies are displayed at the top of each column, and the average, standard deviation, skewness, and kurtosis are reported in the relevant rows. The return column indicates the excess return of investing in an international portfolio. The currencies indicate investors' excess currency return from shorting their domestic currency and going long on the indicated foreign currency. We report the results for investors from each country studied in this research. The averages and standard deviations are reported in annualised percentage points.

	Return	CAD	EU	GBP	JPY	USD
Canada						
Average	1.79	-	−0.37	−1.08	−2.87	−0.79
SD	14.24	-	9.20	8.96	12.06	8.84
Skewness	−0.89	-	0.20	−0.05	0.76	0.44
Kurtosis	4.75	-	3.46	3.94	5.60	5.42
EU						
Average	1.79	0.37	-	−0.71	−2.50	−0.42
SD	14.24	9.20	-	7.78	11.55	9.65
Skewness	−0.89	−0.20	-	−1.09	0.86	0.17
Kurtosis	4.75	3.46	-	8.27	6.10	4.32
UK						
Average	1.79	1.08	0.71	-	−1.79	0.29
SD	14.24	8.96	7.78	-	11.91	8.62
Skewness	−0.89	0.05	1.09	-	0.88	0.31
Kurtosis	4.75	3.94	8.27	-	6.19	4.54
Japan						
Average	1.79	2.87	2.50	1.79	-	2.08
SD	14.24	12.06	11.55	11.91	-	8.82
Skewness	−0.89	−0.76	−0.86	−0.88	-	0.16
Kurtosis	4.75	5.60	6.10	6.19	-	3.61
US						
Average	1.79	0.79	0.42	−0.29	−2.08	-
SD	14.24	8.84	9.65	8.62	8.82	-
Skewness	−0.89	−0.44	−0.17	−0.31	−0.16	-
Kurtosis	4.75	5.42	4.32	4.54	3.61	-

The excess currency returns differ from different investor perspectives. For Canadian investors, the excess currency returns from long foreign currencies are negative. The excess return of shorting the EUR and going long on the CAD has a distribution that is close to normal, with mild fat tails. For the GBP, the excess return is near-symmetric but leptokurtic, which may occasionally show large moves in either direction. The JPY excess return is strongly right-skewed yet very fat-tailed. Lastly, the USD excess return is moderate, right-skewed and exhibits heavy tails.

For Japanese investors, the excess currency returns are all positive. The excess returns are left-skewed if Japanese investors hold the CAD, EUR, and GBP and are right-skewed if they hold the USD. Leptokurtic distributions are observed for all foreign currency excess returns, indicating occasional large moves in either direction.

For EU, UK, and US investors, the excess returns from long foreign currencies are mixed. The skewness in excess currency returns is observed for all investors and foreign currencies. However, when UK investors go long on the CAD and short on the GBP, the excess currency return is near-symmetric. A fat-tailed distribution is observed for all currency excess returns, indicating that investors may expect occasional large return movements.

Table 3.2 presents the Jarque-Bera test results for the international investment excess returns ($X_{0,t+1}$) and the excess currency return from simultaneously shorting domestic currency and buying foreign currencies ($X_{j,t+1}$), as displayed in Equation (3.2). The investment and foreign currencies are displayed at the top of each column and investors' countries are listed at the left of each row. The Jarque–Bera tests indicate that excess international investment returns and excess currency returns do not have a normal distribution, except when considering Canadian and EU investors' excess currency returns in the EUR and CAD, respectively.

Thus, the results show that international investment and foreign currency excess returns are highly volatile. They are typically skewed and show some degree of leptokurtic movement. Investors may expect significant fluctuations in either direction. The normality of distribution only exists in four scenarios out of all the possible combinations. Advanced models should be considered to capture the shape of the distribution.

Table 3.2
Jarque–Bera test of excess portfolio and currency return

We report the Jarque–Bera test for investors studied in this research. Data coverage spans January 2000 to December 2021. The investment and foreign currencies are displayed at the top of each column and investors' countries are listed at the left of each row. The return column indicates the excess return of investing in an international portfolio. The currencies indicate investors' excess currency return from shorting the domestic currency and going long on the indicated foreign currency, which are $X_{0,t+1}$ and $X_{j,t+1}$, respectively, as displayed in Equation (3.2). The parentheses report the p values.

Country	Return	CAD	EU	GBP	JPY	USD
Canada	68.47	-	4.01	9.89	99.96	73.09
	(0.00)	-	(0.13)	(0.01)	(0.00)	(0.00)
EU	68.47	4.01	-	357.86	138.60	20.34
	(0.00)	(0.13)	-	(0.00)	(0.00)	(0.00)
UK	68.47	9.89	357.86	-	146.21	30.30
	(0.00)	(0.01)	(0.00)	-	(0.00)	(0.00)
Japan	68.47	99.96	138.60	146.21	-	5.20
	(0.00)	(0.00)	(0.00)	(0.00)	-	(0.07)
US	68.47	73.09	20.34	30.30	5.20	-
	(0.00)	(0.00)	(0.00)	(0.00)	(0.07)	-

3.4. Static currency risk management for international investors

3.4.1. Optimal static currency demand for the global equity portfolio

Thus far, we have developed equations for the optimal hedge. Investors can adopt the mean–variance framework to vary optimal foreign currency exposure and minimise investment risk actively. Following Campbell et al. (2010), the optimal currency exposures can be found by regressing portfolio excess returns $X_{0,t+1}$ on a constant and the vector of currency excess returns $X_{j,t+1}$ and switching the sign of the slopes:

$$X_{0,t+1} = \alpha + \Psi_1 X_{1,t+1} + \Psi_2 X_{2,t+1} + \cdots + \Psi_4 X_{4,t+1} + \varepsilon_{t+1} \quad (3.3)$$

In Equation (3.3), Ψ_1 through Ψ_4 represent the static optimal currency exposures to the four foreign currencies to which investors are exposed.

Table 3.3 shows the optimal currency exposure estimated with Equation (3.3) for investors from the countries under study. Investors' domestic markets are reported in the leftmost column and optimal currency exposures are reported at the top of each column. The parentheses report the standard error. We mark coefficients with one, two, or three asterisks for which we reject the null hypothesis of zero at 10%, 5%, and 1% significance levels, respectively. We provide results for investments with a horizon of one month.

Table 3.3
Optimal static currency exposure

This table reports optimal currency exposure for investors from five countries estimated with Equation (3.3). The investment horizon is one month. Countries are displayed on the left of each row, and the currencies are reported at the top of each column. The parentheses report the standard error. We mark coefficients with one, two, or three asterisks for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. The optimal static currency positions are the same for investors from Canada, the EU, the UK, the US, and Japan. The full sample spans the years 2000–2021.

Country	CAD	EUR	GBP	JPY	USD
Canada	−0.8679	0.1197	−0.1626	0.3534***	0.5574***
	-	(0.1049)	(0.1122)	(0.0841)	(0.1213)
EU	−0.8679***	0.1197	−0.1626	0.3534***	0.5574***
	(0.0969)	-	(0.1122)	(0.0841)	(0.1213)
UK	−0.8679***	0.1197	−0.1626	0.3534***	0.5574***
	(0.0969)	(0.1049)	-	(0.0841)	(0.1213)
Japan	−0.8679***	0.1197	−0.1626	0.3534	0.5574***
	(0.0969)	(0.1049)	(0.1122)	-	(0.1213)
US	−0.8679***	0.1197	−0.1626	0.3534***	0.5574
	(0.0969)	(0.1049)	(0.1122)	(0.0841)	-

Following Campbell et al. (2010), this study focuses on optimal currency exposure rather than the hedge ratio. If the number in the table is zero, it means that investors have fully hedged their currency exposure. The exact hedging demand for each currency is the difference between the optimal currency exposure and the portfolio weights. Investors in Canada, the EU, the UK, Japan, and the US face the same set of hedging currencies. Thus, as shown by Campbell et al. (2010), optimal currency exposures are the same from different investors' perspectives.

To facilitate explanation, we use the example of Canadian investors with a one-month holding period. Table 3.3 shows that a risk-minimising Canadian investor investing one Canadian dollar in the international market should, on average, deposit 11.97 cents in the euro, 35.34 cents in the JPY and 55.74 cents in the USD. The investment in the EUR, JPY, and USD should be financed by borrowing 86.79 cents from Canada and 16.26 cents from the UK.

Taking the portfolio weights into account and restating the numbers from the hedging perspective, the values indicate that the risk-minimising Canadian investor who invested one CAD in the international portfolio should seek additional exposure of 8.21 cents to the CAD, 5.74 cents to the USD, and 20.34 cents to the JPY. Meanwhile, Canadian investors should reduce their exposure to the EUR by 13.03 cents and to the GBP by 21.26 cents.

Table 3.3 shows that risk-minimising investors from the countries selected in our study always have a positive exposure to the EUR, JPY, and USD, indicating that these currencies tend to appreciate when the global stock market declines. The demands for JPY and USD are typically significant at the 1% significance level; however, the demands for EUR are sometimes not statistically significant, even at the 10% level. Meanwhile, the optimal exposure to other currencies is always negative, indicating that these currencies tend to move in tandem with the global stock market. Shorting the CAD is statistically significant across all investors at the 1% significance level; however, shorting the GBP is not significant, even at the 10% significance level. Thus, the CAD is a vital counterparty in currency risk management when there is a need to buy risk-hedging currencies, such as the EUR, JPY, and USD.

Optimal currency exposure reflects the currency's correlation with the international market. If a currency's optimal exposure is negative/positive, then the currency tends to depreciate/appreciate when the market drops. Thus, investors can utilise currency correlations to hedge their global investment risk. This section uses a long-term average to estimate optimal currency exposure. Within these averages, there may be possible issues with sign reversals in the short term or with different market regimes. Hence, the following section examines the dynamic models to assess how optimal currency exposure evolves.

3.5. Dynamic currency risk management

The multivariate DCC model developed by Engle (2002) enables investors to estimate the conditional covariance matrix in two steps. In the first step, univariate volatility models are fitted for each asset and estimates of variance are obtained. In the second step, the conditional correlations are estimated using the asset returns, which are transformed by the estimated standard deviations obtained from the first step.

Following Cappiello et al. (2006), our study considers a variety of GARCH models that account for asymmetric variance and selects the best model for each asset based on the BIC. This approach allows investors the flexibility to choose the best univariate model for each asset rather than adopting a fixed model for all assets, as a single fixed univariate model may not be suitable for all studied assets. Then, we adopt both the DCC of Engle (2002) and the ADCC of Cappiello et al. (2006) to test whether the asymmetries in correlations are relevant in FX risk management. Lastly, the optimal dynamic currency exposures are calculated and compared to the static model results in the previous section.

3.5.1. Selecting optimal univariate models

We develop the model with an international portfolio and four currency excess returns for investors from each country. For investors from different countries, the international portfolio return is the same, while the currency returns vary by country. The mean equation is as follows:

$$X_{i,t} = \varphi_{i,0} + \varphi_{i,1} X_{i,t-1} + \varepsilon_{i,t} \tag{3.4}$$

In Equation (3.4), $\varepsilon_{i,t}$ is the heteroscedastic error term. Following Cappiello et al. (2006), we consider seven univariate models, all of which have one lag of innovation and one lag of volatility. The first model is the standard GARCH model developed by Bollerslev (1986), which has the conditional variance equation:

$$h_{i,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i h_{i,t-1} \tag{3.5}$$

The second is the AVGARCH model of Taylor (2007). The conditional variance equation is:

$$h_{i,t}^{\frac{1}{2}} = \omega_i + \alpha_i |\varepsilon_{i,t-1}| + \beta_i h_{i,t-1}^{\frac{1}{2}} \tag{3.6}$$

The third model is the EGARCH model of Nelson (1991), in which the conditional variance equation is:

$$log(h_{i,t}) = \omega_i + \alpha_i \frac{|\varepsilon_{i,t-1}|}{\sqrt{h_{i,t-1}}} + \gamma_i \frac{\varepsilon_{i,t-1}}{\sqrt{h_{i,t-1}}} + \beta_i \, log(h_{i,t-1}) \tag{3.7}$$

The fourth model is the ZARCH model of Zakoian (1994) with the conditional variance equation:

$$h_{i,t}^{\frac{1}{2}} = \omega_{i,t} + \alpha_i |\varepsilon_{i,t-1}| + \gamma_i I[\varepsilon_{i,t-1} < 0] |\varepsilon_{i,t-1}| + \beta_i h_{i,t-1}^{\frac{1}{2}} \tag{3.8}$$

The fifth model is the GJR–GARCH model of Glosten et al. (1993) with the conditional variance equation:

$$h_{i,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \gamma_i I[\varepsilon_{i,t-1} < 0] \varepsilon_{i,t-1}^2 + \beta_i h_{i,t-1} \tag{3.9}$$

The sixth model is the APARCH model of Ding et al. (1993) with the conditional variance equation:

$$h_{i,t}^{\frac{\lambda}{2}} = \omega_i + \alpha_i |\varepsilon_{i,t-1}|^{\lambda} + \gamma_i I[\varepsilon_{i,t-1} < 0] |\varepsilon_{i,t-1}|^{\lambda} + \beta_i h_{i,t-1}^{\frac{\lambda}{2}} \tag{3.10}$$

The seventh model is the NAGARCH model of Engle and Ng (1993) with the conditional variance equation:

$$h_{i,t} = \omega_i + \alpha_i\left(\varepsilon_{i,t-1} + \gamma_i\sqrt{h_{i,t-1}}\right)^2 + \beta_i h_{i,t-1} \tag{3.11}$$

In these equations, $h_{i,t}$ is the conditional variance of excess equity and currency returns.

In the first stage of model building, we fit the univariate GARCH models for the excess international portfolio return and each of the currency excess returns from the perspective of all investors. Then, we select the best model using BIC. Table 3.4 presents the specifications of the GARCH processes selected by the BIC, along with the estimated parameters from these models. Following Cappiello et al. (2006), parameters are scaled up to facilitate working with extremely small numbers. The intercept parameters are calculated as 100 times the returns.

Table 3.4
Optimal univariate models and estimated parameters

This table reports the optimal univariate models for investors from each country, considering the models described in Equations (3.5) to (3.11). Stock denotes the international portfolio and is the same for all investors. CAD, EUR, GBP, JPY, and USD on the left of the table indicate the excess currency returns to these currencies. The selected model displays the optimal univariate model, chosen based on the BIC, along with the estimated parameters of the optimal model. We mark with one asterisk the coefficient for which we cannot reject the null hypothesis of zero at a 5% significance level. The full sample spans the years 2000–2021. Intercept parameters are calculated as 100 times the returns to facilitate working with extremely small numbers.

Asset	Model selected	ω	α	γ or δ	β
Stock	EGARCH	0.3758	−0.2913	0.1291	0.8494
			Canada		
CAD	-	-	-	-	-
EUR	SGARCH	0.0095*	0.0404*	-	0.9560
GBP	SGARCH	0.4079*	0.1047	-	0.8372
JPY	SGARCH	0.3320*	0.0541	-	0.9165
USD	SGARCH	0.4089*	0.0560	-	0.8825
			EU		
CAD	SGARCH	0.0095*	0.0404*	-	0.9560
EUR	-	-	-	-	-
GBP	EGARCH	0.7997	−0.0927*	0.6837	0.4431*
JPY	SGARCH	0.1383*	0.0706*	-	0.9148
USD	SGARCH	0.3547*	0.0909*	-	0.8610
			UK		
CAD	SGARCH	0.4079*	0.1047	-	0.8372
EUR	EGARCH	0.7997	0.0943*	0.6837	0.4431*
GBP	-	-	-	-	-
JPY	GJR–GARCH	2.3707	0.1118*	−0.2425	0.7844
USD	EGARCH	0.3164	0.1361	−0.0542*	0.8215

Table 3.4 Continued

Asset	Model selected	ω	α	γ or δ	β
			Japan		
CAD	SGARCH	0.3320*	0.0541	-	0.9165
EUR	SGARCH	0.1384*	0.0706*	-	0.9148
GBP	NAGARCH	1.5866*	0.0101*	9.1507	0.0000*
JPY	-	-	-	-	-
USD	SGARCH	0.1429*	0.0697	-	0.9067
			US		
CAD	SGARCH	0.4089*	0.0560	-	0.8825
EUR	SGARCH	0.3545*	0.0909*	-	0.8610
GBP	NAGARCH	1.0952	0.0068	9.7714	0.1608*
JPY	SGARCH	0.1430*	0.0696	-	0.9067
USD	-	-	-	-	-

The excess return of the international portfolio is best described by the EGARCH model, which incorporates a significant asymmetry term. In addition, for 3 of the 20 currency excess returns, the EGARCH model is preferable. Similarly, NAGARCH and GJR–GARCH models are preferable for 2 and 1 currency returns, respectively. For Canadian investors, the SGARCH model is sufficient to model the conditional variance of excess currency returns for all foreign currencies. For investors from the EU, Japan, and the US, only the excess currency return to the GBP requires models containing asymmetry terms. For UK investors, except for excess currency returns in CAD, all excess currency returns require a model with asymmetry terms, indicating the difficulty in modelling the excess currency return for UK investors holding foreign currencies. One possible reason is that the GBP is neither considered a safe-haven currency like the USD nor a counterparty of a safe-haven currency like the CAD. Thus, the conditional variance does not follow a clear pattern, which makes it difficult to estimate.

In addition, if currency excess returns are best described by a standard GARCH model, the estimated parameters are the same for both sides of the currency trading counterparties. For example, the estimated parameters are the same for trading CAD/EUR from the perspectives of Canadian and EU investors. If the asymmetry GARCH model is preferred, the selected optimal univariate GARCH model may change. For example, the optimal univariate model for the GBP/JPY currency pair is GJR–GARCH from the perspective of UK investors, whereas it changes to NAGARCH from the perspective of Japanese investors. In contrast, it may not change, for example, the GBP/EUR currency pair, which depends on the univariate GARCH model's sensitivity to the reversed sign in excess currency returns.

3.5.2. Selecting optimal multivariate models

With the standardised residuals $z_{i,t} = X_{i,t}/\sqrt{h_{i,t}}$ obtained from the first stage, the dynamics of the correlation can be estimated following the DCC model of Engle (2002):

$$\boldsymbol{Q}_t = (1 - a - b)\overline{\boldsymbol{Q}} + a\boldsymbol{z}_{t-1}\boldsymbol{z}'_{t-1} + b\boldsymbol{Q}_{t-1} \quad (3.12)$$

In Equation (3.12), $\overline{\boldsymbol{Q}} = E[\boldsymbol{z}_t\boldsymbol{z}'_t]$, a and b are scalars and $\boldsymbol{z}$ is the $k \times 1$ vector of standardised residuals. The dynamic correlation matrix is:

$$\boldsymbol{R}_t = diag(\boldsymbol{Q}_t)^{-\frac{1}{2}} \cdot \boldsymbol{Q}_t \cdot diag(\boldsymbol{Q}_t)^{-\frac{1}{2}} \quad (3.13)$$

The full conditional covariance matrix is:

$$\boldsymbol{H}_t = \boldsymbol{D}_t\boldsymbol{R}_t\boldsymbol{D}_t \quad (3.14)$$

In this equation, $\boldsymbol{D}_t$ is the diagonal matrix of conditional volatilities. To allow for asset-specific news impact or asymmetries, Cappiello et al. (2006) provide a modified equation:

$$\boldsymbol{Q}_t = \left(\overline{\boldsymbol{Q}} - \boldsymbol{A}'\overline{\boldsymbol{Q}}\boldsymbol{A} - \boldsymbol{B}'\overline{\boldsymbol{Q}}\boldsymbol{B} - \boldsymbol{G}'\overline{\boldsymbol{N}}\boldsymbol{G}\right) + \boldsymbol{A}'\boldsymbol{z}_{t-1}\boldsymbol{z}'_{t-1}\boldsymbol{A} + \boldsymbol{B}'\boldsymbol{Q}_{t-1}\boldsymbol{B} + \boldsymbol{G}'\boldsymbol{n}_{t-1}\boldsymbol{n}'_{t-1}\boldsymbol{G} \quad (3.15)$$

For the asymmetric DCC (ADCC) multivariate GARCH, $\boldsymbol{A} = [\sqrt{a}]$, $\boldsymbol{B} = [\sqrt{b}]$, and $\boldsymbol{G} = [\sqrt{g}]$ are scalars. Thus, the equation can be reduced to:

$$\boldsymbol{Q}_t = (1 - a - b)\overline{\boldsymbol{Q}} - \gamma\overline{\boldsymbol{N}} + a(\boldsymbol{z}_{t-1}\boldsymbol{z}'_{t-1}) + b\boldsymbol{Q}_{t-1} + g(\boldsymbol{n}_{t-1}\boldsymbol{n}'_{t-1}) \quad (3.16)$$

In Equation (3.16), $\overline{\boldsymbol{N}} = E[\boldsymbol{n}_t \boldsymbol{n}_t']$ and $\boldsymbol{n}_t = I[\boldsymbol{z}_t < 0] \odot \boldsymbol{z}_t$. The parameters a, b, and g can be estimated via quasi-maximum likelihood.

Table 3.5 displays the estimation results for the two models described in Equations (3.12) and (3.16). The first model is a standard DCC, while the second model is an asymmetric DCC model where asymmetry terms are introduced to allow for different news impacts across the assets. In Table 3.5, a and b under 'Standard DCC' represent the estimated parameters of the DCC model as specified in Equation (3.12). In contrast, a, b, and g under 'Asymmetric DCC' correspond to the estimated parameters of the ADCC model presented in Equation (3.16). For the standard DCC model, all parameters in the estimated models are significant at the 5% significance level. For the asymmetric DCC model, the estimated asymmetry effect is almost zero, and the assumption of zero cannot be rejected in all cases, even at the 10% significance level. For investors from the UK and Japan, the estimated a are also affected. Although the exact values are the same as in the standard DCC model, they are not deemed significant at the 5% significance level.

Table 3.5
Parameters estimated for symmetrical and asymmetrical models

This table displays the estimation results for the two models. The first model is a standard DCC, where a and b represent the estimated parameters of the DCC model as specified in Equation (3.12). The second estimated model is an asymmetric DCC model, where a, b, and g correspond to the estimated parameters of the ADCC model presented in Equation (3.16). Investors' countries are listed in the leftmost column and the estimated parameters are presented at the top of each column. Following Cappiello et al. (2006), we mark with one asterisk the coefficient for which we cannot reject the null hypothesis of zero at a 5% significance level. The full sample spans the years 2000–2021.

	Standard DCC		Asymmetric DCC		
	a	b	a	b	g
Canada	0.0462	0.8442	0.0462	0.8442	0.0000*
EU	0.0397	0.8722	0.0397	0.8722	0.0000*
UK	0.0312	0.9125	0.0312*	0.9125	0.0000*
Japan	0.0175	0.9414	0.0175*	0.9414	0.0000*
US	0.0212	0.9265	0.0211	0.9266	0.0000*

Our findings show that the optimal strategy for investors is to adopt tailored univariate GARCH models combined with the standard DCC model. For excess currency returns, although asymmetrical univariate GARCH models are preferred in many cases, they are all related to the inclusion of the GBP, which indicates the difficulty of modelling their conditional variance. Alternatively, the excess return of the international portfolio is best modelled by the EGARCH model, which demonstrates its unbalanced response to market rises and falls. Thus, investors should consider variance asymmetry when selecting a model rather than relying solely on a standard GARCH model.

3.5.3. Optimal dynamic currency demand

Thus far, we have developed optimal models for the dynamic optimal hedge and investigated the estimated parameters. Investors can adopt a tailored model to obtain the variance and covariance matrix of assets. Therefore, optimal currency exposure can be calculated to reflect the most recent market conditions as follows:

$$Minimise_{\Psi_{1,t},\Psi_{2,t},\cdots\Psi_{4,t}}: Var\left[X_{p,t}^{h} | X_{1,t-1}, X_{2,t-1}, \cdots X_{4,t-1}\right] \tag{3.17}$$

Table 3.6 shows the optimal currency exposure by minimising investment risk with respect to currency exposure shown by Equation (3.17) for investors from the five countries. The sample periods are listed to the left of each row, and the currencies are listed at the top of each column. We provide results for investments with a one-month horizon. The result is the simple average of the dynamic currency exposure for the full sample and each of its subsamples.

