

Betting Against Uncovered Interest Rate Parity

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The President:

Prof. Ernst Mohr, PhD

It will be unnecessary to trouble the Reader with an Account of the Pains or Care I have taken in composing this Work; since every Person, acquainted with the Doctrine of [foreign] Exchanges, will readily allow that it could not have been executed without considerable Trouble and Assiduity. It will therefore be sufficient, to inform the Public, that this Performance has employed my leisure Hours for several Years; and if I have rendered the Business of Exchanges easy and intelligible to young Merchant-Adventurers, Factors and Agents, I shall not repent of the Pains I have taken.

[S. Thomas, The British negociator, 1759]

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Abstract

An ever growing number of allegedly savvy investors exploit interest rate differentials by borrowing in low-yield currencies or by investing in high-yield currencies. Uncovered interest rate parity (UIP) assumes that high-yield currencies depreciate and that low-yield currencies appreciate so that currency movements exactly countervail interest rate differentials on average. If UIP held, betting against interest rate differentials would turn out to be a futile gamble, leaving investors with a profit of zero in the long run. Although UIP seems to draw on sound foundations, empirical work produces ample evidence for its systematic failure. Deviation from UIP is a well-established feature commonly known as the “UIP puzzle” or the “forward rate anomaly”. This thesis sheds light on potential explanations by interpreting deviation from UIP as compensation for bearing risk.

The introductory part of this work provides a comprehensive literature review on deviation from UIP. It starts with a summary on studies testing for departure from UIP where particular emphasis is put on work based on exchange rate surveys. The literature aiming at a solution of the puzzle is then presented by categorizing existing contributions into four broad theory blocks, viz. explanations relating the forward rate anomaly to either (1) market irrationality, (2) in-sample bias, (3) regime shifts and heterogeneous beliefs or to (4) currency risk premia.

The main part first examines risk-reward opportunities of carry trades, which is an increasingly prominent form of speculation against UIP. It is shown that carry trade activity exposes investors to potentially large losses in times of financial crises. This finding is supported by results from a multivariate GARCH analysis, which reveals that carry traders experience a diversification meltdown in times of equity market downturns. In fact, the correlation between returns on carry trades and returns on global equity markets gets out of hand during stock market crises.

The UIP puzzle dwindles if the alleged anomaly is tackled with consumption-based asset pricing models (C-CAPM). A conditional C-CAPM using ultimate consumption as the risk factor can explain a surprisingly large fraction of the total cross-sectional variation in deviation from UIP. The capital asset pricing model (CAPM) proves to be similarly successful if the model is upgraded by an additional factor capturing coskewness with equity market returns. In view of these results, betting against UIP appears to be a bold venture because excess returns simply reflect risk premia