To facilitate explanation, we use the example of Canadian investors with a one-month holding period. The results show that risk-minimising Canadian investors who invest one CAD in the international market, on average, have 15.09 cents invested in the EUR, 36.48 cents in the JPY, and 39.41 cents in the USD. The investment in EUR, JPY, and USD, on average, is financed by borrowing 73.24 cents from Canada and 17.73 cents from the UK.

Table 3.6
Average dynamic optimal currency exposure

This table reports the average optimal currency exposure for each country's investors. Optimal currency exposure is achieved by minimising investment risk, as shown in Equation (3.17). The sample periods are reported in the leftmost column and the currencies are reported at the top of each column. We provide results for investments with a horizon of one month. The result is the simple average of the dynamic currency exposure for the full sample and each of its subsamples.

Horizon	CAD	EUR	GBP	JPY	USD
			Canada		
Full sample	−0.7324	0.1509	−0.1773	0.3648	0.3941
2000–2005	−0.9231	0.2368	−0.1612	0.2817	0.5657
2006–2010	−0.6732	0.0302	−0.0799	0.4467	0.2763
2011–2015	−0.5769	0.0994	−0.1810	0.3565	0.3019
2016–2021	−0.7207	0.2085	−0.2716	0.3864	0.3974
			EU		
Full sample	−0.7261	0.0773	−0.0855	0.4045	0.3298
2000–2005	−0.8774	0.1901	−0.0554	0.2927	0.4499
2006–2010	−0.6233	−0.1191	0.0286	0.5247	0.1891
2011–2015	−0.5688	0.0607	−0.0912	0.3310	0.2683
2016–2021	−0.7916	0.1418	−0.2058	0.4773	0.3783
			UK		
Full sample	−0.7182	0.1376	−0.1606	0.3764	0.3648
2000–2005	−0.9076	0.2425	−0.1595	0.2763	0.5482
2006–2010	−0.6366	0.0149	−0.0745	0.4475	0.2486
2011–2015	−0.6468	0.0613	−0.1366	0.4304	0.2916
2016–2021	−0.6564	0.1986	−0.2536	0.3721	0.3394
			Japan		
Full sample	−0.6825	0.1086	−0.1666	0.4012	0.3392
2000–2005	−0.9055	0.1964	−0.1647	0.4083	0.4655
2006–2010	−0.5950	−0.0031	−0.0624	0.4541	0.2064
2011–2015	−0.5419	0.0447	−0.1758	0.3928	0.2801
2016–2021	−0.6495	0.1672	−0.2475	0.3571	0.3727
			US		
Full sample	−0.7306	0.1388	−0.1575	0.3969	0.3524
2000–2005	−0.9559	0.2392	−0.1657	0.2986	0.5838
2006–2010	−0.6710	0.0488	−0.0693	0.4742	0.2173
2011–2015	−0.5967	0.0492	−0.1303	0.3832	0.2946
2016–2021	−0.6665	0.1882	−0.2456	0.4421	0.2819

The full sample result of Table 3.6 shows that maintaining a positive exposure to the EUR, JPY, and USD is optimal for risk-minimising investors from all countries. The overall strategy of the dynamic hedge is similar to that of the static model. However, although the overall strategy is similar, there are some key differences worth noting.

First, the overall negative position towards the CAD and positive demand for the USD are overestimated when adopting a static model compared to dynamic models. Second, the overall positive position of the JPY is underestimated when adopting a static model compared with dynamic models. Third, the absolute value of the currency positions is lower for dynamic models than for static models, meaning that the dynamic model, on average, requires fewer hedging positions to achieve the risk-minimising position.

We also draw some findings by comparing the results in the four subsamples[21] and the dynamics of optimal currency positions shown in Figures 3.1 to 3.5. The average dynamic exposure moves differently in the subsamples for the three risk-hedging currencies: the EUR, JPY, and USD. The EUR and USD are similar to each other, as their optimal currency exposures start at a high level at the beginning of the sample, decrease in the second subperiod and maintain a low level in the third subperiod. In the fourth subperiod, however, their optimal exposure tends to bounce back to a relatively higher level. Conversely, the optimal JPY exposure is low at the beginning of the first subsample and then peaks in the first, second, and fourth subsamples.

In our research, the second and third subsamples contain the global financial crisis and the European debt crisis. As these two crises are closely connected to the US and EU economies, it is expected that the USD and EUR risk-hedging effects will diminish. Figures 3.1 to 3.5 show that during the global financial crisis, JPY exposure was demanded more than EUR and USD exposure. The world economy started to recover in the third subsample. In the last subsample, the world economy experienced trade conflicts and the pandemic. The trade war led to an increased demand for the optimal position in the EUR. The pandemic, however, led to an increased demand for exposures to all three risk-hedging currencies.

Similar to Section 3.4.1, the overall hedge strategy remains unchanged, with positive exposure to the EUR, JPY, and USD indicated as desirable. However, adopting the dynamic model

[21] The four subsamples are identical to those presented in Table 3.6.

results in a reduced overall currency exposure. The subsample analysis provides deeper insight into optimal currency exposure by revealing how it varies across different economic crises. Although the crises in the second and final subsamples both originated in or significantly affected the US economy, their impact on the US dollar differed markedly. During the Global Financial Crisis of 2008–2009, optimal demand for the USD fell to a level well below its full-sample average, and was also low relative to other safe-haven currencies such as the Japanese yen. In contrast, during the COVID-19 pandemic (the final subsample), demand for the USD remained robust, comparable to that of other safe-haven currencies such as the JPY and the euro.

These contrasting dynamics carry an important implication: safe-haven currencies do not respond uniformly to crises. While investors may expect such currencies to strengthen during periods of turmoil, their behaviour is also shaped by broader market conditions and policy responses specific to each crisis. Consequently, investors should avoid over-reliance on any single safe-haven currency. A diversified approach—holding a basket of multiple safe-haven currencies—offers a more robust strategy for mitigating risk across different types of market stress.

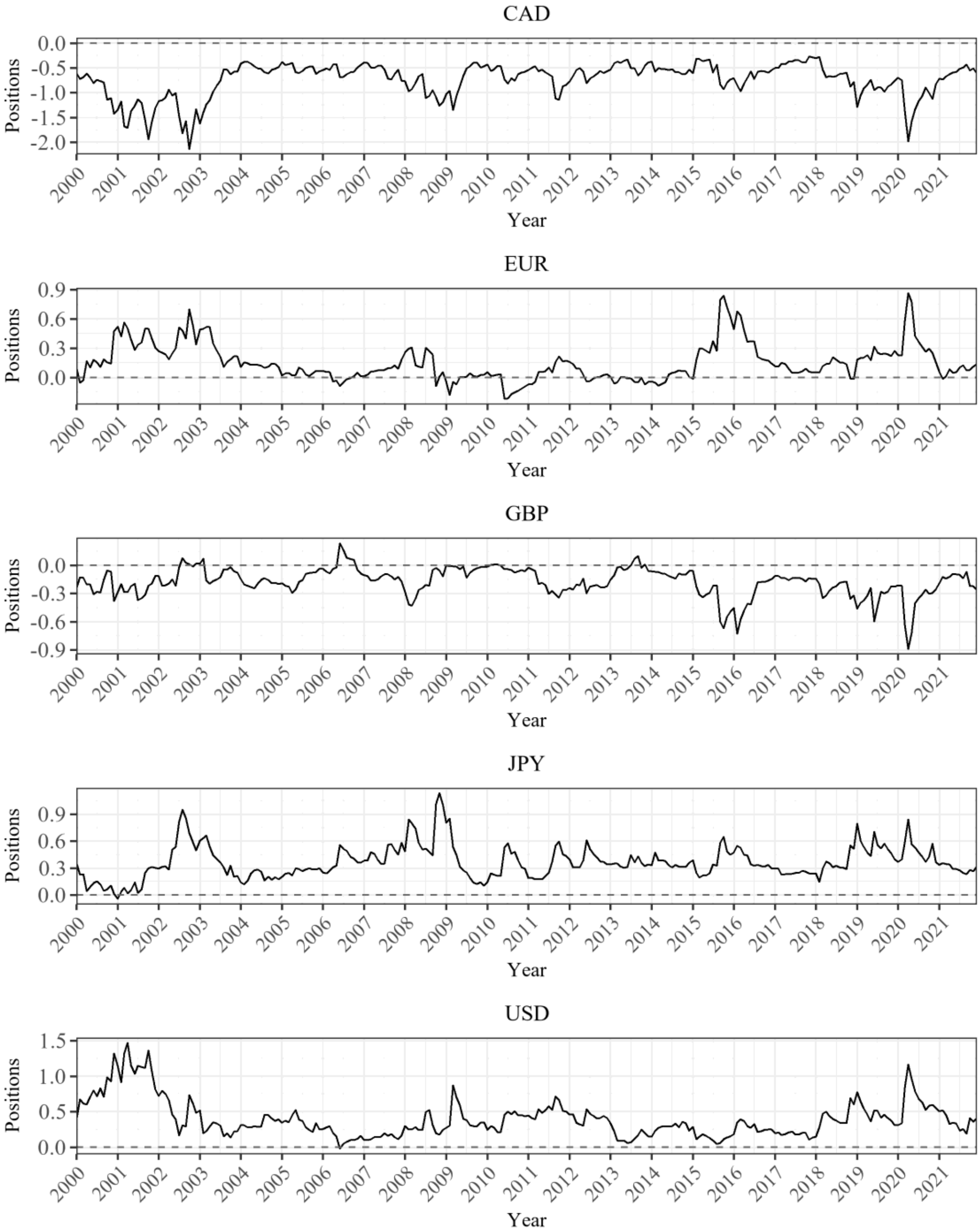

Figure 3.1 Optimal currency positions for Canadian investors

Time-varying optimal currency positions for investors from Canada. The vertical axis displays the optimal positions for each currency, and the horizontal axis displays the years. Optimal currency exposure is achieved by minimising investment risk, as shown in Equation (3.17).

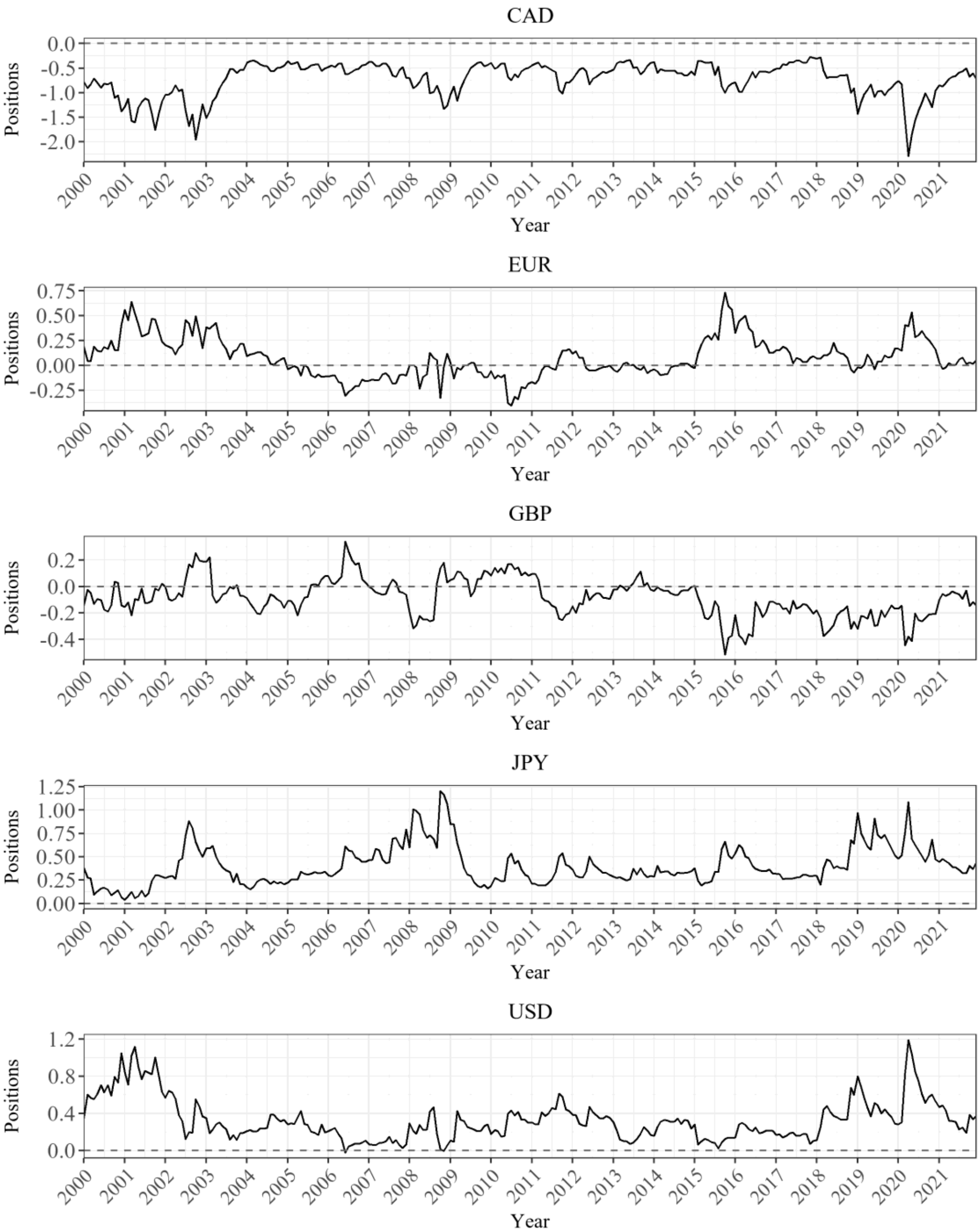

Figure 3.2 Optimal currency positions for EU investors

Time-varying optimal currency positions for investors from the EU. The vertical axis displays the optimal positions for each currency, and the horizontal axis displays the years. Optimal currency exposure is achieved by minimising investment risk, as shown in Equation (3.17).

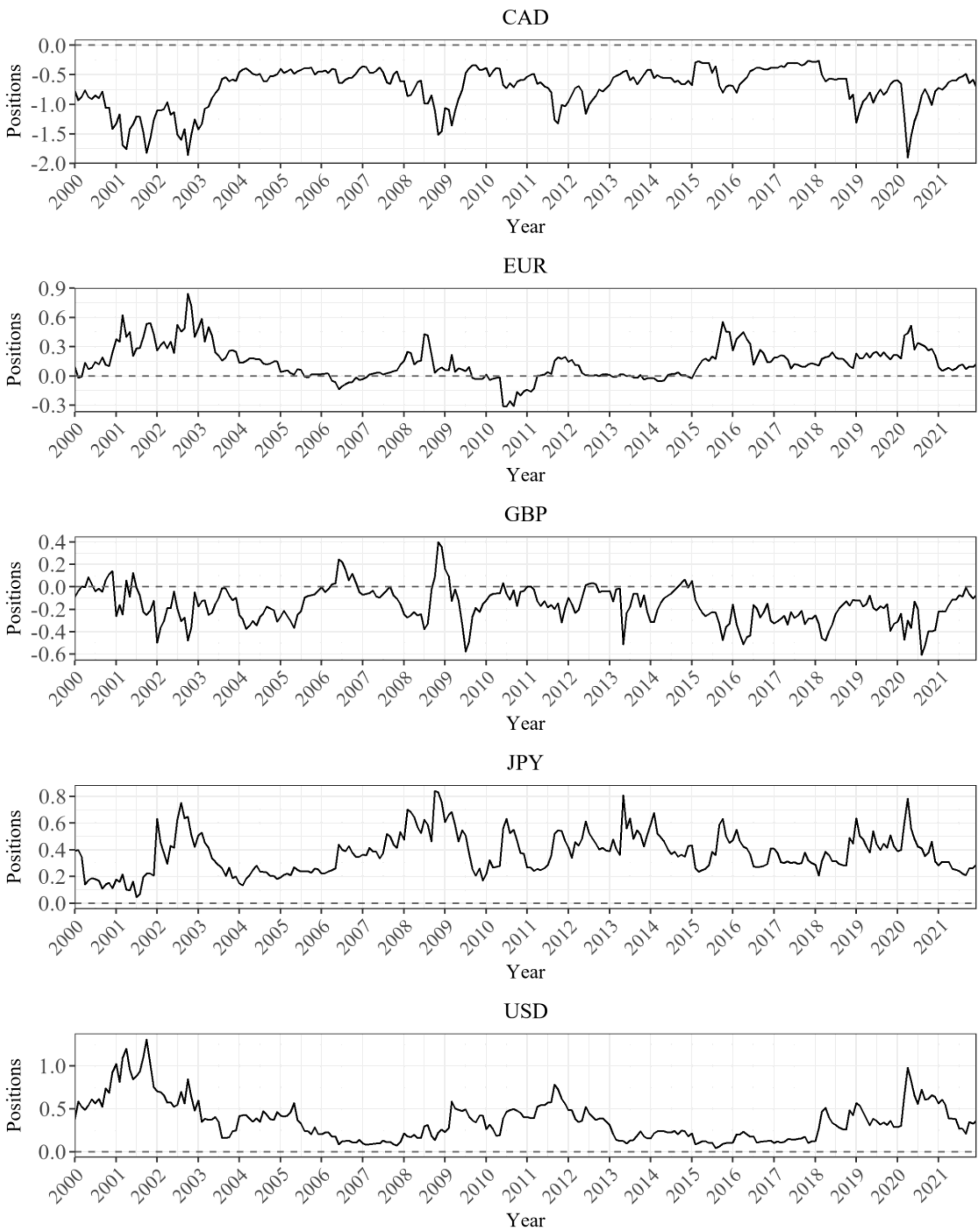

Figure 3.3 Optimal currency positions for UK investors

Time-varying optimal currency positions for investors from the UK. The vertical axis displays the optimal positions for each currency, and the horizontal axis displays the years. Optimal currency exposure is achieved by minimising investment risk, as shown in Equation (3.17).

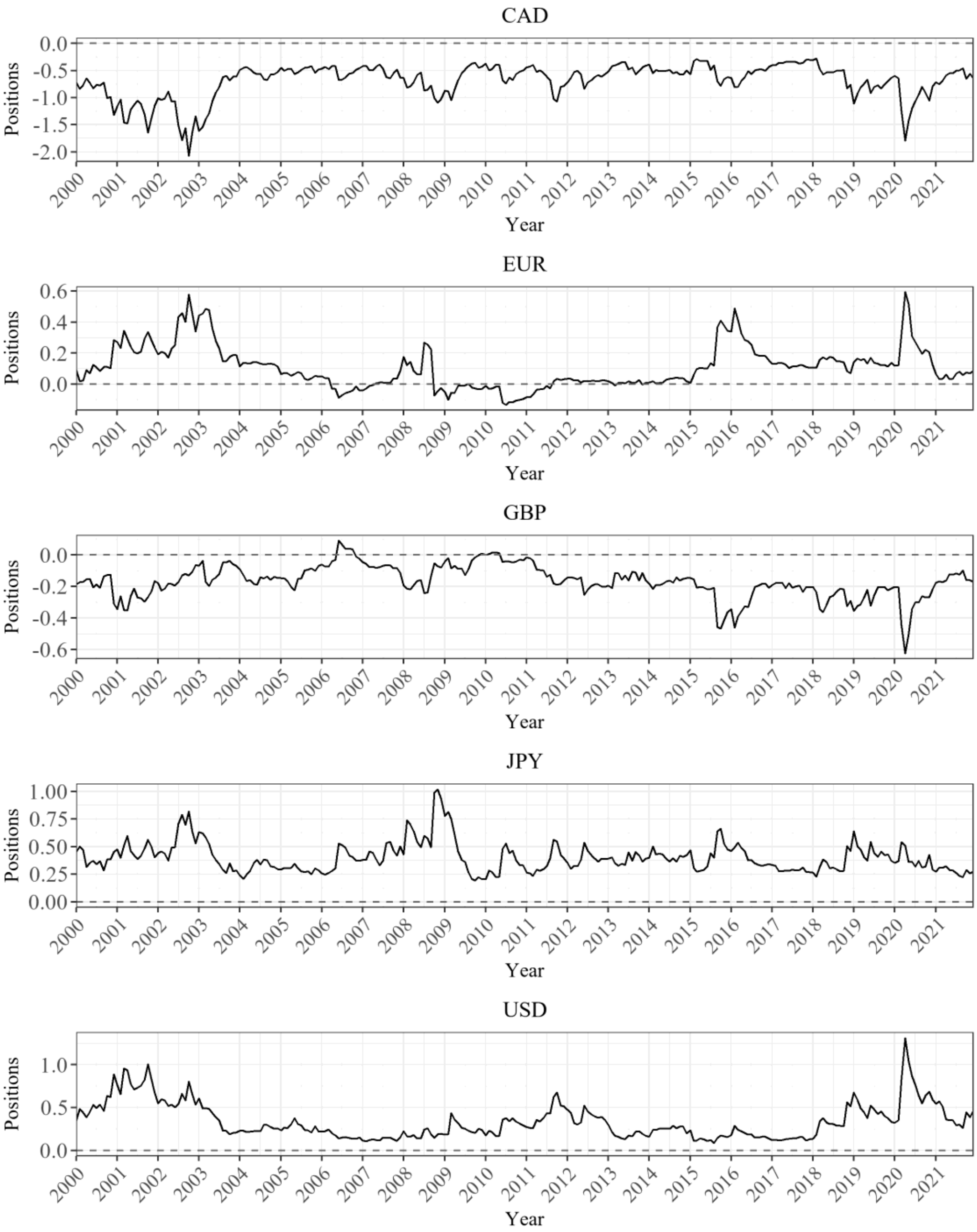

Figure 3.4 Optimal currency positions for Japanese investors

Time-varying optimal currency positions for investors from Japan. The vertical axis displays the optimal positions for each currency, and the horizontal axis displays the years. Optimal currency exposure is achieved by minimising investment risk, as shown in Equation (3.17).

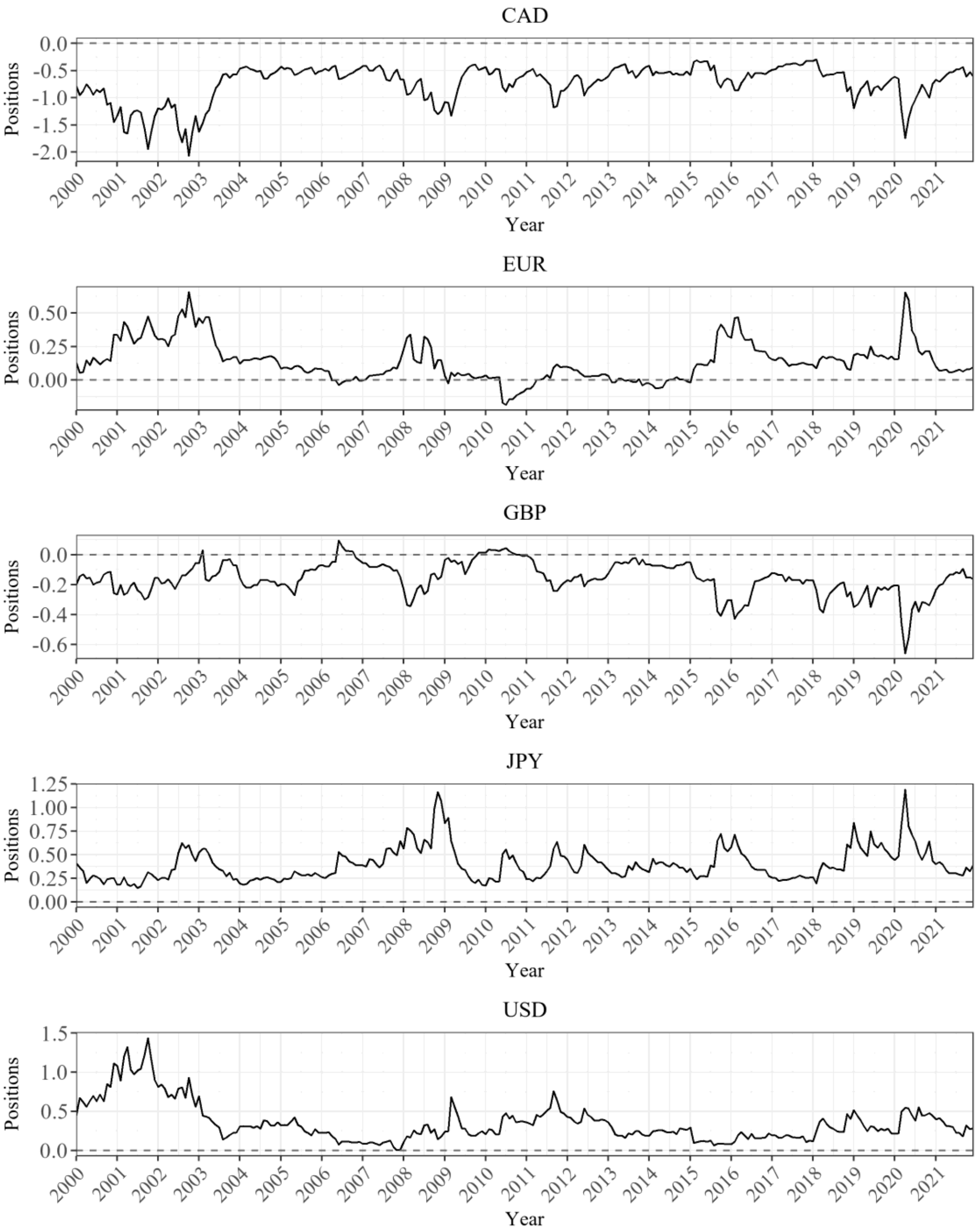

Figure 3.5 Optimal currency positions for US investors

Time-varying optimal currency positions for investors from the US. The vertical axis displays the optimal positions for each currency, and the horizontal axis displays the years. Optimal currency exposure is achieved by minimising investment risk, as shown in Equation (3.17).

3.6. The performance of currency hedging

In the previous sections, we presented models and results for static and dynamic optimal currency exposure. Table 3.7 reports the investment standard deviations investors can achieve with risk-minimising optimal currency positions. Following Campbell et al. (2010), we choose the zero, half, and full hedges as benchmarks. We employ the *F* test to assess the statistical significance of the risk reduction achieved by the optimal static hedge in comparison to the benchmark and dynamic strategies.

Table 3.7 presents the annualised standard deviation of monthly returns for each country and its corresponding hedging strategies. The first three columns present the risks associated with unhedged, half-hedged, and fully hedged investments. Next to the results of the simple hedge, we report the risk of the optimally hedged investment with static and dynamic models. The *F* statistics are displayed to compare the strategies. We mark with one, two, or three asterisks coefficients for which the risk reduction is statistically significant at a 10%, 5%, and 1% significance level, respectively. The reported standard deviations are measured in percentage points.

As indicated in Equation (3.2), the fully hedged (zero foreign currency exposure) excess return of international investment equals the excess returns of the constituent assets in their local currency. Thus, the fully hedged return is the same for investors from all countries. The risk of a partially hedged investment depends on investors' home currencies. If an investor's home currency is one of the safe-haven currencies, such as the JPY and USD, they can reduce investment risk by eliminating foreign currency exposure and seeking exposure to their home currency. Thus, a fully hedged investment has a lower risk than an unhedged or half-hedged investment, as shown in Panel A of Table 3.7. Conversely, for the other countries under study, either the zero hedge or half hedge has a lower risk than the fully hedged investment. For these investors, reducing exposure to their home currency and seeking exposure to safe-haven currencies is the optimal strategy.

Panel A of Table 3.7 shows that without risk management, Canadian and Japanese investors have the lowest and highest unhedged portfolio risk, respectively. The full hedge leads all investors to the same risk level; however, compared to the zero hedge and half hedge, it is the best benchmark strategy for EU, Japanese, and US investors. For Canadian and UK investors, as their domestic currencies do not provide risk reduction, the full hedge increases portfolio risk compared to the zero-hedge and half-hedge strategies.

The optimal hedge minimises risk for all investors compared to benchmark hedging strategies. When comparing the static optimal hedge with the benchmarks, *F* test results show that although the static optimal hedge reduces risk for Canadian investors, the risk reduction compared to the zero and half hedges is not statistically significant at 10% and 5% significance levels, respectively. The above results indicate that unhedged Canadian investors take the most advantage of investing internationally, and currency risk management only marginally improves their investment risk. For other investors, the static optimal hedge consistently reduces international portfolio risk to a level significantly lower than that of any benchmark at the 1% significance level.

When comparing the risk of the dynamic optimal hedge with the static optimal hedge, the *F* test indicates that the risk reduction from the dynamic optimal model is not statistically significant at the 10% significance level. However, the dynamic optimal hedge consistently reduces investment risk to a lower level than the static optimal hedge. An additional test is conducted for Canadian investors in Panel B of Table 3.7, comparing the zero and half hedges with the dynamic optimal hedge, as the static hedge performed poorly in comparison to these benchmarks. The results show that the dynamic optimal hedge can outperform the zero and half hedges at the 10% and 5% significance levels for Canadian investors, respectively, representing an improvement compared to the static optimal hedge.

Therefore, currency risk management policies allow international investors to achieve significant risk reduction in most cases. Although a more sophisticated dynamic model provides additional benefits compared to the static optimal model in all cases, it does not yield a statistically significant risk reduction. However, it does perform better than the static model for Canadian investors, indirectly, as it outperforms the zero-hedge strategy statistically at the 10% significance level, which the static optimal model cannot. This raises the question: Does the risk reduction come with a cost?

Table 3.7
Performance of currency hedging

Panel A reports the annualised standard deviation of monthly returns for each country and its corresponding hedging strategies. The first three columns present the risk for unhedged, half-hedged, and fully hedged investments. Next to the benchmark results, we report the risk of optimally hedged investments calculated with the optimal currency exposure discussed in Sections 3.4 and 3.5. The *F* statistics displayed in the table test the statistical significance of the risk reduction achieved by the optimal static hedge in relation to zero, half, and full hedges, as well as the risk reduction achieved by the optimal dynamic hedge in relation to the optimal static hedge. We mark with one, two, or three asterisks coefficients for which the risk reduction is statistically significant at a 10%, 5%, and 1% significance level, respectively. The reported standard deviations are measured in percentage points. Panel B presents additional tests for the dynamic hedge compared to the zero hedge and half hedge.

Panel A

Country	Zero hedge	Half hedge	Full hedge	Static optimal	Dynamic optimal	Static vs Zero hedge	Static vs Half hedge	Static vs Full hedge	Static vs Dynamic
Canada	11.92	12.59	14.24	11.57	10.93	1.0612	1.1834*	1.5132***	1.1215
EU	14.36	13.91	14.24	11.57	10.98	1.5386***	1.4449***	1.5132***	1.1115
UK	14.02	13.71	14.24	11.57	10.95	1.4676***	1.4025***	1.5132***	1.1164
Japan	18.02	15.80	14.24	11.57	11.12	2.4229***	1.8633***	1.5132***	1.0826
US	15.23	14.64	14.24	11.57	11.01	1.7320***	1.6000***	1.5132***	1.1042

Panel B

Country	Dynamic vs Zero hedge	Dynamic vs Half hedge
Canada	1.1901*	1.3272**

3.7. Return of hedged investment

The next area of interest is the return of hedged investments. Although entering a foreign exchange forward contract does not involve any cash changing hands, changes in currency exposure would affect the hedged foreign investment return. Following the comparison of risk, we choose the zero hedge, half hedge, and full hedge as benchmarks and examine the differences in relation to the static and dynamic optimal hedges discussed in Sections 3.4 and 3.5, using the paired *t* test.

Table 3.8
Benchmark and optimally hedged returns

This table presents the in-sample results for the investment returns of optimally hedged and benchmark strategies, considering the optimal currency positions discussed in Sections 3.4.1 and 3.5.3 The domestic countries are displayed on the left of each row and the hedging strategies are displayed at the top of each column. The benchmark strategies adopted are zero hedge, half hedge, and full hedge. The static hedge refers to the static optimal hedge and the dynamic hedge refers to the dynamic optimal hedge. The *p* value of the paired *t* test is used to determine whether the dynamic optimal hedge yields a higher return than the static optimal hedge. Reported excess returns are annualised and measured in percentage points.

Country	Zero hedge	Half hedge	Full hedge	Static hedge	Dynamic hedge	Static vs dynamic
Canada	0.8183	1.3056	1.7928	0.4665	1.5423	0.1040
EU	1.1884	1.4906	1.7928	0.4665	1.5480	0.1097
UK	1.8996	1.8462	1.7928	0.4665	1.3977	0.1089
Japan	3.6920	2.7424	1.7928	0.4665	0.9482	0.2615
US	1.6119	1.7023	1.7928	0.4665	1.6248	0.0818

Table 3.8 shows the annualised excess returns of simple and optimal hedges, in which the hedging strategies are displayed at the top of each column, while investors' home countries are displayed at the left of each row. To facilitate interpretation, we use the example of the annualised excess return of Canadian investors investing in the global market and adopting the zero (0.8183), half (1.3056), full (1.7928), static (0.4665) and dynamic (1.5423) hedge strategies, as shown in Table 3.8. For simple hedging strategies, the lower the foreign currency exposure (i.e., the higher the hedge ratio), the higher the hedged investment return. This effect implies that shorting foreign currencies and holding long CAD positions is profitable for

international investors. This effect also applies to EU and US investors, even though their domestic currencies are safe-haven currencies.

Comparing the excess returns of the zero hedge and static optimal hedge, we find that the static optimal hedge reduces the excess return of international investments for all investors. The dynamic optimal hedge, however, allows investors to maintain a similar excess return compared to benchmarks, except for Japanese investors. For all investors, the hedged return with dynamic models is always higher than that with a static model. In most cases, the return with a dynamic model is three times that of adopting a static model, although we only find it to be statistically significant for US investors at the 10% significance level.

In Section 3.6, the dynamic model consistently provides a larger risk reduction (although not statistically significant) than the static optimal model. Taking the hedged return into account, we conclude that dynamic optimal models provide more efficient solutions for international investors. They reduce the international investment risk to a lower level compared with static models, with fewer losses in investment returns.

3.8. Conclusion

This study examined foreign currency risk management from the perspectives of equity investors in Canada, the EU, the UK, Japan, and the US. We assumed that investors from these countries hold international portfolios with assets listed in the US, EU, Japanese, UK, and Canadian markets. Based on this assumption, we drew the implications for risk-minimising investors.

Our first novel finding concerns the selection of optimal univariate models for each asset's excess return. With the exception of Canadian investors, when the excess return variance involves the British pound, the estimation of conditional variance typically requires sophisticated GARCH models incorporating asymmetric terms. This finding indicates the inherent difficulty of modelling GBP behaviour. Investors should therefore either adopt advanced models or avoid the GBP when selecting hedging currencies. In contrast, the variances in currency excess returns are uniformly symmetric for Canadian investors and can be adequately described by the standard GARCH model. Furthermore, the optimal model for the same currency pair may differ depending on the investor's perspective, suggesting that asymmetric variance is currency-specific.

Our second novel finding arises from comparisons of optimal multivariate models. Contrary to the established literature, the estimated parameters of the ADCC model reveal that asymmetry in dynamic conditional correlation is not detected for all investors. This result—potentially attributable to the portfolio's unique composition, numeraire effects, or sample period characteristics—validates the sufficiency of the standard DCC model in this specific context.

Our third novel finding is evident in the comparison between static and dynamic optimal currency positions. The dynamic optimal hedge consistently yields lower absolute optimal currency positions than the static optimal hedge, implying that dynamic models require fewer hedging operations. Additionally, relative to the dynamic model, the static model tends to overestimate investors' optimal exposure to the CAD and USD in absolute terms, while underestimating optimal exposure to the JPY. Overall, dynamic optimal models demonstrate greater efficiency in terms of the currency positions required to minimise investment risk.

The dynamics of optimal currency exposure also reflect each currency's role in international markets. When a currency helps reduce foreign investment risk through negative correlation with foreign assets, its estimated optimal exposure is positive and increases as investors perceive greater risk. For example, optimal currency positions for the EUR, JPY, and USD spiked during the Global Financial Crisis and the COVID-19 pandemic. Conversely, the CAD serves as a stable counterparty currency to the EUR, JPY, and USD, with spikes to negative positions consistently observed during market crises.

Consistent with the existing literature, we employed zero, half, and full hedges as benchmarks, comparing both static and dynamic optimal hedges against these benchmarks. Optimally hedged investments consistently exhibited lower risk than all benchmarks. The risk reduction achieved by adopting the static optimal hedge is statistically significant at the 1% level for all investors except those from Canada. For Canadian investors, the risk reduction relative to the zero hedge is not significant at the 10% level, while the reduction relative to the half hedge is significant at the 10% level. One possible explanation is that the CAD's negative correlation with international portfolios means foreign currency exposure already helps reduce investment risk; indeed, Canadian investors' unhedged investment risk closely approximates that achieved with the static optimal hedge.

The dynamic optimal hedge further reduces investors' risk compared to the static optimal hedge. The F test, however, indicates that these additional risk reductions are not statistically significant, even at the 10% level. The usefulness of the dynamic optimal hedge is nonetheless demonstrated by its ability to provide risk reduction for Canadian investors relative to the zero hedge at the 10% significance level—a benchmark that the static optimal hedge cannot meet at the same significance level.

Currency risk management affects hedged returns, depending on the investors' home currency. We found that the dynamic optimal model provides a higher hedged return than the static optimal model for all investors, with the hedged return of the dynamic model being two to three times that of the static optimal model. The paired t test shows that the higher return is statistically significant for US investors at the 10% significance level.

The dynamic optimal hedge thus proves more efficient than the static model in terms of both optimal currency positions and hedged return enhancement. Among all investors, Canadian investors gain the most from the dynamic model, as it significantly reduces the risk of unhedged international portfolios—a benefit unattainable with the static model. This finding applies specifically to Canadian investors because the CAD's negative correlation with international investments helps reduce risk without requiring active currency management. Consequently, Canadian investors exhibit the lowest unhedged investment risk among all investors, comparable to the risk level achieved with the static optimal hedge. As a result, the static model cannot provide statistically significant risk reduction for unhedged Canadian investors. The additional risk reduction from the dynamic model, although modest and not statistically significant compared to the static hedge, enables unhedged investment risk to be reduced at the 10% significance level. For other investors, the dynamic model outperforms the static model in risk reduction to a similar degree as for Canadian investors. However, since the static model already provides significant risk reduction relative to benchmarks for these investors, the additional benefit of the dynamic model is less critical—except in the Canadian case. Overall, while the improvement in dynamically hedged returns is not statistically significant for most investors, it is economically significant, rendering the dynamic model the preferred choice.

This study employed an advanced framework to estimate the optimal currency exposures. The contrasting dynamics of USD in the second and last subperiods carry an important implication: safe-haven currencies do not respond uniformly to crises. Their behaviour is also shaped by broader market conditions and policy responses specific to each crisis. Consequently, investors should avoid over-reliance on any single safe-haven currency. A diversified approach—holding a basket of multiple safe-haven currencies—offers a more robust strategy for mitigating risk across different types of market stress. Future research should focus on exploring alternative assets that are suitable for currency risk management.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Zhennan Mao
Name and title of main supervisor:	Jianguo Chen, Doctor
In which chapter is the manuscript/published work?	Chapter four

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Chapter Four includes Study Three - Currency Risk Management for Diversified and Home-Biased Investors and the Effectiveness of Gold and Bitcoin.
Zhennan Mao is primarily resposible for the research design, data collection, empirical analysis, and manuscript writing.

Please select one of the following three options:

○ **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

○ **The manuscript is currently under review for publication**

Please provide the name of the journal:

◉ **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Zhennan Mao — Digitally signed by Zhennan Mao Date: 2025.07.25 14:12:59 +12'00'	Main supervisor's signature:	Jianguo Chen — Digitally signed by Jianguo Chen DN: cn=Jianguo Chen, c=NZ, o=Massey University, ou=School of Economics and Finance, email=j.g.chen@massey.ac.nz Date: 2025.07.25 15:26:13 +12'00'

This form should be placed at the beginning of each relevant thesis chapter.

[1] Refer to the Massey University Publishing and Authorship guidelines (OneMassey for staff, Stream for students) and/ or Contributor Roles Taxonomy (CRediT) guidelines for guidance.

CHAPTER FOUR STUDY THREE CURRENCY RISK MANAGEMENT FOR DIVERSIFIED AND HOME-BIASED INVESTORS AND THE EFFECTIVENESS OF GOLD AND BITCOIN

This research investigates currency risk management from the perspective of investors in ten countries (Canada, the EU, the UK, Japan, the US, Australia, Brazil, Indonesia, South Korea, and South Africa), using static mean–variance frameworks for both diversified and home-biased portfolios. The results reveal two distinct patterns: optimal currency exposures shift for Japanese, Brazilian, Indonesian, and South African investors across portfolio types, but remain stable for Canadian, EU, UK, US, Australian, and South Korean investors. Moreover, currency hedging delivers comparable risk reduction for investors from Canada, the EU, the UK, the US, and Australia. Extending the analysis to alternative hedging assets, we find that adding gold futures generates positive optimal demand for all diversified investors and improves hedged returns in selected countries, yet offers limited reduction in USD exposure or overall risk. Bitcoin demand is near zero, suggesting it is irrelevant to currency risk management over the limited sample period available.

Keywords: currency risk management, gold, bitcoin, diversification, home bias

4.1. Introduction

Currency risk management is essential for international investors, as holding foreign assets inherently exposes them to exchange rate fluctuations in the absence of hedging. Such exposure can lead to a deviation between the actual returns realised by investors and the returns on assets denominated in the pricing currency. This exchange rate fluctuation can either enhance or erode the value of foreign investments when measured in the investor's domestic currency, thereby introducing an additional layer of uncertainty to international investment.

Fidora et al. (2007) note that real exchange rate volatility is a key driver of portfolio home bias—the empirical tendency for investors to favour domestic assets over their global market weight. Investors may shift to domestic assets to avoid foreign exchange (FX) risk. Investors may shift to domestic assets to avoid foreign exchange (FX) risk. Although such investors still hold foreign assets, their weights are significantly lower than those of internationally diversified portfolios. Practitioners might expect the optimal currency position to be affected when applying the risk-minimising hedge. However, Campbell et al. (2010) demonstrate that the optimal currency risk management policy remains stable even when investors' portfolios change. They conducted their research with an equally weighted international portfolio and compared it with the results of value-weighted and home-biased portfolios with 75% of investment in the domestic market. The similarity of their optimal currency demands indicates that the change in investment weight and the implied foreign currency exposure do not affect the optimal currency exposure for minimising investment risk. These insights have rightfully made the Campbell et al. (2010) study a cornerstone of the currency hedging literature.

However, the very nature of their contribution also highlights several avenues for further research that could enhance its practical applicability. First, the home-biased portfolios considered by Campbell et al. (2010) are hypothetical. Although these portfolios show that optimal currency positions are stable across different portfolios, this finding is of limited practical value for investors seeking to draw implications for their optimal hedging policies, as investors from different countries exhibit varying home-bias effects. Sercu and Vanpee (2012) utilised International Monetary Fund (IMF) data and noted that the home-bias effect varies significantly across different countries. Following their measurement of the home-bias effect, the present study constructs home-biased portfolios that represent the average preferences of investors. Unlike the fixed and uniform home-biased portfolio used by Campbell et al. (2010), the results obtained in this study provide empirical implications tailored to average home-biased investors from different economies.

Second, Campbell et al. (2010) only considered investors from developed economies, namely Australia, Canada, the EU, Japan, Switzerland, the UK, and the US. Although their research has extensive coverage, emerging markets have different systematic presence and market access; thus, the results may not apply to investors from emerging economies. It is therefore necessary to consider investors from emerging economies and identify the relevant implications. This study addresses this issue by including investors from Brazil, Indonesia, and South Africa, which are important regional economies.

Third, Campbell et al. (2010) found that optimal currency positions are 'qualitatively and quantitatively similar' across different portfolios. However, their findings lack statistical tests to prove that the optimal currency positions are equal for different portfolios. This study employs the *z* test, as proposed by Clogg et al. (1995), to statistically compare the optimal currency demand for diversified and home-biased investors.

Lastly, the performance of optimal currency hedging across various portfolios remains unexplored. Knowing that the optimal currency position is stable does not guarantee that the hedge's performance is equally stable. Since hedging performance is central to investors' decision-making, this study examines optimally hedged investment risk and risk reduction relative to benchmark strategies.

In this study, we denote value-weighted portfolios as diversified investments. Following Campbell et al. (2010), we assume that investors hold exogenous, diversified, and home-biased international portfolios and utilise the currency position to minimise investment risk. We consider investors from Australia, Brazil, Canada, the Eurozone, Indonesia, Japan, South Korea, the UK, the US, and South Africa and utilise the US dollar (USD), euro (EUR), Canadian dollar (CAD), British pound (GBP), Japanese yen (JPY), and investors' domestic currencies to manage the risk. Using realistic home-bias data and a broadened investor base, we test how optimal hedging differs for investors who hold diversified versus home-biased investments.

A key finding of this research is that the demand for the USD dominates as the primary hedging currency. While Campbell et al. (2010) show that the USD plays a vital role in the full sample and first subsample, our study shows its importance is magnified for South Korean, Indonesian, Brazilian, and South African investors with home-biased portfolios. Although taking a long position in the USD is a sound strategy for risk-minimising investors, relying solely on it is not optimal. Investors should explore alternatives to improve the diversification of optimal currency positions.

One such alternative is the inclusion of safe-haven assets that either behave similarly to the USD or protect against USD depreciation. Reboredo and Rivera-Castro (2014), Reboredo (2013) and Joy (2011) document that gold serves as a hedge against USD weakness. Nguyen et al. (2020) extend this finding, showing that gold is an effective and robust hedge against depreciation of the USD, EUR, and JPY. More recently, Kang et al. (2020) suggest that bitcoin may function as an effective safe haven, mitigating downside risk in portfolio management.

Cheong (2019) goes further, arguing that cryptocurrencies can hedge FX risk more effectively than traditional instruments such as gold or diversified currency portfolios.

Against this backdrop, we incorporate gold and bitcoin as alternative hedging assets to address three questions. First, is the demand for gold and bitcoin exposure statistically significant? Second, do these assets improve the diversification of optimal currency positions by reducing excessive exposure to the USD? Third, how do they affect the risk and return of optimally hedged investments?

The remainder of this paper is structured as follows. Section 2 reviews the related literature. Section 3 describes the data and the construction of home-biased portfolios. Section 4 outlines the methodology. Section 5 presents the empirical results. Section 6 concludes.

4.2. Literature review

4.2.1. Diversification and Home-bias effect

The core principle of Markowitz's (1952) portfolio selection theory is diversification—investors are better off holding a portfolio composed of assets from different classes rather than similar ones. The benefits of international diversification have been examined by many subsequent empirical studies. For instance, it could reduce investment risk compared to a domestic one (Solnik, 1974b) and double the mean return at the same level of risk (Levy & Lerman, 1988). Recent research shows that diversifying into emerging markets is beneficial (Gupta & Donleavy, 2009), and investors based in developing countries gain most by diversifying their portfolios across international markets (Driessen & Laeven, 2007). Given these advantages, investors are encouraged to diversify internationally.

However, in practice, numerous barriers[22] prevent investors from fully diversifying their investments internationally. Exchange rate fluctuations further complicate international diversification, as currency fluctuations can significantly affect investment returns when converted back into the investor's domestic currency.[23] These and other frictions collectively constrain the extent to which investors can achieve optimal international diversification.

Although various constraints limit the extent of international diversification, several studies have proven that its benefits persist. Cosset and Suret (1995) showed that diversification among politically risky countries improves the risk–return characteristics of optimal portfolios. Furthermore, Li et al. (2003) demonstrated that even under short-selling constraints, international diversification benefits remain substantial for U.S. equity investors who are prohibited from short selling in emerging markets. In the presence of such risks, international investors face a trade-off between the benefits of diversification and the additional layers of risk associated with foreign investments, leading to the phenomenon known as home bias.

French and Poterba (1991) showed that over 98.1% of Japanese investors' equity investment is held domestically; the corresponding figures were 93.8% for the United States and 82% for the United Kingdom. Coeurdacier and Rey (2013) provided the trend of home bias for major developed and emerging economies. They showed that the home bias effect declined from 2001 to 2008 for developed countries and several emerging Asian economies, while it increased in Central and Eastern European countries. Nevertheless, most investors continued to allocate more than 60% of their portfolios to domestic assets. Karolyi and Stulz (2003) contributed to the measurement of home bias for US investors from 1973 to 2000, while Lewis (1999)

[22] These barriers include capital controls, whereby governments impose restrictions on the movement of capital across borders, thereby limiting investment opportunities (Daly & Vo, 2013). Additionally, information asymmetry—stemming from limited access to reliable data about foreign markets—can impede informed decision-making (Ahearne et al., 2004).
[23] If monthly exchange rate volatility were hypothetically reduced to zero, equity and bond home bias would drop by about 20 and 60 percentage points on average (Fidora et al., 2007).

measured the home bias effect for institutional investors in developed economies from 1980 to 1993. Overall, although the level of home bias has been reducing over recent decades, it remains at a high level.

Thus, the weights of the constituent assets in a home-biased portfolio differ structurally from those in a diversified portfolio. Following the same reasoning, the foreign currency exposure should differ between home-biased and diversified investors. For home-biased investors, the foreign currency exposures are lower than those fully diversified internationally. The need for currency risk management arises primarily from investors' desire to control the foreign exchange rate risk associated with foreign currency–denominated investments. Thus, a decrease in foreign currency exposure should result in a decrease in the demand for foreign currency risk management.

On the contrary, Campbell et al. (2010) adopted equally weighted, value-weighted and home-biased portfolios with 75% investment in the domestic market and claimed that the optimal currency demands are 'qualitatively and quantitatively similar' across different portfolios. This similarity implies that optimal currency demands do not vary with changes in the weight of the assets constituting the investment and the investment-implied currency exposure. The findings are valuable and innovative, and might provide empirical support for the universal hedge developed by Black (1989).

However, the research of Campbell et al. (2010) is confined to developed markets, and it remains unclear whether their conclusions can be generalised to emerging markets. Emerging and developed markets exhibit significant differences in currency properties, correlation structures, and micro-market characteristics, suggesting that their findings may not be universal. Thus, this research extends Campbell et al.'s (2010) framework to emerging markets and focuses on the difference between home-biased and value-weighted investments. We improve their study by providing statistical tests on the difference between home-biased and value-weighted optimal currency exposures.

4.2.2. Mean–variance framework

Investors who perceive foreign currency exposure as unoptimised assets could employ the mean–variance framework, which uses the correlation between foreign assets and currencies. This framework enables investors to use the FX derivative to vary their foreign currency positions, thereby maximising their portfolios' Sharpe ratio or minimising overall investment risk, as seen in studies by Eun and Resnick (1988), Gastineau (1995), Glen and Jorion (1993), and Campbell et al. (2010).

This study extends Campbell et al.'s (2010) framework and adopts the static mean-variance work for three reasons. Firstly, it is the standard approach in the currency hedging literature, used extensively by Glen and Jorion (1993), Campbell et al. (2010) and de Roon et al. (2003). Secondly, as we are primarily interested in the structural differences between home-biased and diversified investments rather than short-term tactical allocation, the static framework captures the long-term average relationships that matter for our research. Thirdly, though Glen and Jorion (1993) and Campbell et al. (2010) have introduced improved static models adopting indicators. The effectiveness is inconsistent[24] across studies with different asset choices, currencies, and sample periods.

[24] Glen and Jorion (1993) included a conditional strategy that depends on interest rate differentials. The improvement of stock and bond portfolio performance is significant both in and out of sample. They found that the hedged portfolio return increases without an increase in risk. Campbell et al. (2010) investigated the usefulness of interest rate differences within the mean–variance framework. However, they found that the indicator did not provide a significant additional risk reduction compared with an optimally hedged portfolio in sample.

We acknowledge the framework's limitations, including its sensitivity to estimation risk and its static nature. However, for the purpose of establishing baseline results, it provides an appropriate and transparent starting point.

4.2.3. The importance of the USD

The USD was involved in nearly 90% of global FX transactions, and its dominance is evident across all FX instruments and counterparties. At least 85% of trading in the spot, forward, and swap markets involves the USD in one leg of the transaction (Maronoti, 2022). In addition, Avdjiev et al. (2019) claimed that the strength of the US dollar has real effects on real investment in emerging market economies.

In the context of currency risk management, the importance of the USD stems from its negative correlation with global markets (Campbell et al., 2010). Fratzscher (2009) claimed that the USD appreciated against most currencies during the financial crisis. Min et al. (2016) found that the USD, JPY, and Swiss franc (CHF) have negative dynamic correlations between equity and currency returns. From a Latin American perspective, Walker (2008) concluded that exposure to the USD could be used to counter negative stock returns. Thus, it is a crucial tool for mitigating investment risk. Campbell et al. (2010) show that USD exposure is highly demanded in the full sample and first subsamples. Although the strategy of going long on USD is sound, relying solely on it creates additional risk; therefore, investors and practitioners should seek alternatives that serve as safe havens.

4.2.3.1. Alternatives to conventional safe-haven currencies

Numerous studies have explored gold's relationship with the stock and FX markets. Reboredo and Rivera-Castro (2014), Reboredo (2013), and Joy (2011) found that gold can act as a hedge against the depreciation of the USD. Using USD, EUR, and JPY, Nguyen et al. (2020) found that gold is an effective and robust hedge against the depreciation of these currencies.

Gold also acts as a hedge against many assets. Qureshi et al. (2018) studied the role of gold from the perspective of Pakistani investors. They found that gold serves as a consistent short-run hedge against exchange rate fluctuations. Similarly, Iqbal (2017) examined the exchange rates for India, Pakistan, and the US and demonstrated that gold is a consistent hedge against the exchange rates for Pakistan and India. Using high-frequency data, Madani and Ftiti (2022) argue that gold serves as a strong hedge against currency market movements and demonstrates a strong safe-haven capability against extreme currency fluctuations. Going beyond individual currencies or stock markets, Gomis-Porqueras et al. (2022) state that gold exhibits hedging properties when investors face risks associated with currency, European sovereign debt, stock markets, and oil price inflation.

While many studies advocate gold as a hedge against currency risk, others have pointed out its limitations. Wang and Lee (2011) demonstrate that the effectiveness of gold as an exchange rate hedge depends on the depreciation rate of the currency. Additionally, Wang and Lee (2022) highlight that gold cannot hedge against long-term currency depreciation but can hedge against short-term currency depreciation risk. Similarly, Ghorbel et al. (2022) state that gold can act as a hedge or safe-haven asset in the short run.

In addition to gold, Bitcoin has emerged as a potential alternative to the US dollar in currency hedging strategies. Since Dyhrberg's (2016) pioneering work comparing Bitcoin, gold, and the dollar, a growing body of literature has examined the hedging and safe-haven properties of cryptocurrencies. Kang et al. (2020) conducted research using bitcoin, the S&P 500 index, the USD, and US bonds. They found that bitcoin may be an effective safe haven for investors, as it reduces downside risk in portfolio risk management. Meshcheryakov and Ivanov (2020) obtained similar results, finding that Ethereum serves as a hedge against US stocks. Cheong (2019) found that cryptocurrencies can hedge against FX risks and are more effective than other common hedging instruments and techniques, such as gold or diversified currency portfolios. Feng et al. (2018) studied cryptocurrency in relation to four stock indices and stated that it could serve as a diversifier for the stock market, similar to gold, but it is insufficient as a tail hedging tool.

Many researchers have proposed that gold and cryptocurrency can be used together as worthwhile risk management sources for international investors. For example, Owusu Junior et al. (2020) concluded that gold and cryptocurrencies can act as hedges and diversifiers for other traditional asset classes, such as fiat currencies. Chemkha et al. (2021) advocate for the effectiveness of bitcoin and gold as hedging assets in reducing the risk of international portfolios. Hsu et al. (2021) claim that cryptocurrencies, traditional currencies, and gold can be incorporated into financial portfolios for financial market participants seeking effective risk management. Gold displays substantial safe-haven properties during periods of turmoil and high uncertainty (Nguyen et al., 2020), while cryptocurrency shows the ability to hedge against geopolitical risks and economic policy uncertainty risk (Almeida & Gonçalves, 2023), which could lead to unpredictable jumps in investment risk.

Given that gold and bitcoin have been extensively studied in the academic literature and are widely recognised as effective instruments for mitigating market downturns and currency depreciation, their potential to reduce investors' optimal demand for the US dollar in risk-minimising hedging strategies warrants further investigation. However, its effectiveness in optimal currency hedging strategies remains underexplored. To the best of our knowledge, no study has systematically examined, within a mean-variance framework, how the introduction of gold or bitcoin affects optimal currency exposures.

This study employs a mean-variance framework to compare the optimal USD exposure of portfolios with and without the inclusion of gold or bitcoin. It aims to fill the gap by addressing the research question: Does incorporating gold or bitcoin into the hedging strategy reduce over-reliance on the US dollar? In addition, it evaluates the performance of currency hedging strategies after incorporating these alternative assets, thereby assessing their effectiveness within the context of emerging market portfolios.

4.3. Data and research design

This study examines hedge performance by assuming a scenario in which investors from Australia, Brazil, Canada, the Eurozone, Indonesia, Japan, South Korea, the UK, the US, and South Africa hold a predetermined equity portfolio and asks what currency overlay position is optimal to minimise investment risk. While the existing literature extensively covers currency risk management in various economies, studies concerning major developing economies are notably scarce. Our research addresses this gap by including Brazil, South Africa, and Indonesia – three significant economies in South America, Africa, and Asia. We hope that this inclusion will stimulate their greater participation in the international market.

The market index of each country can be found in Morgan Stanley Capital International. The country index is denominated in its local currency and contains large and mid-cap stocks. Exchange and interest rates are sourced from the IMF's International Financial Statistics database. We use the interest rates to calculate forward contract rates. This study uses the official cash rate (OCR) for three reasons. Firstly, LIBOR (London InterBank Offered Rate) have stopped publishing new data. Secondly, the Reserve Bank of New Zealand suggest using OCR as the fall-back benchmark interest rate (Reserve Bank of New Zealand, 2020). Thirdly, the position of LIBOR is shaken after the systematic manipulation of LIBOR rates in 2012 (Kendall, 2017). This study presents exchange rates as the base currency per unit of foreign currency. Gold and bitcoin data are sourced from Datastream, and the data on continuous futures contracts and spot prices are used to calculate the normalised payoff. All data series are available monthly, and we present results for investments with a one-month horizon.

4.3.1. Construction of the diversified and home-biased portfolios

There are two purposes for conducting this research. The initial goal is to test how the optimal currency hedging strategy shifts for diversified and home-biased investors. Paternoster et al. (1998) discussed several tests that statistically compare the parameters estimated with the same set of factors on different groups of dependent variables. These tests enable investors to assess whether the estimated optimal currency exposures differ for diversified and home-biased investors. We calculate the z statistics using the method outlined by Clogg et al. (1995). The null hypothesis is that optimal currency exposure is equal for diversified and home-biased investors. We then adopt the z test to statistically compare the optimal currency demand for diversified and home-biased investors.

Following Campbell et al. (2010), the predetermined equity portfolios have fixed weights. The fully diversified foreign investment is a value-weighted international portfolio, with 50% assigned to the US market, 25% to the EU market, 15% to the Japanese market, and 5% each to both the UK and Canadian markets. Sercu and Vanpee (2012) utilised International Monetary Fund (IMF) data and noted that the home-bias effect varies significantly across countries. They found that investors from certain regions tend to allocate their total investments in their respective domestic markets as follows: 77.04% in Australia, 98.90% in Brazil, 68.40% in Canada, 58.46% in the Eurozone,[25] 99.72% in Indonesia, 87.37% in Japan, 88.22% in South Korea, 53.35% in the UK, 78.61% in the US and 87.98% in South Africa. We structure our home-biased foreign investment based on the findings of Sercu and Vanpee (2012) and assume

[25] The average of France and Germany.

that investors allocate most of their capital to the domestic market and the remainder to fully diversified international portfolios.

Regarding investors from Australia, Brazil, Indonesia, South Korea, and South Africa, we assume that they allocate most of their funds to the domestic market and the remainder to a value-weighted, fully diversified international portfolio. For example, Australian investors allocate 77.04% of their capital to the Australian equity market. The left funds are distributed across the US, EU, Japanese, UK, and Canadian markets, with a 50:25:15:5:5 ratio.

In contrast, for investors from Canada, the Eurozone, Japan, the UK and the US, their domestic markets are the components that make up the fully diversified portfolio. We assume they allocate the remaining funds to other constituent markets to form the fully diversified portfolio. For example, home-biased Canadian investors allocate 68% of their assets to domestic markets. The remaining assets, constituting 32% of the total funds, should be purchased in the EU, UK, Japanese, and US markets, with a ratio of 25:5:15:50, as the Canadian market is excluded from the diversified portfolio. Thus, 25/95 of the remaining funds should be spent in the EU market, representing 8.42% of the total investment. Following the calculation, investors should allocate 5/95 of the remaining funds to the UK market, 15/95 to the Japanese market, and 50/95 to the US market, which are 1.68%, 5.05%, and 16.84% of the total funds.

Table 4.1 presents the allocation of market weights for international investors. While all investors primarily allocate most of their wealth to their home countries, investors from developed markets tend to invest more in foreign markets than investors from emerging markets. Among all countries, Eurozone countries exhibit the least home-bias effect.

Table 4.1
The home-biased portfolio

This table reports the weight of each county's equity index in the home-biased portfolio. Investors' countries are displayed on the left of each row and the constituted markets are reported at the top of each column. The methodology is discussed in Section 4.3.1. Domestic denotes the weight of domestic assets held by investors from Australia, Brazil, South Korea, Indonesia, and South Africa. The reported weights are in percentage points.

	Weight					
Country	Domestic	Canada	EU	UK	Japan	US
Canada	-	68.00	8.42	1.68	5.05	16.84
EU	-	2.80	58.00	2.80	8.40	28.00
UK	-	2.47	12.37	53.00	7.42	24.74
Japan	-	0.76	3.82	0.76	87.00	7.65
US	-	2.10	10.50	2.10	6.30	79.00
Australia	77.04	1.15	5.74	1.15	3.44	11.48
Brazil	98.90	0.06	0.28	0.06	0.17	0.55
South Korea	88.22	0.59	2.95	0.59	1.77	5.89
Indonesia	99.72	0.01	0.07	0.01	0.04	0.14
South Africa	87.98	0.60	3.01	0.60	1.80	6.01

4.3.2. The effectiveness of gold and bitcoin

The second goal is to investigate how gold and bitcoin impact the effectiveness of currency risk management. To statistically measure the effect of adding gold or bitcoin futures contracts, we adopt the method introduced by Clogg et al. (1995). Following their method, we can statistically measure the change in the parameters of existing variables after introducing additional factors, such as gold and bitcoin futures contracts. We calculate the *t* statistics and statistically examine whether the null hypothesis of equal optimal currency exposure before and after adding gold or bitcoin futures contracts holds. This study also presents the risk and returns of optimally hedged investments. The model, which includes gold and bitcoin, is compared with the base model, which only considers conventional currencies. We examine whether gold and bitcoin mitigate additional risk or enhance investment returns for international investors.

4.4. Methodology and equations

4.4.1. Estimation of optimal hedge ratios and currency positions

The optimal hedge is based on estimating risk-minimising currency demands for a stock portfolio in the international market. We develop our equations based on those of Schmittmann (2010). The unhedged return from time t to $t+1$ for international investors who spot their local currency for a foreign currency and invest in the foreign market *i* is as follows:

$$r_{i,U,t+1} = \left(1 + e_{i,t+1}\right)\left(1 + r_{i,t+1}\right) - 1 \tag{4.1}$$

In Equation (4.1), $r_{i,t+1}$ represents the return on market i in foreign currency *i,* and $e_{i,t+1}$ represents the exchange gain/loss in the base currency per unit of foreign currency over the same period.

For an international investment, its return $r_{i,U,t+1}$ is subject to the return on the investment itself $r_{i,t+1}$ and the gain/loss on the exchange rate $e_{i,t+1}$. If investors worry about exchange rate volatility, they could take a hedged position (shorting a foreign currency and going long on their home currency) with FX forward or futures contracts. We define $S_{i,t}$ as the spot domestic price of foreign currency at time *t* and $F_{i,t}$ as the one-month forward contract rate calculated with interest rate. Based on the model by Glen and Jorion (1993), the normalised payoff on the long forward contract is equal to:

$$R_{i,f,t+1} = (S_{i,t+1} - F_{i,t})/S_{i,t} \tag{4.2}$$

The normalised payoff on the long gold or bitcoin futures contracts is calculated by setting $S_{i,t+1} = F_{i,t+1}$, as we adopt continuous futures contracts. As $f_{i,t+1}$ denotes the forward premium/discount,[26] we can overlay Equation (4.2) to analyse optimal hedging demand for minimising investment risk:

$$r_{i,H,t+1} = r_{i,U,t+1} - \theta_{i,t}\left(e_{i,t+1} - f_{i,t+1}\right) \tag{4.3}$$

We are interested in the amount of foreign currency sold forward $\theta_{i,t}$ that minimises the variance of portfolio return:

$$\min_{\theta} Var(r_{i,H,t+1})$$

Following Schmittmann (2010), the optimal static hedge position can be developed by performing the OLS estimation:

$$r_{i,U,t+1} = \alpha_i + \beta_{i,t+1}\left[e_{i,t+1} - f_{i,t+1}\right] + \varepsilon_{i,t+1} \tag{4.4}$$

In Equation (4.4), the estimated $\beta_{i,t+1}$ is the optimal static hedge position.[27] For investors with investments involving multiple-country portfolios, the equation can be expanded as follows:

$$\begin{aligned}\sum_{i=1}^{N} w_{i,t+1} r_{i,U,t+1} = \alpha + \beta_{1,t+1}\left[e_{1,t+1} - f_{1,t+1}\right] + \beta_{2,t+1}\left[e_{2,t+1} - f_{2,t+1}\right] + \\ \ldots + \beta_{i,t+1}\left[e_{i,t+1} - f_{i,t+1}\right] + \varepsilon_{t+1}\end{aligned} \tag{4.5}$$

In this equation, $w_{i,t+1}$ is the weight of market i, and $\beta_{1,t+1}$ to $\beta_{i,t+1}$ are the hedging positions. The hedge ratio is the hedging positions $\beta_{i,t+1}$ divided by the corresponding weight $w_{i,t+1}$.

---

[26] Following Schmittmann (2010), $1 + f_{i,t+1} = \left(1 + I_{d,t}\right)/\left(1 + I_{f,t}\right)$, where $I_{d,t}$ and $I_{f,t}$ are the domestic and foreign interest rates.
[27] The position represents the amount of foreign currency that investors should short to minimise investment risk. If it is a negative number, it means investors should gain exposure to that foreign currency.

Conversely, if investors are primarily interested in the optimal currency positions that minimise investment risk, following Campbell et al. (2010), they can introduce the variable[28] $\varphi_{i,t} = w_{i,t} - \theta_{i,t}$ and estimate the optimal currency positions instead of the optimal hedge positions:

$$\sum_{i=1}^{N} w_{i,t+1}(r_{i,U,t+1} + f_{i,t+1} - e_{i,t+1}) = \alpha + \sum_{i=1}^{N} \varphi_{i,t+1}[f_{i,t+1} - e_{i,t+1}] + \varepsilon_{t+1} \quad (4.6)$$

4.5. Optimal currency exposure

Up to this point, we have formulated the equations for the optimal hedge and constructed the diversified and home-biased portfolios. Investors can employ the mean–variance framework to adjust their optimal foreign currency exposure to minimise investment risk. Initially, the similarities and differences between diversified and home-biased portfolios are examined.

4.5.1. Optimal hedge for diversified and home-biased investors

Recent literature has shown a preference for employing seven major currencies to hedge foreign exchange risk: the AUD, CAD, CHF, EUR, USD, GBP, and JPY (Campbell et al., 2010). Our research, however, opts for five of the seven currencies, omitting the CHF and AUD. This choice is based on Campbell et al. (2010), who demonstrate that the EUR and CHF, as well as the AUD and CAD, serve as substitutes for investors. Given that the optimal positions for the CAD and USD are interdependent (Campbell et al., 2010), we include the CAD instead of the AUD. Furthermore, the EUR is a far more critical currency in international trading, borrowing and lending; thus, the CHF is excluded.

4.5.1.1. Optimal hedge positions

Table 4.2 displays the results of the estimated optimal hedge positions utilising Equation (4.5) and shows that investors with diversified portfolios tend to pursue additional JPY and reduce

[28] This variable represents the overall exposure to the foreign currency. It is the investment-implied foreign currency exposure minus the amount short through the forward contract.

CAD and GBP exposures. The hedging demand for the EUR and USD is minor, and the null hypothesis of zero hedge demand cannot be rejected at the 5% significance level in all cases. This indicates that the implied exposure of the EUR and USD is optimal for investors and no additional hedging is required.

Table 4.2
Optimal hedge demands for diversified investors

This table reports the optimal hedge demands estimated using Equation (4.5) for diversified investors from 10 countries. It considers investors holding a predetermined diversified portfolio. The investment horizon is one month. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. Standard errors are displayed below the optimal hedge ratios. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. The full sample spans the years 2000–2021.

Diversified	Currency				
Country	CAD	EUR	GBP	JPY	USD
Canada	-	0.1300	0.2133*	−0.2051**	−0.0433
	-	(0.1031)	(0.1110)	(0.0824)	(0.1200)
EU	0.9101***	-	0.2094*	−0.2044**	−0.0516
	(0.0946)	-	(0.1110)	(0.0816)	(0.1190)
UK	0.9138***	0.1357	-	−0.2093**	−0.0479
	(0.0944)	(0.1011)	-	(0.0813)	(0.1187)
Japan	0.9161***	0.1240	0.2021*	-	−0.0587
	(0.0963)	(0.1041)	(0.1120)	-	(0.1196)
US	0.9135***	0.1273	0.2056*	−0.2063**	-
	(0.0950)	(0.1026)	(0.1102)	(0.0825)	-
Australia	0.6080***	−0.0732	0.1164	−0.2421***	0.0980
	(0.1069)	(0.1060)	(0.1070)	(0.0778)	(0.1166)
Brazil	0.7379***	0.0749	0.2134**	−0.1883**	−0.0941
	(0.0975)	(0.0974)	(0.1055)	(0.0782)	(0.1136)
South Korea	0.7506***	0.0031	0.1800*	−0.2675***	−0.1231
	(0.0943)	(0.1004)	(0.1059)	(0.0780)	(0.1131)
Indonesia	0.7908***	0.0770	0.2219**	−0.2396***	−0.1603
	(0.0947)	(0.0997)	(0.1060)	(0.0786)	(0.1150)
South Africa	0.7746***	0.0687	0.1897*	−0.2270***	0.0028
	(0.0993)	(0.1013)	(0.1082)	(0.0791)	(0.1157)

Table 4.3 is also based on Equation (4.5) and presents the estimated optimal hedge ratios for home-biased investors. Home-biased investors have different investment-implied currency exposures than diversified investors, so the optimal hedge demands differ. The results indicate that going short on the CAD and long on the USD or JPY are effective strategies to reduce investment risk, except for Japanese investors. The demand for the USD is more prominent and

statistically significant at the 1% level for home-biased investors from Canada, Brazil, South Korea, Indonesia, and South Africa.

Table 4.3
Optimal hedge demands for home-biased investors

This table reports the optimal hedge demands estimated using Equation (4.5) for home-biased investors from 10 countries. It considers investors holding a predetermined home-biased portfolio. The investment horizon is one month. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. Standard errors are displayed below the optimal hedge ratios. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. The full sample spans the years 2000–2021.

Home-biased	Currency				
Country	CAD	EUR	GBP	JPY	USD
Canada	-	−0.0166	0.1860*	−0.1877**	−0.4764***
	-	(0.1010)	(0.1087)	(0.0808)	(0.1175)
EU	0.8782***	-	0.2282**	−0.2777***	−0.1590
	(0.0985)	-	(0.1155)	(0.0849)	(0.1238)
UK	0.8792***	0.1472	-	−0.2426***	−0.1834
	(0.0927)	(0.0992)	-	(0.0798)	(0.1165)
Japan	0.7411***	−0.0778	0.2640**	-	−0.0380
	(0.1125)	(0.1216)	(0.1308)	-	(0.1396)
US	0.9197***	0.0513	0.1607	−0.2151**	-
	(0.0991)	(0.1071)	(0.1150)	(0.0861)	-
Australia	0.3895***	−0.1564	0.0196	−0.3036***	−0.1476
	(0.1067)	(0.1058)	(0.1069)	(0.0777)	(0.1164)
Brazil	0.9820***	0.1708	0.0347	−0.0964	−1.5496***
	(0.1520)	(0.1517)	(0.1645)	(0.1218)	(0.1770)
South Korea	0.8635***	−0.1244	−0.0694	−0.2208*	−0.8554***
	(0.1593)	(0.1697)	(0.1789)	(0.1318)	(0.1911)
Indonesia	0.4328**	0.2162	0.0523	−0.1153	−1.5656***
	(0.1672)	(0.1760)	(0.1872)	(0.1387)	(0.2030)
South Africa	0.7430***	0.2038	−0.0180	−0.0965	−0.6835***
	(0.1282)	(0.1308)	(0.1397)	(0.1021)	(0.1495)

4.5.1.2. Optimal currency positions

Although the optimal hedge demands differ for investors with diversified and home-biased investments, they serve the same purpose: to adjust foreign currency exposure and achieve the optimal position that minimises investment risk. More importantly, as different investors have different starting points, such as those with diversified/home-biased investments facing more/less foreign currency exposure, the final optimal currency positions better reflect investors' currency hedging demands. Thus, we adopt the optimal currency exposure, as expressed in Equation (4.6), to compare optimal currency positions for diversified and home-biased investments.

Tables 4.4 and 4.5 display the optimal currency exposure estimated with Equation (4.6) for investors with diversified and home-biased portfolios. Investors' domestic markets are listed on the left side of each row and optimal currency exposures are presented at the top of each column. For investors from Canada, the EU, Japan, the UK, and the US, their domestic currency is one of the hedging currencies. Consequently, their exposure is limited to the five hedging currencies. Investors from other countries are also exposed to their own domestic currencies. As a result, the term 'domestic' denotes the optimal domestic currency exposure for investors from Australia, South Korea, Brazil, Indonesia, and South Africa.

To illustrate, let us examine a specific example. For Canadian investors with a one-month holding period, the values indicate that the risk-minimising Canadian investor who invests one CAD in the international portfolio should seek 12.00 cents to the EUR, 54.33 cents to the USD, and 35.51 cents of exposure to the JPY. Canadian investors finance the exposure with 85.51 cents from CAD and 16.33 cents from GBP. Considering the portfolio weights, they are related to the hedging positions displayed in Table 4.2. The values indicate that a risk-minimising Canadian investor who invests one CAD in the international market should hold long forward contracts to buy CAD, JPY, and USD worth 14.49, 20.51, and 4.33 CAD cents, respectively. Conversely, investors should short 13.00 CAD cents to the EU and 21.33 CAD cents to the UK.

Table 4.4
Optimal currency exposure for diversified investors

This table reports the optimal currency exposures estimated using Equation (4.6) for investors from 10 countries. It considers investors holding a predetermined diversified portfolio. The investment horizon is one month. Standard errors are displayed below the optimal currency exposures. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The full sample spans the years 2000–2021.

Diversified	Currency					
Country	Domestic	CAD	EUR	GBP	JPY	USD
Canada	-	−0.8551	0.1200	−0.1633	0.3551***	0.5433***
	-	-	(0.1031)	(0.1110)	(0.0824)	(0.1200)
EU	-	−0.8601***	0.1134	−0.1594	0.3544***	0.5516***
	-	(0.0946)	-	(0.1110)	(0.0816)	(0.1190)
UK	-	−0.8638***	0.1143	−0.1576	0.3593***	0.5479***
	-	(0.0944)	(0.1011)	-	(0.0813)	(0.1187)
Japan	-	−0.8661***	0.1260	−0.1521	0.3335	0.5587***
	-	(0.0963)	(0.1041)	(0.1120)	-	(0.1196)
US	-	−0.8635***	0.1227	−0.1556	0.3563***	0.5401
	-	(0.0950)	(0.1026)	(0.1102)	(0.0825)	-
Australia	−0.4929	−0.5580***	0.3232***	−0.0664	0.3921***	0.4020***
	-	(0.1069)	(0.1060)	(0.1070)	(0.0778)	(0.1166)
Brazil	−0.2562	−0.6879***	0.1751*	−0.1634	0.3383***	0.5941***
	-	(0.0975)	(0.0974)	(0.1055)	(0.0782)	(0.1136)
South Korea	−0.4569	−0.7006***	0.2469**	−0.1300	0.4175***	0.6231***
	-	(0.0943)	(0.1004)	(0.1059)	(0.0780)	(0.1131)
Indonesia	−0.3102	−0.7408***	0.1730*	−0.1719	0.3896***	0.6603***
	-	(0.0947)	(0.0997)	(0.1060)	(0.0786)	(0.1150)
South Africa	−0.1912	−0.7246***	0.1813*	−0.1397	0.3770***	0.4972***
	-	(0.0993)	(0.1013)	(0.1082)	(0.0791)	(0.1157)

The results of diversified portfolios in Table 4.4 illustrate that risk-minimising investors from the selected countries consistently seek positive exposure to the JPY and USD, suggesting that these currencies tend to appreciate when the global stock market experiences a decline. This behaviour is independent of the investor's home currency. Moreover, maintaining a sizeable negative position to the CAD is preferable for all investors to counter foreign investment risk, indicating that the CAD is a popular counterparty in reducing investment risk. Though maintaining positive exposure to the EUR is optimal, the demand is lower than the 25% position held implicitly for all except Australian investors. Furthermore, a negative position to the GBP is preferred by all investors; however, statistically, the demand is not significant for all investors.

The optimal currency position also indicates that the risk-minimising investors should at least reverse half of their foreign currency exposure back to their domestic currency, except for Canadian investors. Among these investors, Japanese and US investors require the highest domestic currency for risk reduction, which is 33.35 cents and 54.01 cents, respectively. Canadian investors benefit most from holding a globally diversified portfolio. They have the lowest demand for exchanging foreign currencies for their domestic currency among all the tested investors.

Table 4.5
Optimal currency exposure for home-biased investors

This table reports the optimal currency exposure estimated using Equation (4.6) for investors from 10 countries. It considers investors holding a predetermined home-biased portfolio. The investment horizon is one month. Standard errors are displayed below the optimal currency exposures. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The full sample spans the years 2000–2021.

Home-biased	Currency					
Country	Domestic	CAD	EUR	GBP	JPY	USD
Canada	-	−0.8146	0.1008	−0.1692	0.2382***	0.6448***
	-	-	(0.1010)	(0.1088)	(0.0808)	(0.1175)
EU	-	−0.8502***	0.2496	−0.2002*	0.3617***	0.4390***
	-	(0.0985)	-	(0.1155)	(0.0849)	(0.1238)
UK	-	−0.8544***	−0.0235	0.1303	0.3168***	0.4308***
	-	(0.0927)	(0.0992)	-	(0.0798)	(0.1165)
Japan	-	−0.7335***	0.1160	−0.2564*	0.7593	0.1145
	-	(0.1125)	(0.1216)	(0.1308)	-	(0.1397)
US	-	−0.8987***	0.0537	−0.1397	0.2781***	0.7066
	-	(0.0991)	(0.1071)	(0.1150)	(0.0861)	-
Australia	−0.4281	−0.3780***	0.2138**	−0.0079	0.3381***	0.2624**
	-	(0.1067)	(0.1058)	(0.1069)	(0.0777)	(0.1164)
Brazil	−0.4695	−0.9814***	−0.1680	−0.0342	0.0981	1.5551***
	-	(0.1520)	(0.1517)	(0.1645)	(0.1218)	(0.1770)
South Korea	−0.5243	−0.8576***	0.1539	0.0753	0.2385*	0.9143***
	-	(0.1593)	(0.1697)	(0.1788)	(0.1318)	(0.1910)
Indonesia	−0.9824	−0.4326**	−0.2155	−0.0521	0.1157	1.5670***
	-	(0.1672)	(0.1760)	(0.1872)	(0.1387)	(0.2030)
South Africa	0.0285	−0.7370***	−0.1738	0.0241	0.1146	0.7436***
	-	(0.1282)	(0.1308)	(0.1397)	(0.1021)	(0.1495)

Alternatively, home-biased risk-minimising investors also require positive exposure to the JPY and USD and negative exposure to the CAD. Nevertheless, demands for the JPY are not statistically significant for investors from Brazil, Indonesia, and South Africa. Regarding the

USD, demand is statistically significant for most investors but not for Japanese investors. Australian investors are the only ones who show statistically significant demand for the EUR. Although demand for the GBP is not statistically significant for all diversified investors, it is significant for home-biased EU and Japanese investors at the 10% significance level.

To compare the optimal currency demand for diversified and home-biased investors, we employ the z test, following Clogg et al. (1995), with a null hypothesis of equal optimal currency positions for diversified and home-biased portfolios:

$$Z = \frac{b_1 - b_2}{\sqrt{SEb_1^2 - SEb_2^2}} \tag{4.7}$$

In Equation (4.7), b_1 and b_2 are the estimated optimal currency exposures of diversified and home-biased investors and SEb_1^2 and SEb_2^2 are the coefficient variances associated with the optimal currency exposures. For Canadian, EU, UK, US, Australian, and South Korean investors, the null hypothesis of equal demand for estimated diversified and home-biased optimal foreign currency positions cannot be rejected at the 5% significance level for each exposed foreign currency (see Table 4.6). Thus, for the above investors, although the investments changed, the optimal currency positions are comparable for the diversified and home-biased portfolios, which aligns with Campbell et al. (2010).

For the other investors, the results typically record the rejection of the null hypothesis at the 5% significance level for one or two currencies. For example, the demand for the USD is significantly different when Japanese investors adopt different investment styles. While it is large and significant for diversified Japanese investors, it decreases to one-fifth of the demand if investors adopt the home-biased portfolio. For investors from Brazil and Indonesia, the differences are significant at the 5% level for optimal exposure to the USD. For South African investors, the optimal exposure to the JPY and EUR changes significantly at the 5% significance level.

Table 4.6
***Z* test for diversified and home-biased investors**

This table reports the results of the *z* test calculated using Equation (4.7) for diversified and home-biased investors from 10 countries. We report the *z* score. The *p* values are displayed under the *z* score. The null hypothesis is that the optimal currency position is equal for diversified and home-biased portfolios. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The full sample spans the years 2000–2021.

Country	CAD	EUR	GBP	JPY	USD
Canada	-	0.1316	0.0386	1.0121	−0.6041
	-	0.8953	0.9692	0.3115	0.5458
EU	−0.0724	-	0.2547	−0.0630	0.6554
	0.9423	-	0.7989	0.9497	0.5122
UK	−0.0713	0.9758	-	0.3725	0.7047
	0.9432	0.3291	-	0.7095	0.4810
Japan	−0.8953	0.0623	0.6053	-	2.4165
	0.3706	0.9503	0.5450	-	0.0157
US	0.2567	0.4650	−0.1000	0.6566	-
	0.7974	0.6419	0.9203	0.5114	-
Australia	−1.1914	0.7312	−0.3868	0.4921	0.8474
	0.2335	0.4646	0.6989	0.6226	0.3968
Brazil	1.6260	1.9031	−0.6610	1.6597	−4.5686
	0.1040	0.0570	0.5086	0.0970	0.0000
South Korea	0.8482	0.4720	−0.9880	1.1690	−1.3113
	0.3963	0.6369	0.3231	0.2424	0.1898
Indonesia	−1.6032	1.9207	−0.5570	1.7184	−3.8856
	0.1089	0.0548	0.5776	0.0857	0.0001
South Africa	0.0757	2.1468	−0.9262	2.0323	−1.3033
	0.9397	0.0318	0.3544	0.0421	0.1925

For investors from Canada, the EU, the UK, Japan, the US, South Africa, and Australia, the optimal domestic currency demand is higher in the home-biased portfolio than in the diversified portfolio. This variation reflects the shift in the weights of investors' domestic assets; however, it is not proportional to changes in the weights of the constituent assets. Conversely, for investors from Brazil, South Korea, and Indonesia, the need to short the domestic currency increases, highlighting the utility of holding foreign currency to mitigate investment risk and calling into question the usefulness of home-biased portfolio construction.

In conclusion, home-biased portfolios tend to require more hedging operations than diversified portfolios to minimise investment risk. However, optimal currency positions are similar in many cases, especially for investors from Canada, the EU, the UK, the US, South Korea, and Australia. Overall, investors from emerging economies face more substantial differences in optimal currency exposure for diversified and home-biased investments than those from developed economies.

Investors holding diversified or home-biased portfolios demand significant exposure to the USD to minimise investment risk. For diversified investors, the demand is 0.5518 on average, and for home-biased investors, the demand is 0.7378 on average. Although large exposure to the USD is optimal for minimising risk, it is not optimal for investors to solely depend on it. For instance, optimal hedging could fail if the market decline is related to the US market and the strength of the USD. In addition, if the optimal strategy heavily relies on USD, the hedging could also fail when USD demand increases and it becomes unavailable for investors. Thus, this study proposes adopting gold and bitcoin to improve the diversification of hedging currencies.

4.5.2. Improving the conventional model with gold

Following the above findings, this section discusses optimal currency hedging for investors, considering the base model with conventional currencies in addition to futures contracts for gold and bitcoin. First, we present the optimal demand for gold and bitcoin. We then examine whether gold and bitcoin improve currency diversification by reducing the demand for the USD.

We adopt the optimal currency exposure, as shown in Section 4.5.1.2, to compare the influence of adding gold futures contracts to international portfolios. Table 4.7 displays the results for diversified investors, where the countries of the investors are listed on the left side of each row and the relevant currencies are presented at the top of each column. The 'gold' column indicates the optimal exposure to gold futures contracts.

Adding gold futures contracts to the base model does not significantly impact the optimal currency exposure for diversified investments. Although the difference is minimal, some changes are still worth mentioning. First, all investors demand moderate positive exposures to the gold futures contract, which are all statistically significant at the 1% level. Second, after adding gold, the short position on CAD and EUR increases and the need for JPY is reduced. Lastly, incorporating gold futures contracts into the hedging strategy leads to a higher optimal demand for USD.

Table 4.7
Optimal currency positions including gold for diversified investors

This table reports the optimal currency exposure, estimated using Equation (4.6), including gold, for investors from 10 countries. It considers investors holding a predetermined diversified portfolio. The investment horizon is one month. Standard errors are displayed below the optimal currency exposures. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The term 'gold' indicates the optimal exposure to futures contracts of gold. The full sample spans the years 2000–2021.

	Currency						
Country	Domestic	CAD	EUR	GBP	JPY	USD	Gold
Canada	-	−0.9130	0.0602	−0.1522	0.2818***	0.5814***	0.1418***
	-	-	(0.1039)	(0.1096)	(0.0854)	(0.1191)	(0.0502)
EU	-	−0.9211***	0.0521	−0.1472	0.2766***	0.5928***	0.1467***
	-	(0.0955)	-	(0.1095)	(0.0846)	(0.1181)	(0.0498)
UK	-	−0.9259***	0.0519	−0.1440	0.2820***	0.5895***	0.1465***
	-	(0.0954)	(0.1018)	-	(0.0844)	(0.1178)	(0.0498)
Japan	-	−0.9251***	0.0627	−0.1380	0.2556	0.5957***	0.1490***
	-	(0.0971)	(0.1049)	(0.1105)	-	(0.1185)	(0.0508)
US	-	−0.9232***	0.0619	−0.1416	0.2794***	0.5782	0.1452***
	-	(0.0959)	(0.1033)	(0.1087)	(0.0855)	-	(0.0501)
Australia	−0.5185	−0.6146***	0.2649**	−0.0485	0.3068***	0.4430***	0.1670***
	-	(0.1058)	(0.1049)	(0.1048)	(0.0798)	(0.1146)	(0.0471)
Brazil	−0.2648	−0.7521***	0.1039	−0.1453	0.2532***	0.6394***	0.1656***
	-	(0.0972)	(0.0974)	(0.1034)	(0.0803)	(0.1119)	(0.0472)
South Korea	−0.4432	−0.7648***	0.1833*	−0.1174	0.3421***	0.6588***	0.1413***
	-	(0.0953)	(0.1012)	(0.1043)	(0.0809)	(0.1120)	(0.0473)
Indonesia	−0.3156	−0.8038***	0.1051	−0.1575	0.3110***	0.7045***	0.1563***
	-	(0.0949)	(0.1000)	(0.1041)	(0.0807)	(0.1136)	(0.0472)
South Africa	−0.1980	−0.7929***	0.1138	−0.1263	0.2927***	0.5465***	0.1642***
	-	(0.0993)	(0.1012)	(0.1061)	(0.0813)	(0.1143)	(0.0481)

This study incorporates gold to enhance the diversification of optimal currency positions, aiming to reduce the demand for the USD. However, the results contradict this expectation, as the optimal demand for USD slightly increases—though the magnitude of the change is minor in quantitative terms. Following Clogg et al. (1995), we calculate the *t* statistics to statistically examine whether the addition of gold futures contracts affects the estimated optimal currency positions:

$$t = \frac{b_{yx} - b_{yx.z}}{\left[s^2\left(b_{yx.z}\right) - s^2\left(b_{yx}\right)\sigma_v^2/\sigma_\epsilon^2\right]^{1/2}} \tag{4.8}$$

In Equation (4.8), b_{yx} is the estimated optimal currency position with conventional currencies, $b_{yx.z}$ is the corresponding parameter after adding the gold or bitcoin futures contract, $s^2\left(b_{yx.z}\right)$ and $s^2\left(b_{yx}\right)$ are the squared standard errors, and σ_v^2 and σ_ϵ^2 are the error variances after and before adding new safe-haven assets. We calculate the *t* statistics for each currency position for all investors included in this study to test whether the position changes after the inclusion of an additional safe-haven asset.

The null hypothesis is that the demand for foreign currency positions remains unchanged before and after the addition of gold futures contracts. Although our focus is on exposure to the USD, we provide results for all currencies in Table 4.8. The results show that including gold significantly affects the demand for USD exposure at the 1% significance level for all investors. Although the difference is minor in quantity, it affects the demand for the USD in all cases.

Table 4.8
***T* test for optimal currency positions change after including gold for diversified investors**

This table reports the *t* statistics calculated using Equation (4.8) for the change in optimal currency exposure for diversified investors after including the gold futures contracts. It considers investors holding a given diversified portfolio with predetermined weights. The *p* values are displayed below the *t* statistics. The investment horizon is one month. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The full sample spans the years 2000–2021.

	Currency				
Country	CAD	EUR	GBP	JPY	USD
Canada	-	0.5758	0.1017	0.8586	2.8271
	-	(0.5653)	(0.9191)	(0.3914)	(0.0051)
EU	0.6388	-	0.1118	0.9194	2.9470
	(0.5235)	-	(0.9110)	(0.3588)	(0.0035)
UK	0.6509	0.6122	-	0.9170	2.9443
	(0.5157)	(0.5409)	-	(0.3600)	(0.0035)
Japan	0.6079	0.6031	0.1276	-	2.9321
	(0.5438)	(0.5470)	(0.8985)	-	(0.0037)
US	0.6224	0.5886	0.1293	2.9006	-
	(0.5342)	(0.5566)	(0.8972)	(0.0040)	-
Australia	0.5348	0.5557	0.1705	1.0694	3.5474
	(0.5933)	(0.5789)	(0.8648)	(0.2859)	(0.0005)
Brazil	0.6610	0.7301	0.1749	1.0600	3.5096
	(0.5092)	(0.4660)	(0.8613)	(0.2901)	(0.0005)
South Korea	0.6738	0.6292	0.1205	0.9327	2.9856
	(0.5011)	(0.5298)	(0.9042)	(0.3519)	(0.0031)
Indonesia	0.6640	0.6795	0.1382	0.9750	3.3111
	(0.5073)	(0.4974)	(0.8902)	(0.3305)	(0.0011)
South Africa	0.6875	0.6666	0.1259	1.0367	3.4160
	(0.4924)	(0.5056)	(0.8999)	(0.3009)	(0.0007)

For investors with home-biased portfolios, the optimal demand for gold futures contracts varies for investors from different countries. Table 4.9 shows that for EU, UK, and US investors, the demand for gold futures contracts is statistically significant at the 1% significance level. For Japanese and Australian investors, the demand for gold futures contracts is statistically significant at the 5% significance level. For Canadian, Brazilian, South Korean, Indonesian, and South African investors, the demand for going long or shorting gold futures contracts is statistically insignificant.

Table 4.9
Optimal currency positions including gold for home-biased investors

This table reports the optimal currency exposure estimated using Equation (4.6) for investors from 10 countries. It considers investors holding a given home-biased portfolio with predetermined weights. The investment horizon is one month. Standard errors are displayed below the optimal currency exposures. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The term 'gold' indicates the optimal exposure to futures contracts of gold. The full sample spans the years 2000–2021.

Home-biased	Currency						
Country	Domestic	CAD	EUR	GBP	JPY	USD	Gold
Canada	-	−0.8279	0.0875	−0.1668	0.2217***	0.6534***	0.0321
	-	-	(0.1033)	(0.1089)	(0.0849)	(0.1184)	(0.0499)
EU	-	−0.9099***	0.1895	−0.1883	0.2857***	0.4794***	0.1435***
	-	(0.0996)	-	(0.1141)	(0.0882)	(0.1231)	(0.0519)
UK	-	−0.9133***	−0.0831	0.1437	0.2435***	0.4702***	0.1390***
	-	(0.0938)	(0.1001)	-	(0.0829)	(0.1158)	(0.0489)
Japan	-	−0.7898***	0.0555	−0.2429*	0.6849	0.1498	0.1424**
	-	(0.1140)	(0.1232)	(0.1298)	-	(0.1392)	(0.0597)
US	-	−0.9642***	−0.0129	−0.1243	0.1937**	0.7485	0.1592***
	-	(0.0999)	(0.1076)	(0.1133)	(0.0891)	-	(0.0522)
Australia	−0.4444	−0.4139***	0.1768*	0.0034	0.2840***	0.2883**	0.1056**
	-	(0.1072)	(0.1063)	(0.1062)	(0.0809)	(0.1161)	(0.0477)
Brazil	−0.4660	−0.9553***	−0.1390	−0.0416	0.1327	1.5367***	−0.0675
	-	(0.1548)	(0.1552)	(0.1647)	(0.1278)	(0.1783)	(0.0752)
South Korea	−0.5179	−0.8875***	0.1242	0.0812	0.2034	0.9308***	0.0658
	-	(0.1637)	(0.1737)	(0.1791)	(0.1388)	(0.1923)	(0.0812)
Indonesia	−0.9798	−0.4023**	−0.1829	−0.0590	0.1535	1.5457***	−0.0752
	-	(0.1708)	(0.1799)	(0.1874)	(0.1452)	(0.2045)	(0.0850)
South Africa	0.0312	−0.7094***	−0.1466	0.0186	0.1486	0.7238***	−0.0662
	-	(0.1308)	(0.1333)	(0.1398)	(0.1071)	(0.1506)	(0.0633)

Similar to the approach for diversified portfolios above, we calculate the *t* statistics to statistically examine whether the addition of gold futures contracts affects the estimated optimal currency positions. The null hypothesis is that there is no difference in the demand for foreign currency positions before and after the addition of gold futures contracts. The results in Table 4.10 show that for those who statistically demand exposure to gold futures, the change in currency exposure is statistically significant at the 5% level for USD exposures, although the difference is minor in quantity and increases USD demand.

Table 4.10
***T* test for optimal currency positions change after including gold for home-biased investors**

This table reports the *t* test calculated using Equation (4.8) for the change in optimal currency exposure for home-biased investors after including the gold futures contracts. It considers investors holding a given portfolio with predetermined weights. The *p* values are displayed below the *t* statistics. The investment horizon is one month. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The full sample spans the years 2000–2021.

	Currency				
Country	CAD	EUR	GBP	JPY	USD
Canada	-	0.1313	0.0232	0.1958	0.6449
	-	(0.8956)	(0.9815)	(0.8449)	(0.5196)
EU	0.5992	-	0.1049	0.8624	2.7645
	(0.5496)	-	(0.9165)	(0.3893)	(0.0061)
UK	0.6282	0.5909	-	0.8850	2.8416
	(0.5304)	(0.5551)	-	(0.3770)	(0.0048)
Japan	0.4946	0.4907	0.1039	-	2.3858
	(0.6213)	(0.6240v	(0.9174)	-	(0.0178)
US	0.6550	0.6194	0.1361	3.0526	-
	(0.5130)	(0.5362)	(0.8918)	(0.0025)	-
Australia	0.3339	0.3470	0.1064	0.6677	2.2146
	(0.7387)	(0.7289)	(0.9153)	(0.5050)	(0.0277)
Brazil	0.1691	0.1867	0.0447	0.2712	0.8977
	(0.8659)	(0.8520)	(0.9644)	(0.7865)	(0.3702)
South Korea	0.1827	0.1707	0.0327	0.2530	0.8098
	(0.8551)	(0.8646)	(0.9740)	(0.8005)	(0.4188)
Indonesia	0.1775	0.1816	0.0369	0.2606	0.8848
	(0.8593)	(0.8561)	(0.9706)	(0.7946)	(0.3771)
South Africa	0.2105	0.2041	0.0385	0.3174	1.0458
	(0.8335)	(0.8384)	(0.9693)	(0.7512)	(0.2966)

These findings imply that in most cases, gold acts similarly to the role of safe-haven assets and tends to move in the opposite direction of the global equity market. When diversified investors switch to home-biased portfolios, the demand for gold becomes irrelevant for investors from Canada, South Korea, Brazil, Indonesia, and South Africa. This effect suggests that gold is a less universal hedge than the JPY and USD. This raises the question of whether its usefulness is only linked to some uncovered factors shared by EU, UK, US, Japanese, and Australian investors.

4.5.3. Improving the conventional model with bitcoin

Bitcoin is a recent concept in finance. Its futures contract was introduced in December 2017. Thus, the analysis involving bitcoin runs from 2018 to 2021. For comparison, we provide the estimation results and optimal currency exposures for the base model using conventional currencies during the same period. It allows us to briefly examine the base model's subsample results and the optimal currency exposure before and after the introduction of bitcoin futures contracts. Our analysis starts with the optimal currency exposures for the base model in the subsample.

Table 4.11 displays the base model results estimated using Equation (4.6), considering only conventional currencies. Table 4.12 presents the results for the model that includes bitcoin futures contracts following the same equation. The base model results in Table 4.11 show that when investors adopt diversified international portfolios, the most noticeable change in the subsample is the demand for shorting the CAD and going long on the USD. In the full sample, the usefulness of the JPY and EUR is observed; however, in the subsample, we barely see a statistically significant demand for currencies other than the CAD and USD.

Although the literature shows that bitcoin is negatively correlated with the global equity market, the relationship is not relevant for minimising the risk of diversified international portfolios. First, the demand for bitcoin is minor and statistically insignificant for all investors, even at the 10% significance level. Second, including bitcoin does not statistically affect the optimal exposure of any currencies calculated using Equation (4.8), as presented in Table 4.13.

The usefulness of the bitcoin futures contract is similar for home-biased investors. Nevertheless, for home-biased Australian and South African investors, the demand for bitcoin futures contracts is statistically significant at the 10% level, although the quantity is minor. In addition, for Australian and South African investors, adding bitcoin also affects the optimal USD position at the same significance level, as shown in Table 4.13.

Table 4.11
Subsample optimal currency exposure

This table reports the optimal currency exposure estimated using Equation (4.6) for investors from 10 countries. It considers investors holding a given portfolio with predetermined weights. The investment horizon is one month. Standard errors are displayed below the optimal currency exposures. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The full sample spans the years 2018–2021.

Country	Domestic	CAD	EUR	GBP	JPY	USD
Diversified						
Canada	-	−1.8083	0.3693	−0.2056	0.3608	1.2838***
	-	-	(0.3758)	(0.2995)	(0.3459)	(0.3665)
EU	-	−1.8112***	0.3684	−0.2023	0.3479	1.2972***
	-	(0.3284)	-	(0.3017)	(0.3447)	(0.3669)
UK	-	−1.8110***	0.3612	−0.2039	0.3650	1.2886***
	-	(0.3271)	(0.3759)	-	(0.3463)	(0.3676)
Japan	-	−1.8128***	0.3344	−0.1862	0.3584	1.3062***
	-	(0.3270)	(0.3759)	(0.2980)	-	(0.3649)
US	-	−1.8214***	0.3544	−0.1909	0.3469	1.3110
	-	(0.3240)	(0.3732)	(0.2967)	(0.3426)	-
Australia	−0.6824	−1.2143***	0.6474*	−0.1439	0.3925	1.0008***
	-	(0.3678)	(0.3648)	(0.2789)	(0.3211)	(0.3524)
Brazil	−0.1063	−1.7626***	0.5167	−0.2017	0.2994	1.2544***
	-	(0.3341)	(0.3788)	(0.3004)	(0.3422)	(0.3728)
South Korea	−0.1735	−1.7820***	0.4204	−0.1918	0.3507	1.3762***
	-	(0.3347)	(0.3960)	(0.3018)	(0.3466)	(0.3892)
Indonesia	−0.5723	−1.1457***	0.0348	−0.1450	0.6140*	1.2141***
	-	(0.3490)	(0.3477)	(0.2667)	(0.3164)	(0.3243)
South Africa	−0.1839	−1.5677***	0.4762	−0.2296	0.3784	1.1266***
	-	(0.3599)	(0.3699)	(0.2937)	(0.3380)	(0.3756)
Home-biased						
Canada	-	−1.7419	0.7273*	−0.3512	0.1428	1.2230***
	-	-	(0.3730)	(0.2973)	(0.3433)	(0.3637)
EU	-	−1.7825***	0.4300	−0.2202	0.4452	1.1276***
	-	(0.3256)	-	(0.2992)	(0.3418)	(0.3638)
UK	-	−1.8379***	0.2999	0.1000	0.4607	0.9773***
	-	(0.3162)	(0.3635)	-	(0.3348)	(0.3554)
Japan	-	−1.4220***	0.0324	−0.1039	1.0879	0.4056
	-	(0.3519)	(0.4045)	(0.3207)	-	(0.3926)
US	-	−1.9219***	0.3473	−0.2201	0.1416	1.6531
	-	(0.3486)	(0.4014)	(0.3191)	(0.3686)	-
Australia	−0.3107	−1.4962***	0.8922*	−0.0879	−0.1154	1.1180**
	-	(0.4501)	(0.4464)	(0.3413)	(0.3929)	(0.4313)
Brazil	−0.9090	−1.5574***	0.7844	−0.1278	−0.8072	2.6169***
	-	(0.4846)	(0.5496)	(0.4358)	(0.4964)	(0.5409)
South Korea	−0.6542	−1.2907***	−0.0907	−0.2751	0.2526	2.0580***
	-	(0.4292)	(0.5077)	(0.3869)	(0.4445)	(0.4991)
Indonesia	−0.9657	−0.4010	−0.6985	0.0028	0.0869	1.9756***
	-	(0.4755)	(0.4738)	(0.3633)	(0.4311)	(0.4419)
South Africa	−0.0659	−1.0400**	0.3577	−0.4359	0.1447	1.0393*
	-	(0.5037)	(0.5176)	(0.4109)	(0.4730)	(0.5256)

Table 4.12
Optimal currency exposure including bitcoin

This table reports the optimal currency exposure estimated using Equation (4.6) for investors from 10 countries. It considers investors holding a given portfolio with predetermined weights. The investment horizon is one month. Standard errors are displayed below the optimal currency exposures. We mark with one, two, or three asterisks coefficients for which we reject the null hypothesis of zero at the 10%, 5%, and 1% significance levels, respectively. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The term 'bitcoin' indicates the optimal exposure to bitcoin futures contracts. The full sample spans the years 2018–2021.

Country	Domestic	CAD	EUR	GBP	JPY	USD	Bitcoin
			Diversified				
Canada	-	−1.7613	0.3684	−0.2180	0.3635	1.2558***	−0.0084
	-	-	(0.3793)	(0.3035)	(0.3491)	(0.3748)	(0.0182)
EU	-	−1.7628***	0.3675	−0.2149	0.3496	1.2693***	−0.0087
	-	(0.3467)	-	(0.3056)	(0.3479)	(0.3749)	(0.0183)
UK	-	−1.7639***	0.3606	−0.2173	0.3686	1.2603***	−0.0082
	-	(0.3461)	(0.3795)	-	(0.3496)	(0.3763)	(0.0182)
Japan	-	−1.7608***	0.3340	−0.1990	0.3584	1.2767***	−0.0093
	-	(0.3451)	(0.3792)	(0.3016)	-	(0.3725)	(0.0182)
US	-	−1.7729***	0.3546	−0.2040	0.3482	1.2828	−0.0087
	-	(0.3421)	(0.3766)	(0.3006)	(0.3457)	-	(0.0181)
Australia	−0.6829	−1.1692***	0.6459*	−0.1560	0.3954	0.9749***	−0.0081
	-	(0.3832)	(0.3682)	(0.2827)	(0.3241)	(0.3599)	(0.0169)
Brazil	−0.1065	−1.7272***	0.5138	−0.2094	0.3016	1.2339***	−0.0061
	-	(0.3539)	(0.3830)	(0.3045)	(0.3459)	(0.3818)	(0.0183)
South Korea	−0.1788	−1.7316***	0.4216	−0.2052	0.3526	1.3501***	−0.0089
	-	(0.3535)	(0.3996)	(0.3058)	(0.3499)	(0.3965)	(0.0183)
Indonesia	−0.5718	−1.1025***	0.0359	−0.1570	0.6144*	1.1888***	−0.0079
	-	(0.3632)	(0.3509)	(0.2703)	(0.3193)	(0.3315)	(0.0162)
South Africa	−0.1889	−1.5065***	0.4732	−0.2417	0.3838	1.0896***	−0.0095
	-	(0.3812)	(0.3731)	(0.2971)	(0.3411)	(0.3853)	(0.0181)
			Home-biased				
Canada	-	−1.6717	0.7260*	−0.3698	0.1470	1.1811***	−0.0126
	-	-	(0.3752)	(0.3002)	(0.3454)	(0.3708)	(0.0180)
EU	-	−1.7186***	0.4288	−0.2370	0.4475	1.0908***	−0.0115
	-	(0.3431)	-	(0.3024)	(0.3442)	(0.3709)	(0.0181)
UK	-	−1.7794***	0.2990	0.0834	0.4651	0.9421**	−0.0103
	-	(0.3341)	(0.3663)	-	(0.3375)	(0.3633)	(0.0176)
Japan	-	−1.4354***	0.0325	−0.1006	1.0879	0.4131	0.0024
	-	(0.3725)	(0.4092)	(0.3256)	-	(0.4020)	(0.0196)
US	-	−1.8733***	0.3474	−0.2332	0.1429	1.6249	−0.0087
	-	(0.3681)	(0.4052)	(0.3235)	(0.3721)	-	(0.0194)
Australia	−0.3126	−1.2782***	0.8850**	−0.1464	−0.1017	0.9929**	−0.0389*
	-	(0.4496)	(0.4320)	(0.3317)	(0.3803)	(0.4223)	(0.0199)
Brazil	−0.9094	−1.4863***	0.7784	−0.1432	−0.8029	2.5757***	−0.0123
	-	(0.5127)	(0.5549)	(0.4412)	(0.5012)	(0.5532)	(0.0265)
South Korea	−0.6594	−1.2404***	−0.0894	−0.2884	0.2546	2.0319***	−0.0089
	-	(0.4537)	(0.5130)	(0.3926)	(0.4491)	(0.5090)	(0.0235)
Indonesia	−0.9637	−0.2366	−0.6943	−0.0429	0.0885	1.8791***	−0.0300
	-	(0.4851)	(0.4687)	(0.3609)	(0.4264)	(0.4427)	(0.0217)
South Africa	−0.0880	−0.7692	0.3443	−0.4896	0.1688	0.8758	−0.0421*
	-	(0.5170)	(0.5060)	(0.4029)	(0.4626)	(0.5226)	(0.0245)

Table 4.13
***T* test for optimal currency position change after including bitcoin**

This table reports the *t* statistics calculated using Equation (4.8) for the change in optimal currency exposure for diversified and home-biased investors after including the bitcoin futures contracts. It considers investors holding a given portfolio with predetermined weights. The *p* values are displayed below the *t* statistics. The investment horizon is one month. Countries are displayed on the left of each row and the hedging currencies are reported at the top of each column. The full sample spans the years 2000–2021.

Diversified					
Country	CAD	EUR	GBP	JPY	USD
Canada	-	0.0022	0.0410	0.0079	0.4629
	-	(0.9983)	(0.9675)	(0.9937)	(0.6458)
EU	0.1395	-	0.0414	0.0049	0.4741
	(0.8897)	-	(0.9672)	(0.9961)	(0.6379)
UK	0.1358	0.0018	-	0.0101	0.4523
	(0.8926)	(0.9986)	-	(0.9920)	(0.6534)
Japan	0.1508	0.0011	0.0426	-	0.5122
	(0.8809)	(0.9991)	(0.9662)	-	(0.6112)
US	0.1417	0.0004	0.0436	0.4809	-
	(0.8880)	(0.9997)	(0.9655)	(0.6331)	-
Australia	0.1178	0.0041	0.0428	0.0088	0.4756
	(0.9068)	(0.9968)	(0.9660)	(0.9930)	(0.6368)
Brazil	0.0998	0.0078	0.0253	0.0062	0.3333
	(0.9210)	(0.9939)	(0.9800)	(0.9951)	(0.7406)
South Korea	0.1425	0.0032	0.0438	0.0056	0.4844
	(0.8873)	(0.9975)	(0.9653)	(0.9956)	(0.6306)
Indonesia	0.1189	0.0031	0.0444	0.0013	0.4856
	(0.9060)	(0.9975)	(0.9648)	(0.9990)	(0.6298)
South Africa	0.1606	0.0081	0.0409	0.0159	0.5266
	(0.8732)	(0.9936)	(0.9676)	(0.9874)	(0.6012)
Home-biased					
Country	CAD	EUR	GBP	JPY	USD
Canada	-	0.0033	0.0620	0.0120	0.7001
	-	(0.9974)	(0.9509)	(0.9905)	(0.4877)
EU	0.1864	-	0.0554	0.0066	0.6336
	(0.8530)	-	(0.9561)	(0.9948)	(0.5298)
UK	0.1751	0.0023	-	0.0130	0.5831
	(0.8618)	(0.9982)	-	(0.9897)	(0.5629)
Japan	0.0360	0.0003	0.0102	-	0.1224
	(0.9714)	(0.9998)	(0.9919)	-	(0.9032)
US	0.1318	0.0004	0.0405	0.4463	-
	(0.8958)	(0.9997)	(0.9679)	(0.6577)	-
Australia	0.4849	0.0168	0.1764	0.0361	1.9584
	(0.6303)	(0.9867)	(0.8608)	(0.9713)	(0.0568)
Brazil	0.1385	0.0108	0.0351	0.0086	0.4627
	(0.8905)	(0.9915)	(0.9722)	(0.9932)	(0.6460)
South Korea	0.1108	0.0025	0.0341	0.0044	0.3767
	(0.9123)	(0.9980)	(0.9730)	(0.9965)	(0.7083)
Indonesia	0.3388	0.0089	0.1266	0.0037	1.3843
	(0.7364)	(0.9929)	(0.8998)	(0.9970)	(0.1736)
South Africa	0.5237	0.0265	0.1333	0.0519	1.7175
	(0.6032)	(0.9790)	(0.8946)	(0.9589)	(0.0932)

In conclusion, this section examines whether gold and bitcoin futures are suitable assets for currency risk management. We present the optimal demand and its interaction with other currencies. For diversified investors, the demand for gold is statistically significant and consistent across all investors; however, for more than half of the investors, the demand becomes insignificant when they switch to home-biased portfolios. On the contrary, the demand for bitcoin is minor in all cases and only significant for home-biased Australian and South African investors at the 10% significance level. Our results indicate that adding gold and bitcoin affects optimal USD positions when the demand is statistically significant. Nonetheless, it does not improve diversification by reducing the demand for USD exposure. As the demand for bitcoin is uncertain, we will not include it in our analysis of hedging performance. As the demand for gold is significant for most investors, we assess its hedging performance in FX risk management and explore the benefits of including gold.

4.6. The performance of currency hedging

After investigating the optimal currency exposure, we now assess whether the risk reduction is statistically meaningful. Following Campbell et al. (2010), we choose zero, half, and full hedge as benchmarks. We employ the *F* test to assess the statistical significance of the risk reduction achieved by the optimal hedge in comparison to the benchmarks.

First, we focus on risk reduction through optimal hedging for diversified and home-biased investors. Although Campbell et al. (2010) found that their optimal currency positions are similar, the performance of the optimal hedge on these portfolios remains unknown. Second, we present the risk reduction from adding gold to the risk-minimising hedge. Although gold does not improve the diversification of the optimal hedge, the demand for gold is statistically significant for many investors. Thus, it is necessary to examine the benefits of including it in the investment. Nevertheless, as bitcoin is not a relevant asset in risk management in this study, we exclude it from further discussion.

Table 4.14 reports the investment standard deviations investors can achieve with the risk-minimising optimal currency hedge. The first three columns present the risk for the benchmark investments. Alongside the benchmark results, we report the risk of the optimally hedged investment. The table reports F statistics and shows the statistical significance of the risk reduction achieved by the optimal static hedge in relation to benchmarks. We mark with one, two, or three asterisks coefficients for which the risk reduction is statistically significant at a 10%, 5%, and 1% significance level, respectively.

4.6.1. Diversified and home-biased portfolios

When investors adopt a diversified portfolio, the foreign currencies held implicitly account for a significant proportion of the investment's value, and the risk associated with benchmark strategies varies noticeably. If investors hold a home-biased portfolio, however, the risk of benchmark strategies shows slight variation, as most assets are denominated in investors' domestic currencies. Thus, the implicitly held foreign currencies have little influence on investment risk. In this case, the most considerable difference between simple hedges across all investors is 1.17%, achieved by Canadian unhedged and fully hedged investments.

Table 4.14 shows that home-biased portfolios do not necessarily have a lower unhedged investment risk than diversified portfolios. Only UK, Japanese, Australian, and South African investors achieve lower unhedged investment risk by adopting home-biased portfolios. The absolute risk differences between unhedged diversified and home-biased portfolios are under 0.75%, and the difference is not statistically significant even at the 10% level for all investors except those from Brazil, South Korea, and Indonesia.[29] This implies that for most investors, reducing diversification and FX exposure together leads home-biased investors to a risk level comparable to that of diversified investors.

Canadian, EU, UK, US, and Australian investors have similar levels of optimally hedged risk for both diversified and home-biased portfolios when applying the optimal hedge.[30] The null hypothesis of equal variance cannot be rejected at the 1% significance level for these investors. This suggests that their risk profiles remain invariant regardless of whether they adopt diversified and home-biased portfolios. Choosing between a home-biased or diversified strategy does not significantly affect optimal currency exposure, unhedged investment risk, and optimally hedged investment risk for these investors. This outcome extends the findings of Campbell et al. (2010), which highlight the similarity of optimal currency positions across different portfolio types.

While Japanese and South African investors also have similar unhedged risks for diversified and home-biased investments, their optimally hedged home-biased portfolios are significantly riskier than diversified portfolios at the 1% significance level. This indicates that the performance of the optimal hedge deteriorates when applied to home-biased investments.

The countries left are worse off by adopting home-biased portfolios in two ways. First, Brazilian, South Korean, and Indonesian investors experience a riskier unhedged home-biased foreign investment than diversified investment. Second, although the optimal hedge performs

[29] The p values of the F statistics for Canadian, EU, UK, Japanese, US, Australian, Brazilian, South Korean, Indonesian and South African investors are 0.3722, 0.9191, 0.6021, 0.4839, 0.9980, 0.9757, 0.0000, 0.0000, 0.0000 and 0.7462, respectively.

[30] The p values of the F statistics for Canadian, EU, UK, Japanese, US, Australian, Brazilian, South Korean, Indonesian and South African investors are 0.7408, 0.5196, 0.7652, 0.0120, 0.4868, 0.9813, 0.0000, 0.0000, 0.0000 and 0.0000, respectively.

well, the *F* statistic of the optimally hedged investment relative to the unhedged investment is lower than that of an optimally hedged diversified portfolio.

Table 4.14 also reports each country's annualised standard deviation of monthly returns and hedging strategies involving gold futures contracts. The table shows that optimally hedged portfolios that adopt gold futures contracts always have a lower risk for all diversified and home-biased investors than portfolios that adopt simple hedging strategies. Adding gold futures contracts to international portfolios also reduces risk compared to the base optimal model. The risk reduction relative to the base optimal model, however, is minor and not statistically significant for all investors.

In conclusion, the currency risk management strategy offers international investors the potential for significant risk reduction in most instances, proving effective for both diversified and home-biased investors. However, the strength of the risk reduction decreases for investors from Japan and South Africa if they move from diversified portfolios to home-biased portfolios. The currency risk management strategy with gold offers international investors the potential for risk reduction in all instances. The level of risk reduction relative to the base optimal model is not significant in all cases. The following section investigates how currency hedging affects international investment returns.

Table 4.14
Performance of currency hedging

This table reports each country's annualised standard deviation of monthly returns and hedging strategies. The first three columns present the risk for unhedged, half-hedged and fully hedged investments. Besides the results of the simple hedge, we report the risk of optimally hedged investments. The *F* statistics are displayed to compare strategies. We mark with one, two, or three asterisks coefficients for which the risk reduction is statistically significant at a 10%, 5%, and 1% significance level, respectively. The reported standard deviations are measured in percentage points.

Country	Zero hedge	Half hedge	Full hedge	Optimal base	Optimal gold	Base vs zero	Base vs half	Base vs full	Base vs gold
Diversified									
Canada	11.75	12.42	14.10	11.40	11.22	1.0633	1.1879*	1.5298***	1.0310
EU	14.09	13.67	14.03	11.31	11.12	1.5537***	1.4612***	1.5407***	1.0337
UK	13.79	13.47	14.03	11.28	11.10	1.4941***	1.4251***	1.5456***	1.0336
Japan	17.64	15.46	13.95	11.41	11.22	2.3911***	1.8367***	1.4965***	1.0333
US	14.95	14.36	13.97	11.32	11.14	1.7433***	1.6096***	1.5230***	1.0326
Australia	12.04	12.15	14.17	10.79	10.53	1.2466**	1.2680**	1.7252***	1.0490
Brazil	16.27	12.73	14.40	10.83	10.58	2.2557***	1.3814***	1.7682***	1.0479
South Korea	13.01	12.82	14.13	10.74	10.55	1.4686***	1.4251***	1.7313***	1.0347
Indonesia	14.34	13.18	14.19	10.85	10.62	1.7480***	1.4767***	1.7100***	1.0427
South Africa	16.06	12.99	14.23	11.02	10.78	2.1234***	1.3887***	1.6668***	1.0454
Home-biased									
Canada	12.42	12.96	13.59	11.17	11.16	1.2367**	1.3464***	1.4818***	1.0016
EU	14.18	14.09	14.24	11.76	11.59	1.4530***	1.4339***	1.4645***	1.0296
UK	13.35	13.28	13.42	11.08	10.91	1.4536***	1.4368***	1.4681***	1.0313
Japan	16.89	16.61	16.33	13.32	13.18	1.6072***	1.5532***	1.5028***	1.0221
US	14.95	14.73	14.54	11.82	11.61	1.6004***	1.5534***	1.5140***	1.0361
Australia	12.02	12.45	12.97	10.77	10.67	1.2455**	1.3361***	1.4497***	1.0191
Brazil	22.84	22.89	22.94	16.88	16.85	1.8310***	1.8386***	1.8463***	1.0031
South Korea	20.44	20.60	20.78	18.14	18.12	1.2698**	1.2902**	1.3123**	1.0025
Indonesia	24.09	24.10	24.11	19.15	19.12	1.5827***	1.5837***	1.5847***	1.0030
South Africa	15.74	15.84	15.99	14.23	14.20	1.2236*	1.2383**	1.2618**	1.0043

4.7. Return of hedged investment

Varying the currency exposure would affect the hedged foreign investment return. Following the comparison of risk, we choose the zero-hedge, half-hedge, and full-hedge strategies as benchmarks and examine the difference in their returns. We employ the paired *t* test to determine whether optimally hedged investments yield a higher or lower return than benchmarks. Additionally, the optimal currency exposure to gold is significant in many cases. Nonetheless, it displays minimal improvement in the risk reduction of an optimally hedged investment. Thus, we also examine whether gold improves the hedged return for risk-minimising investors.

4.7.1. Diversified and home-biased portfolios

Table 4.15 shows the annualised returns of diversified and home-biased portfolios, in which the hedging strategies are reported at the top of each column and investors' home countries are reported at the left of each row. To facilitate interpretation, we use the example of Canadian investors showing the annualised returns of diversified investment in the global market when adopting the zero (3.64), half (3.91), full (4.18) and optimal (3.32) hedge strategies. For simple hedging strategies, the higher the hedge ratio, the higher the return on the hedged investment. This effect implies that shorting foreign currencies and going long on the CAD is profitable for Canadian investors.

For the diversified portfolio, the optimally hedged investment has a lower return than all benchmark strategies for diversified Canadian, EU, UK, Japanese, US, South Korean, and South African investors. The differences are only significant for Japanese unhedged and half-hedged investors at the 10% significance level. For Australian, Brazilian, and Indonesian investors, while the optimally hedged investments have a higher investment return than some benchmark strategies, the differences are not significant in all cases.

When comparing the return for home-biased investors, it becomes apparent that the optimal hedge consistently decreases the return compared to benchmark hedged investments. The optimally hedged investments have the lowest return among all strategies, even though the differences are only significant for Japanese investors at the 10% significance level.

4.7.2. The benefit of gold

The optimally hedged return changes as investors adopt gold futures contracts. In Panel A of Table 4.15, the 'Optimal gold' column represents the optimally hedged return after considering futures contracts for gold. If diversified investors consider gold futures contracts as hedging vehicles, the optimally hedged return improves drastically compared with the base model, which only considers conventional currencies. On average, the optimally hedged return increases by 1.85%, with Brazilian and Japanese investors experiencing the highest and lowest increases of 3.20% and 1.21%, respectively. While adding gold futures does not reduce risk compared to optimally hedged investments, it significantly improves their returns at the 1% significance level for all investors – and in some cases even delivers the highest returns among all hedging strategies. The Sharpe ratio in Panel B shows that it is doubled for investors from Canada, the EU, the UK, and the US. The improvements are even greater for investors from Australia, Brazil, South Korea, Indonesia, and South Africa.

However, for home-biased investors, the effect of adopting gold derivatives depends on their domestic currencies. For EU, UK, Japanese, US, and Australian investors, as their optimally hedged investments require significant exposure to gold, the optimally hedged return improves when adopting gold futures. The increases are also statistically significant at the 1% level. For Canadian and South Korean investors, although the demand for gold is insignificant, including gold also improves the optimally hedged return at the 1% significance level. Brazilian, Indonesian, and South African investors demand a short position on gold, and the results show that it decreases the optimally hedged returns at the 1% significance level.

To summarise, the inclusion of gold futures contracts statistically increases or decreases the return of the base optimal hedging model using conventional currencies, depending on whether the demand is positive or negative. The difference between benchmark strategies and the base optimal hedge is sometimes noticeable. Nonetheless, the differences are only significant for Japanese investors at the 10% significance level.

Table 4.15
Benchmark and optimally hedged returns and Sharpe ratios

This table reports each country's annualised monthly returns for hedging strategies in panel A. The first three columns present the returns for unhedged, half-hedged and fully hedged investments. In addition to the results of the simple hedge, we report the risk of optimally hedged investments. The *p* values are displayed to compare hedged returns. Reported returns are measured in percentage points. Panel B reports the Sharpe ratios for diversified and home-biased investments with and without gold. The full sample runs from 2000 to 2021.

Panel A	Zero hedge	Half hedge	Full hedge	Optimal base	Optimal gold	Base vs zero	Base vs half	Base vs full	Base vs gold
				Diversified					
Canada	3.64	3.91	4.18	3.32	4.73	0.3010	0.2875	0.3130	0.0005
EU	3.93	4.05	4.16	2.92	4.33	0.2876	0.2463	0.2419	0.0007
UK	5.27	5.03	4.78	3.58	5.08	0.1593	0.1794	0.2512	0.0003
Japan	5.57	4.41	3.24	1.53	2.74	0.0801	0.0986	0.1592	0.0030
US	4.60	4.59	4.57	3.04	4.45	0.2270	0.2064	0.1906	0.0006
Australia	3.72	4.69	5.66	3.92	5.80	0.4310	0.2598	0.1883	0.0001
Brazil	9.98	11.67	13.36	11.72	14.92	0.2514	0.4870	0.2088	0.0000
South Korea	4.49	4.81	5.13	3.73	5.27	0.3143	0.2344	0.2365	0.0001
Indonesia	7.69	8.86	10.03	8.16	10.59	0.4086	0.3298	0.1689	0.0000
South Africa	9.07	9.18	9.29	8.40	10.92	0.3948	0.2984	0.3222	0.0000
				Home-biased					
Canada	4.67	4.76	4.85	4.20	4.52	0.3433	0.3450	0.3469	0.0005
EU	3.09	3.15	3.22	1.98	3.36	0.2556	0.2386	0.2343	0.0007
UK	3.21	3.09	2.97	1.62	3.03	0.1583	0.1728	0.2015	0.0003
Japan	2.88	2.70	2.52	−0.10	1.06	0.0888	0.0920	0.0960	0.0030
US	5.66	5.65	5.65	4.15	5.70	0.2198	0.2112	0.2034	0.0006
Australia	4.53	4.75	4.97	3.49	4.67	0.1790	0.1705	0.1667	0.0001
Brazil	10.02	10.04	10.06	7.81	6.51	0.2501	0.2492	0.2484	0.0000
South Korea	8.30	8.34	8.38	7.06	7.78	0.2694	0.2707	0.2721	0.0001
Indonesia	12.10	12.11	12.11	9.27	8.10	0.1811	0.1810	0.1809	0.0000
South Africa	9.54	9.56	9.57	9.02	8.00	0.3580	0.3587	0.3615	0.0000

Table 4.15 Continued

Panel B	Canada	EU	UK	Japan	US	Australia	Brazil	South Korea	Indonesia	South Africa
					Diversified					
Base	0.1215	0.1229	0.1199	0.1295	0.1217	0.0264	-0.0490	0.0813	0.0126	0.0707
Gold	0.2492	0.2518	0.2570	0.2395	0.2502	0.2056	0.2523	0.2287	0.2417	0.3060
					Home-biased					
Base	0.2028	0.0383	-0.0548	-0.0115	0.2105	-0.0135	-0.2631	0.2317	0.0651	0.0983
Gold	0.2317	0.1579	0.0736	0.0764	0.3478	0.0970	-0.3407	0.2717	0.0040	0.0267

4.8. Conclusion

This study examined currency risk management for international equity investors from ten countries, extending the influential work of Campbell et al. (2010) in several important directions. While Campbell et al. (2010) demonstrated that optimal currency exposure is similar across equal-weighted, value-weighted, and hypothetical home-biased portfolios, the present study focused specifically on value-weighted and home-biased investments using realistic home-bias data, thereby providing more practically relevant implications for international investors.

The first contribution of this study is to subject the similarity of optimal currency positions to formal statistical testing. Through systematic comparison of diversified and home-biased portfolios, the results reveal that optimal exposures to certain currencies shift significantly for Japanese, Brazilian, Indonesian, and South African investors. For Canadian, EU, US, UK, Australian, and South Korean investors, however, the findings align with those of Campbell et al. (2010): optimal currency exposures remain similar regardless of whether investors adopt home-biased or diversified portfolios. This suggests that investors from developed economies—with the notable exception of Japan—face stable optimal currency positions across portfolio types, whereas their emerging-market counterparts exhibit statistically significant variations. Importantly, with the exception of South African investors, these variations centre primarily on the demand for the US dollar.

The second novel finding concerns the efficacy of currency hedging. The analysis demonstrates that currency hedging delivers comparable risk reduction for Canadian, EU, UK, US, and Australian investors. Specifically, the null hypotheses of equal unhedged risks, equal hedged risks, and equal optimally hedged risks between diversified and home-biased investments cannot be rejected at the one per cent significance level. This result extends the findings of

Campbell et al. (2010) beyond the similarity of optimal positions to encompass the actual performance of hedging strategies.

Building on this, a striking implication emerges: for Canadian, EU, US, UK, and Australian investors, effective currency risk management renders the choice between diversified and home-biased portfolios irrelevant. These investors can achieve equivalent risk outcomes regardless of their portfolio composition, provided currency risk is optimally managed.

Given the heavy reliance on US dollar exposure in optimal currency hedging—a reliance that is particularly pronounced for home-biased investors due to reduced currency diversification—the present study investigated whether gold and bitcoin could serve as effective alternatives. The findings reveal a nuanced picture. For home-biased investors, the inclusion of gold or bitcoin futures does not reduce overall US dollar exposure. Notably, positive demand for gold tends to be associated with increased demand for the US dollar, suggesting complementarity rather than substitution. Among diversified investors, demand for gold is statistically significant, while demand for bitcoin is consistently near zero. For home-biased Australian and South African investors, bitcoin demand is marginally significant at the ten per cent level but economically negligible. It is therefore concluded that bitcoin plays no meaningful role in currency risk management over the limited sample period examined.

The performance of optimal currency hedging varies across countries and portfolio types. With the exception of Canadian investors, the optimal hedge statistically outperforms all benchmarks in terms of risk reduction for both diversified and home-biased investments. For Canadian, EU, UK, US, and Australian investors, risk profiles remain invariant across portfolio types. The same cannot be said, however, for other investors in the sample. Japanese and South African investors face a different reality. Although their unhedged risks are similar across portfolio types, optimally hedged home-biased portfolios are significantly riskier than their diversified counterparts at the one per cent level. This indicates that the performance of the optimal hedge deteriorates when applied to home-biased investments for these investors. Brazilian, South Korean, and Indonesian investors experience higher unhedged risk in home-biased foreign investments, and while the optimal hedge improves outcomes, the risk reduction is less pronounced than for diversified portfolios.

The inclusion of gold futures in optimal currency hedging does not improve risk reduction for either diversified or home-biased investors. However, it materially affects hedged returns. Investors with positive optimal gold demand experience significantly higher hedged returns compared to the base model, while those with negative gold demand see significantly lower returns.

The significant demand for gold across multiple investor types, coupled with the persistent centrality of the US dollar, reveals a nuanced picture of risk management. Rather than serving as a substitute, gold plays a complementary role, addressing risks beyond the scope of traditional currency hedging. This finding suggests that investors construct multi-layered defence mechanisms, challenging the conventional view of hedging instruments as simple substitutes. Currency risk management thus emerges as a sophisticated exercise in which investors deploy multiple tools in a layered fashion, each targeting a distinct risk dimension. The complementarity between the US dollar and gold—evidenced by the positive correlation between their optimal demands—underscores this complexity. Investors do not choose between the two; they determine the appropriate combination, calibrated to their unique risk profile and investment horizon.

If exchange rate risk constitutes a key driver of home bias, then effective currency risk management should encourage investors to diversify internationally. The findings suggest that the benefits of such diversification are particularly pronounced for investors from emerging economies, who face greater variation in optimal currency positions and hedging performance across portfolio types. The similarity of optimal currency exposure across portfolio types appears to depend on the degree of globalisation. As trade conflicts and economic decoupling become increasingly prominent themes in the contemporary landscape, future research could extend this study by examining how the divergence in optimal currency positions evolves in response to shifting globalisation trends. Such studies would provide valuable insights into the dynamics of currency risk management in an increasingly fragmented global economy.

CHAPTER FIVE CONCLUSION

This chapter provides the findings, conclusions and policy implications of the three studies and the dissertation as a whole. This chapter concludes by describing the limitations of the thesis and some possible recommendations for future research.

5.1. Major findings and policy implications

5.1.1. The natural hedge effect and optimal hedging with the violation of CIP

The first study found that foreign currency exposure may not increase the risk of unhedged international investments. Although exchange rate variance contributes to the volatility of unhedged foreign positions, its covariance with the underlying asset returns reduces overall investment risk for almost all short-term horizons. For Australian, Canadian, UK, and South Korean investors, the net contribution of currency risk actually lowers short-term investment risk in the absence of hedging. These results quantify the magnitude of the natural hedge effect and imply that foreign currency exposure should not be automatically treated as an additional layer of risk. We expect this effect to encourage greater allocation to US dollar-denominated assets, thereby strengthening the position of the US equity market.

However, the performance of the optimal hedge indicates that its risk-reducing effect is not statistically significant relative to an unhedged position when foreign currency exposure exhibits a natural hedge—with the exception of Turkish and South African investors. This in-sample finding should further encourage allocation to the US market: if even in-sample analysis fails to yield significant risk reduction, out-of-sample performance is likely to offer even weaker hedging benefits. As a result, the barrier to entry for investment in the US market is effectively lowered.

When comparing the performance of the optimal hedge across different hedging vehicles, we found that violations of covered interest rate parity do not create significant differences in optimal hedge ratios. Consequently, optimally hedged investment risk and returns remain similar across vehicles in most cases. Investors and practitioners can therefore adopt any hedging instrument that best suits their operational constraints, allowing for cost optimisation and improved operational flexibility.

Finally, our analysis of long-horizon investments revealed that the negative correlation between exchange rate returns and asset returns in the pricing currency tends to reverse over longer holding periods, with the turning point concentrated at 24 and 36 months. For most investors, the negative correlation diminishes and eventually turns positive, causing the natural hedge benefit—observed over short horizons—to dissipate. As a result, the optimal hedge significantly outperforms unhedged positions over long investment horizons. Importantly, for long-term investors, currency risk management becomes vital, as the US dollar no longer exhibits a negative correlation with international investments. The implication is that while investors may disregard short-term currency fluctuations, they should continuously roll over long-term currency forward contracts to maintain adequate protection.

The findings of Study One establish a foundational understanding of currency risk. However, these conclusions are derived from a static framework that assumes constant variances and correlations over time. In practice, financial markets are characterised by time-varying volatility and evolving correlations, particularly during periods of economic stress. A static approach, while informative for long-term averages, may fail to capture the dynamic nature of currency risk and the optimal hedging response required in changing market conditions.

Study Two addresses this limitation by adopting a dynamic framework for currency risk management. Specifically, it employs the DCC–GARCH model to estimate time-varying conditional variances and correlations, allowing for optimal currency positions that adapt to evolving market conditions.

5.1.2. Dynamic currency risk management for international investors

The second study examined foreign currency risk management using both the static mean–variance framework and the DCC–GARCH model. We selected the optimal univariate model for each asset's excess return. First, our findings show that across the seven univariate models considered, four were selected as optimal for different return series. This finding underscores the pitfall of relying on any single model. To accurately estimate conditional variances, investors should select a univariate model aligned with each asset's risk profile, then select the best-performing model for each series.

Secondly, we compared the optimal multivariate models. Contrary to the established literature, the ADCC model's estimated parameter indicates that asymmetry in dynamic conditional correlation is not detected across all investors. This result, potentially attributable to the portfolio's unique composition, numeraire effects, or sample-period characteristics, validates the sufficiency of the standard DCC model in this specific context.

Thirdly, we found that the dynamic optimal hedge tends to have a lower overall currency position than the static optimal hedge, which means that the dynamic approach involves fewer hedging operations. The result indicates that the dynamic model adjusts the hedge ratio downward as it accounts for the time-varying nature of conditional correlations and volatilities. The dynamic model's adaptive nature allows it to mitigate the influence of transient shocks by reverting to normal levels post-crisis.

In addition, we found that the risk reduction achieved by adopting the static optimal hedge is statistically significant for all investors, except those from Canada. Furthermore, adopting the dynamic optimal hedge results in lower risk than the static optimal hedge; however, the difference is not significant for all investors. The comparison between static and dynamic hedges indicates that, though an advanced model provides additional benefits, it may not be justified by the extra effort required.

This study employed an advanced framework to estimate the optimal currency exposures. The contrasting dynamics of USD in the second and last subperiods carry an important implication: safe-haven currencies do not respond uniformly to crises. Their behaviour is also shaped by broader market conditions and policy responses specific to each crisis. Consequently, investors should avoid over-reliance on any single safe-haven currency. A diversified approach—holding a basket of multiple safe-haven currencies—offers a more robust strategy for mitigating risk across different types of market stress. Study three focuses on exploring alternative assets that are suitable for currency risk management.

5.1.3. Currency risk management for diversified and home-biased investors and the effectiveness of gold and bitcoin

This study examined currency risk management for international equity investors from ten countries. The present study focused on value-weighted and home-biased investments using realistic home-bias data and explored the effectiveness of gold and bitcoin as alternative safe havens.

By comparing diversified and home-biased portfolios, the results reveal that optimal exposures to certain currencies shift significantly for Japanese, Brazilian, Indonesian, and South African investors. For Canadian, EU, US, UK, Australian, and South Korean investors, however, the findings align with those of Campbell et al. (2010). This suggests that investors from developed economies—with the notable exception of Japan—face stable optimal currency positions across portfolio types, whereas their emerging-market counterparts exhibit statistically significant variations.

The second novel finding concerns the efficacy of currency hedging. The analysis demonstrates that currency hedging delivers comparable risk reduction for Canadian, EU, UK, US, and Australian investors. This result extends the findings of Campbell et al. (2010) beyond the similarity of optimal positions to encompass the actual performance of hedging strategies.

Building on this, a striking implication emerges: for Canadian, EU, US, UK, and Australian investors, effective currency risk management renders the choice between diversified and home-biased portfolios irrelevant. These investors can achieve equivalent risk outcomes regardless of their portfolio composition, provided currency risk is optimally managed.

The similarity of optimal currency exposure and investment risk across portfolio types appears to depend on the degree of globalisation. As trade conflicts and economic decoupling become increasingly prominent themes in the contemporary landscape, future research could extend this study by examining how the divergence in optimal currency positions evolves in response to shifting globalisation trends. Such studies would provide valuable insights into the dynamics of currency risk management in an increasingly fragmented global economy.

This study investigated whether gold and bitcoin could serve as effective alternatives. The findings reveal a nuanced picture. For home-biased investors, the inclusion of gold or bitcoin futures does not reduce overall US dollar exposure. The inclusion of gold futures in optimal currency hedging does not improve risk reduction for either diversified or home-biased investors. However, it materially affects hedged returns. Investors with positive optimal gold demand experience significantly higher hedged returns compared to the base model, while those with negative gold demand see significantly lower returns.

The significant demand for gold across multiple investor types, coupled with the persistent centrality of the US dollar, reveals a nuanced picture of risk management. Rather than serving as a substitute, gold plays a complementary role, addressing risks beyond the scope of traditional currency hedging. This finding suggests that investors construct multi-layered defence mechanisms, challenging the conventional view of hedging instruments as simple substitutes. Investors do not choose between the two; they determine the appropriate combination, calibrated to their unique risk profile and investment horizon.

If exchange rate risk constitutes a key driver of home bias, then effective currency risk management should encourage investors to diversify internationally. The findings suggest that the benefits of such diversification are particularly pronounced for investors from emerging economies, who face greater variation in optimal currency positions and hedging performance across portfolio types.

5.2. Limitations and recommendations

While the three studies in this thesis offer valuable insights, this research is not without limitations.

The first study was confined to investors with exposure to the US market, primarily due to the limited availability of forward contract data for currency pairs not involving the USD. Although investors can theoretically use the USD as a bridge currency to hedge exposures between two non-USD currencies, in practice, matching forward contracts to implement such strategies effectively presents significant operational challenges. Second, the natural hedge effect was tested exclusively with the USD, imposing restrictions on the construction of international portfolios. Given that the JPY and EUR are also recognised as safe-haven currencies with deep and liquid capital markets, future tests of the natural hedge effect should extend the analysis to include these currencies. Third, our analysis of long-horizon investments considered only horizons of up to three years; potential sign changes in correlations beyond this period remain unexplored. Ideally, further research on the natural hedge effect could be extended to other markets, assuming investors hold internationally diversified portfolios comprising assets from the US, European, and Japanese markets. Although the complexity of variance decomposition would increase substantially under such a framework, the resulting empirical insights would be considerably more informative.

The second study was limited to investors with a one-month investment horizon, a constraint imposed by the frequency and range of the data employed. Furthermore, although we considered a comprehensive set of univariate GARCH specifications, the estimated parameters for certain assets were not statistically significant, revealing the limitations of the model coverage examined. This study also excluded investors from emerging markets, as the significant fluctuations in asset returns for these economies led to failures in maximising the log-likelihood function, precluding the derivation of currency risk management strategies for this important investor group. Future research could address these limitations by employing higher-frequency data. Such an approach would not only increase the number of observations but also help smooth the fluctuations inherent in monthly return series. This would enable researchers to derive insights relevant to different investment horizons, including for investors in developing economies. In addition, further studies could incorporate recent advances in univariate and multivariate volatility modelling, as well as models grounded in alternative theoretical frameworks, such as those drawing on behavioural finance theory (Ogunc, 2008).

The third study has two principal limitations. The first concerns the construction of home-biased portfolios, in which the weight assigned to domestic assets was fixed at a constant rate. While this fixed weight reflects the average home bias across all investors, actual portfolio weights may vary substantially across individuals and investor types. The second limitation relates to the evaluation of alternative safe-haven assets. This study focused exclusively on gold and bitcoin, despite a growing body of literature highlighting the potential usefulness of other cryptocurrencies in risk management. Future research could address these limitations in several ways. First, studies could account for heterogeneity in home bias by using the average weight as a baseline and then considering a range of deviations from this baseline. Second, the coverage of portfolios could be extended to include investors with different investment styles, such as those using exchange-traded funds (Williams, 2016), pension funds (Kurach & Papla, 2016), and superannuation funds (Thorp, 2005). Third, given the rapid development of cryptocurrency markets, further research could examine a broader set of cryptocurrencies and evaluate their potential role in currency risk management.

Finally, following Campbell et al. (2010), this thesis focused on the study of risk-minimising hedges using the primary indicator of the *F* test for comparing investment risk between benchmark and optimal hedging strategies. Future research could extend this analysis by varying currency positions to achieve other investment objectives—such as return enhancement or downside risk protection—and by employing a wider range of statistical tests to evaluate the performance of alternative strategies.

Globalisation has faced unprecedented challenges in recent years. Decoupling and trade conflicts frequently dominate news headlines around the world. While these developments generate greater uncertainty, they also reduce expected correlations among global capital markets, thereby creating expanded opportunities for international diversification. With the expectation that current conflicts will eventually be resolved and a new framework for global cooperation will emerge, investors should maintain positive exposure to international markets. This thesis offers investors willing to venture into foreign markets a comprehensive framework for protecting their portfolios against exchange rate volatility.

REFERENCES

Aftab, M., Ahmad, R., & Ismail, I. (2015). Dynamics between currency and equity in Chinese markets. *Chinese Management Studies*, *9*(3), 333–354. https://doi.org/10.1108/CMS-07-2014-0120

Ahearne, A. G., Griever, W. L., & Warnock, F. E. (2004). Information costs and home bias: An analysis of US holdings of foreign equities. *Journal of International Economics*, *62*(2), 313–336. https://doi.org/10.1016/S0022-1996(03)00015-1

Ajayi, R. A., Friedman, J., & Mehdian, S. M. (1998). On the relationship between stock returns and exchange rates: Tests of Granger causality. *Global Finance Journal*, *9*(2), 241–251.

Akram, Q. F., Rime, D., & Sarno, L. (2008). Arbitrage in the foreign exchange market: Turning on the microscope. *Journal of International Economics*, *76*(2), 237–253. https://doi.org/10.1016/j.jinteco.2008.07.004

Almeida, J., & Gonçalves, T. C. (2023). Portfolio Diversification, Hedge and Safe-Haven Properties in Cryptocurrency Investments and Financial Economics: A Systematic Literature Review. *Journal of Risk and Financial Management*, *16*(1). https://doi.org/10.3390/jrfm16010003

Attfield, C., Glod, M., & James, J. (2001). Options and forwards compete for best hedge. *Quantitative Finance*, *1*(1), 9–11. https://doi.org/10.1080/713665547

Avdjiev, S., Bruno, V., Koch, C., & Shin, H. S. (2019). The Dollar Exchange Rate as a Global Risk Factor: Evidence from Investment. *IMF Economic Review*, *67*(1), 151–173. https://doi.org/10.1057/s41308-019-00074-4

Baba, N., & Packer, F. (2009). Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08. *Financial Globalisation, Risk Analysis and Risk Management*, *33*(11), 1953–1962. https://doi.org/10.1016/j.jbankfin.2009.05.007

Balke, N. S., & Wohar, M. E. (1998). Nonlinear dynamics and covered interest rate parity. *Empirical Economics*, *23*(4), 535–559. https://doi.org/10.1007/BF01205993

Bekaert, G., & Wu, G. (2000). Asymmetric volatility and risk in equity markets. *The Review of Financial Studies*, *13*(1), 1–42. https://doi.org/10.1093/rfs/13.1.1

Black, F. (1989). Universal Hedging: Optimizing Currency Risk and Reward in International Equity Portfolios. *Financial Analysts Journal*, *45*(4), 16–22. https://doi.org/10.2469/faj.v45.n4.16

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, *31*(3), 307–327.

Bucher, M. C. (2020). Conditional currency hedging. *Financial Management*, *49*(4), 897–923. https://doi.org/10.1111/fima.12287

Campbell, J. Y., & Hentschel, L. (1992). No news is good news: An asymmetric model of changing volatility in stock returns. *Journal of Financial Economics*, *31*(3), 281–318. https://doi.org/10.1016/0304-405X(92)90037-X

Campbell, J. Y., Serfaty-De Medeiros, K., & Viceira, L. M. (2010). Global Currency Hedging. *The Journal of Finance*, *65*(1), 87–121. https://doi.org/10.1111/j.1540-6261.2009.01524.x

Cappiello, L., Engle, R. F., & Sheppard, K. (2006). Asymmetric dynamics in the correlations of global equity and bond returns. *Journal of Financial Econometrics*, *4*(4), 537–572. https://doi.org/10.1093/jjfinec/nbl005

Chang, C.-L., González-Serrano, L., & Jimenez-Martin, J.-A. (2013). Currency hedging strategies using dynamic multivariate GARCH. *Mathematics and Computers in Simulation*, *94*, 164–182. https://doi.org/10.1016/j.matcom.2012.02.008

Chemkha, R., BenSaïda, A., Ghorbel, A., & Tayachi, T. (2021). Hedge and safe haven properties during COVID-19: Evidence from Bitcoin and gold. *Quarterly Review of*

Economics and Finance, *82*, 71–85. https://doi.org/10.1016/j.qref.2021.07.006

Cheong, C. W. H. (2019). Cryptocurrencies vs global foreign exchange risk. *Journal of Risk Finance*, *20*(4), 330–351. https://doi.org/10.1108/JRF-11-2018-0178

Chiang, Y.-C., Liao, T. L., & Hsiao, T.-A. (2011). Evaluating hedging strategies in the foreign exchange market with the stochastic dominance approach. *Applied Financial Economics*, *21*(7), 493–503. https://doi.org/10.1080/09603107.2010.532111

Chkili, W., Aloui, C., & Nguyen, D. K. (2012). Asymmetric effects and long memory in dynamic volatility relationships between stock returns and exchange rates. *Journal of International Financial Markets, Institutions and Money*, *22*(4), 738–757. https://doi.org/10.1016/j.intfin.2012.04.009

Cho, J.-B., Min, H.-G., & McDonald, J. A. (2020). Volatility and dynamic currency hedging. *Journal of International Financial Markets, Institutions & Money*, *64*. https://doi.org/10.1016/j.intfin.2019.101163

Cho, J.-W., Choi, J. H., Kim, T., & Kim, W. (2016). Flight-to-quality and correlation between currency and stock returns. *Journal of Banking & Finance*, *62*, 191–212. https://doi.org/10.1016/j.jbankfin.2014.09.003

Christie, A. A. (1982). The stochastic behavior of common stock variances: Value, leverage and interest rate effects. *Journal of Financial Economics*, *10*(4), 407–432. https://doi.org/10.1016/0304-405X(82)90018-6

Clogg, C. C., Petkova, E., & Haritou, A. (1995). Statistical Methods for Comparing Regression Coefficients Between Models. *American Journal of Sociology*, *100*(5), 1261–1293. https://doi.org/10.1086/230638

Coeurdacier, N., & Rey, H. (2013). Home bias in open economy financial macroeconomics. *Journal of Economic Literature*, *51*(1), 63–115. https://doi.org/10.1257/jel.51.1.63

Cosset, J.-C., & Suret, J.-M. (1995). Political Risk and the Benefits of International Portfolio

Diversification. *Journal of International Business Studies*, *26*(2), 301–318. https://doi.org/10.1057/palgrave.jibs.8490175

Daly, K., & Vo, X. V. (2013). The determinants of home bias puzzle in equity portfolio investment in Australia. *International Review of Financial Analysis*, *27*, 34–42. https://doi.org/10.1016/j.irfa.2012.05.005

Davis, J. S., & Van Wincoop, E. (2021). *Asset prices, leverage and portfolio rebalancing drive global capital flows cycle*. Federal Reserve Bank of Dallas. https://www.dallasfed.org/research/economics/2021/1130

de Roon, F. A., Nijman, T. E., & Werker, B. J. M. (2003). Currency hedging for international stock portfolios: The usefulness of mean-variance analysis. *Journal of Banking and Finance*, *27*(2), 327–349. https://doi.org/10.1016/S0378-4266(01)00251-5

Diermeier, J., & Solnik, B. (2001). Global Pricing of Equity. *Financial Analysts Journal*, *57*(4), 37–47. https://doi.org/10.2469/faj.v57.n4.2464

Ding, Z., Granger, C. W., & Engle, R. F. (1993). A long memory property of stock market returns and a new model. *Journal of Empirical Finance*, *1*(1), 83–106. https://doi.org/10.1016/0927-5398(93)90006-D

Driessen, J., & Laeven, L. (2007). International portfolio diversification benefits: Cross-country evidence from a local perspective. *Journal of Banking & Finance*, *31*(6), 1693–1712. https://doi.org/10.1016/j.jbankfin.2006.11.006

Du, W., Tepper, A., & Verdelhan, A. (2018). Deviations from Covered Interest Rate Parity. *The Journal of Finance*, *73*(3), 915–957. https://doi.org/10.1111/jofi.12620

Dumas, B., & Solnik, B. (1995). The world price of foreign exchange risk. *The Journal of Finance*, *50*(2), 445–479. https://doi.org/10.1111/j.1540-6261.1995.tb04791.x

Dyhrberg, A. H. (2016). Bitcoin, gold and the dollar – A GARCH volatility analysis. *Finance Research Letters*, *16*, 85–92. https://doi.org/10.1016/j.frl.2015.10.008

Engel, C. (1996). The forward discount anomaly and the risk premium: A survey of recent evidence. *Journal of Empirical Finance*, *3*(2), 123–192. https://doi.org/10.1016/0927-5398(95)00016-X

Engel, C. (2000). Long-run PPP may not hold after all. *Journal of International Economics*, *51*(2), 243–273. https://doi.org/10.1016/S0022-1996(99)00011-2

Engle, R. (2002). Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. *Journal of Business & Economic Statistics*, *20*(3), 339–350. https://doi.org/10.1198/073500102288618487

Engle, R. (2009). *Anticipating correlations: A new paradigm for risk management*. Princeton University Press. https://doi.org/10.1515/9781400830190

Engle, R. F., & Ng, V. K. (1993). Measuring and testing the impact of news on volatility. *The Journal of Finance*, *48*(5), 1749–1778. https://doi.org/10.1111/j.1540-6261.1993.tb05127.x

Epaphra, M. (2017). Modeling exchange rate volatility: Application of the GARCH and EGARCH models. *Journal of Mathematical Finance*, *7*(1), 121–143. https://doi.org/10.4236/jmf.2017.71007

Eun, C. S., & Resnick, B. G. (1988). Exchange rate uncertainty, forward contracts, and international portfolio selection. *The Journal of Finance*, *43*(1), 197–215. https://doi.org/10.1111/j.1540-6261.1988.tb02597.x

Feng, W., Wang, Y., & Zhang, Z. (2018). Can cryptocurrencies be a safe haven: A tail risk perspective analysis. *Applied Economics*, *50*(44), 4745–4762. https://doi.org/10.1080/00036846.2018.1466993

Fidora, M., Fratzscher, M., & Thimann, C. (2007). Home bias in global bond and equity markets: The role of real exchange rate volatility. *Journal of International Money and Finance*, *26*(4), 631–655. https://doi.org/10.1016/j.jimonfin.2007.03.002

Filipozzi, F., & Harkmann, K. (2020). Optimal currency hedge and the carry trade. *Review of Accounting and Finance*, *19*(3), 411–427. https://doi.org/10.1108/RAF-10-2018-0219

Fratzscher, M. (2009). What explains global exchange rate movements during the financial crisis? *The Global Financial Crisis: Causes, Threats and Opportunities*, *28*(8), 1390–1407. https://doi.org/10.1016/j.jimonfin.2009.08.008

French, K. R., & Poterba, J. M. (1991). Investor Diversification and International Equity Markets. *NBER Working Paper*, (w3609). https://doi.org/10.3386/w3609

Froot, K. A. (2019). Currency hedging over long horizons. *Annals of Economics and Finance*, *20*(1), 37–66.

Gastineau, G. L. (1995). The Currency Hedging Decision: A Search for Synthesis in Asset Allocation. *Financial Analysts Journal*, *51*(3), 8–17. https://doi.org/10.2469/faj.v51.n3.1900

Ghorbel, A., Frikha, W., & Manzli, Y. S. (2022). Testing for asymmetric non-linear short- and long-run relationships between crypto-currencies and stock markets. *Eurasian Economic Review*, *12*(3), 387–425. https://doi.org/10.1007/s40822-022-00206-8

Glen, J., & Jorion, P. (1993). Currency hedging for international portfolios. *The Journal of Finance*, *48*(5), 1865–1886. https://doi.org/10.1111/j.1540-6261.1993.tb05131.x

Glosten, L. R., Jagannathan, R., & Runkle, D. E. (1993). On the relation between the expected value and the volatility of the nominal excess return on stocks. *The Journal of Finance*, *48*(5), 1779–1801. https://doi.org/10.1111/j.1540-6261.1993.tb05128.x

Gomis-Porqueras, P., Shi, S., & Tan, D. (2022). Gold as a financial instrument. *Journal of Commodity Markets*, *27*. https://doi.org/10.1016/j.jcomm.2021.100218

Gupta, R., & Donleavy, G. D. (2009). Benefits of diversifying investments into emerging markets with time-varying correlations: An Australian perspective. *Journal of Multinational Financial Management*, *19*(2), 160–177.

https://doi.org/10.1016/j.mulfin.2008.10.001

Hamza, O., L'Her, J.-F., & Roberge, M. (2007). Active currency hedging strategies for global equity portfolios. *The Journal of Investing*, *16*(4), 146–166. https://doi.org/10.3905/joi.2007.698985

Hazuka, T. B., & Huberts, L. C. (1994). A Valuation Approach to Currency Hedging. *Financial Analysts Journal*, *50*(2), 55–59. https://doi.org/10.2469/faj.v50.n2.55

Higgins, M. L., & Bera, A. K. (1992). A class of nonlinear ARCH models. *International Economic Review*, *33*(1), 137–158. https://doi.org/10.2307/2526988

Hsu, S.-H., Sheu, C., & Yoon, J. (2021). Risk spillovers between cryptocurrencies and traditional currencies and gold under different global economic conditions. *North American Journal of Economics and Finance*, *57*. https://doi.org/10.1016/j.najef.2021.101443

Iqbal, J. (2017). Does gold hedge stock market, inflation and exchange rate risks? An econometric investigation. *International Review of Economics and Finance*, *48*, 1–17. https://doi.org/10.1016/j.iref.2016.11.005

Joy, M. (2011). Gold and the US dollar: Hedge or haven? *Finance Research Letters*, *8*(3), 120–131. https://doi.org/10.1016/j.frl.2011.01.001

Kang, S. H., Yoon, S.-M., Bekiros, S., & Uddin, G. S. (2020). Bitcoin as Hedge or Safe Haven: Evidence from Stock, Currency, Bond and Derivatives Markets. *Computational Economics*, *56*(2), 529–545. https://doi.org/10.1007/s10614-019-09935-6

Karolyi, G. A., & Stulz, R. M. (2003). Chapter 16 Are financial assets priced locally or globally? In *Handbook of the Economics of Finance* (Vol. 1, pp. 975–1020). Elsevier. https://doi.org/10.1016/S1574-0102(03)01025-2

Kasikov, K. (2012). Currency hedging for international bond and equity investors. In J. James, I. W. Marsh, & L. Sarno (Eds.), *Handbook of exchange rates* (pp. 503–543).

https://doi.org/10.1002/9781118445785.ch18

Katechos, G. (2011). On the relationship between exchange rates and equity returns: A new approach. *Journal of International Financial Markets, Institutions and Money*, *21*(4), 550–559. https://doi.org/10.1016/j.intfin.2011.03.001

Kearney, C., & Potì, V. (2006). Correlation dynamics in European equity markets. *Research in International Business and Finance*, *20*(3), 305–321. https://doi.org/10.1016/j.ribaf.2005.05.006

Kendall, A. (2017). Developments in financial market benchmarks. *Reserve Bank of New Zealand Bulletin*, *80*(4), 1–17.

Kotkatvuori-Örnberg, J. (2016). Dynamic conditional copula correlation and optimal hedge ratios with currency futures. *International Review of Financial Analysis*, *47*, 60–69. https://doi.org/10.1016/j.irfa.2016.06.006

Kroencke, T. A., Schindler, F., & Schrimpf, A. (2014). International diversification benefits with foreign exchange investment styles. *Review of Finance*, *18*(5), 1847–1883. https://doi.org/10.1093/rof/rft047

Kurach, R., & Papla, D. (2016). Should pension funds hedge currency risk? The case of Poland. *Baltic Journal of Economics*, *16*(2), 81–94. https://doi.org/10.1080/1406099X.2016.1187429

Kwas, M., Beckmann, J., & Rubaszek, M. (2024). Are consensus FX forecasts valuable for investors? *International Journal of Forecasting*, *40*(1), 268–284. https://doi.org/10.1016/j.ijforecast.2023.02.007

Lee, C.-H., Doong, S.-C., & Chou, P.-I. (2011). Dynamic correlation between stock prices and exchange rates. *Applied Financial Economics*, *21*(11), 789–800. https://doi.org/10.1080/09603107.2010.537631

Levich, R. M., & Thomas, L. R. (1993). The Merits of Active Currency Risk Management:

Evidence from International Bond Portfolios. *Financial Analysts Journal*, *49*(5), 63–70. https://doi.org/10.2469/faj.v49.n5.63

Levy, H., & Lerman, Z. (1988). The Benefits of International Diversification in Bonds. *Financial Analysts Journal*, *44*(5), 56–64. https://doi.org/10.2469/faj.v44.n5.56

Lewis, K. K. (1999). Trying to explain home bias in equities and consumption. *Journal of Economic Literature*, *37*(2), 571–608.

Li, K., Sarkar, A., & Wang, Z. (2003). Diversification benefits of emerging markets subject to portfolio constraints. *Emerging Markets S.I.*, *10*(1), 57–80. https://doi.org/10.1016/S0927-5398(02)00027-0

Madani, M. A., & Ftiti, Z. (2022). Is gold a hedge or safe haven against oil and currency market movements? A revisit using multifractal approach. *Annals of Operations Research*, *313*(1), 367–400. https://doi.org/10.1007/s10479-021-04288-6

Markowitz, H. (1952). Portfolio Selection. *The Journal of Finance*, *7*(1), 77–91.

Maronoti, B. (2022). Revisiting the international role of the US dollar. *BIS Quarterly Review*, *5*. https://www.bis.org/publ/qtrpdf/r_qt2212x.htm?s=09

Meshcheryakov, A., & Ivanov, S. (2020). Ethereum as a hedge: The intraday analysis. *Economics Bulletin*, *40*(1), 101–108.

Min, H.-G., McDonald, J. A., & Shin, S.-O. (2016). What makes a safe haven? Equity and currency returns for six OECD countries during the financial crisis. *Annals of Economics and Finance*, *17*(2), 365–402.

Morey, M. R., & Simpson, M. W. (2001). To hedge or not to hedge: The performance of simple strategies for hedging foreign exchange risk. *Journal of Multinational Financial Management*, *11*(2), 213–223. https://doi.org/10.1016/S1042-444X(00)00050-5

Moussa, W., Bejaoui, A., & Mgadmi, N. (2021). Asymmetric effect and dynamic relationships between stock prices and exchange rates volatility. *Annals of Data Science*, *8*, 837–859.

Neely, C. J. (1997). Technical analysis in the foreign exchange market: A layman's guide. *Federal Reserve Bank of St. Louis Review*, (Sep), 23–38.

Neely, C., Weller, P., & Dittmar, R. (1997). Is technical analysis in the foreign exchange market profitable? A genetic programming approach. *Journal of Financial and Quantitative Analysis*, *32*(4), 405–426. https://doi.org/10.2307/2331231

Nelson, D. B. (1991). Conditional heteroskedasticity in asset returns: A new approach. *Econometrica*, *59*(2), 347–370.

Nguyen, Q. N., Bedoui, R., Majdoub, N., Guesmi, K., & Chevallier, J. (2020). Hedging and safe-haven characteristics of Gold against currencies: An investigation based on multivariate dynamic copula theory. *Resources Policy*, *68*, Article 101766. https://doi.org/10.1016/j.resourpol.2020.101766

Ogunc, K. (2008). Behavioral currency hedging for international portfolios. *International Review of Financial Analysis*, *17*(4), 716–727. https://doi.org/10.1016/j.irfa.2007.09.005

Olbrys, J., & Majewska, E. (2017). Asymmetry effects in volatility on the major European stock markets: The EGARCH based approach. *Quantitative Finance and Economics*, *1*(4), 411–427. https://doi.org/10.3934/QFE.2017.4.411

Opie, W., & Riddiough, S. J. (2020). Global currency hedging with common risk factors. *Journal of Financial Economics*, *136*(3), 780–805. https://doi.org/10.1016/j.jfineco.2019.12.001

Owusu Junior, P., Adam, A. M., & Tweneboah, G. (2020). Connectedness of cryptocurrencies and gold returns: Evidence from frequency-dependent quantile regressions. *Cogent Economics and Finance*, *8*(1). https://doi.org/10.1080/23322039.2020.1804037

Paternoster, R., Brame, R., Mazerolle, P., & Piquero, A. (1998). Using the correct statistical test for the equality of regression coefficients. *Criminology*, *36*(4), 859–866.

https://doi.org/10.1111/j.1745-9125.1998.tb01268.x

Patton, A. J. (2006). Modelling asymmetric exchange rate dependence. *International Economic Review*, *47*(2), 527–556. https://doi.org/10.1111/j.1468-2354.2006.00387.x

Qureshi, S., Rehman, I. U., & Qureshi, F. (2018). Does gold act as a safe haven against exchange rate fluctuations? The case of Pakistan rupee. *Journal of Policy Modeling*, *40*(4), 685–708. https://doi.org/10.1016/j.jpolmod.2018.02.005

Ranaldo, A., & Söderlind, P. (2010). Safe Haven Currencies. *Review of Finance*, *14*(3), 385–407. https://doi.org/10.1093/rof/rfq007

Reboredo, J. C. (2013). Is gold a safe haven or a hedge for the US dollar? Implications for risk management. *Journal of Banking and Finance*, *37*(8), 2665–2676. https://doi.org/10.1016/j.jbankfin.2013.03.020

Reboredo, J. C., & Rivera-Castro, M. A. (2014). Can gold hedge and preserve value when the US dollar depreciates? *Economic Modelling*, *39*, 168–173. https://doi.org/10.1016/j.econmod.2014.02.038

Reserve Bank of New Zealand. (2020, January 28). *Interest rate benchmark reform*. https://www.rbnz.govt.nz/news-and-events/news/2020/01/interest-rate-benchmark-reform

Schmittmann, J. M. (2010). *Currency Hedging for International Portfolios*. *IMF Working Papers*, *2010*(151). https://doi.org/10.5089/9781455201341.001

Sercu, P., & Vanpee, R. (2012). The Home Bias Puzzle in Equity Portfolios. In H. K. Baker & L. A. Riddick (Eds.), *International Finance: A Survey* (pp. 310–330). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199754656.003.0015

Simpson, M. W. (2004). Selectively hedging the US dollar with foreign exchange futures contracts. *Journal of International Financial Markets, Institutions and Money*, *14*(1), 75–86. https://doi.org/10.1016/S1042-4431(03)00045-3

Simpson, M. W., & Dania, A. (2006). Selectively hedging the Euro. *Journal of Multinational Financial Management*, *16*(1), 27–42. https://doi.org/10.1016/j.mulfin.2005.02.002

Skinner, F. S., & Mason, A. (2011). Covered interest rate parity in emerging markets. *International Review of Financial Analysis*, *20*(5), 355–363. https://doi.org/10.1016/j.irfa.2011.06.008

Solnik, B. H. (1974a). An equilibrium model of the international capital market. *Journal of Economic Theory*, *8*(4), 500–524.

Solnik, B. H. (1974b). Why Not Diversify Internationally Rather Than Domestically? *Financial Analysts Journal*, *30*(4), 48–54. https://doi.org/10.2469/faj.v30.n4.48

Tamakoshi, G., & Hamori, S. (2014). Co-movements among major European exchange rates: A multivariate time-varying asymmetric approach. *International Review of Economics & Finance*, *31*, 105–113. https://doi.org/10.1016/j.iref.2014.01.016

Taylor, M. P. (1987). Covered Interest Parity: A High-Frequency, High-Quality Data Study. *Economica*, *54*(216), 429–438. https://doi.org/10.2307/2554178

Taylor, S. J. (2007). *Modelling financial time series* (2nd ed.). World Scientific. https://doi.org/10.1142/6578

Thornton, D. L. (1989). Tests of covered interest rate parity. *Federal Reserve Bank of St. Louis Review*, *1*, 55–66.

Thorp, S. (2005). "That courage is not inconsistent with caution": Currency hedging for superannuation funds. *Economic Record*, *81*(252), 38–50. https://doi.org/10.1111/j.1475-4932.2005.00215.x

Toyoshima, Y., & Hamori, S. (2013). Asymmetric dynamics in stock market correlations: Evidence from Japan and Singapore. *Journal of Asian Economics*, *24*, 117–123. https://doi.org/10.1016/j.asieco.2012.08.001

VanderLinden, D., Jiang, C. X., & Hu, M. (2002). Conditional Hedging and Portfolio

Performance. *Financial Analysts Journal*, *58*(4), 72–82. https://doi.org/10.2469/faj.v58.n4.2455

Walker, E. (2008). Strategic currency hedging and global portfolio investments upside down. *Journal of Business Research*, *61*(6), 657–668. https://doi.org/10.1016/j.jbusres.2007.06.041

Wang, J., & Yang, M. (2009). Asymmetric volatility in the foreign exchange markets. *Journal of International Financial Markets, Institutions and Money*, *19*(4), 597–615.

Wang, K.-M., & Lee, Y.-M. (2011). The yen for gold. *Resources Policy*, *36*(1), 39–48. https://doi.org/10.1016/j.resourpol.2010.06.002

Wang, K.-M., & Lee, Y.-M. (2022). Is gold a safe haven for exchange rate risks? An empirical study of major currency countries. *Journal of Multinational Financial Management*, *63*. https://doi.org/10.1016/j.mulfin.2021.100705

Whaley, R. E. (2006). *Derivatives: Markets, valuation, and risk management*. John Wiley & Sons.

Williams, O. (2016). Foreign currency exposure within country exchange traded funds. *Studies in Economics and Finance*, *33*(2), 222–243. https://doi.org/10.1108/SEF-10-2014-0196

Wu, G. (2001). The determinants of asymmetric volatility. *The Review of Financial Studies*, *14*(3), 837–859. https://doi.org/10.1093/rfs/14.3.837

Zakoian, J.-M. (1994). Threshold heteroskedastic models. *Journal of Economic Dynamics and Control*, *18*(5), 931–955. https://doi.org/10.1016/0165-1889(94)90039-6

Zhao, H. (2010). Dynamic relationship between exchange rate and stock price: Evidence from China. *Research in International Business and Finance*, *24*(2), 103–112. https://doi.org/10.1016/j.ribaf.2009.09.001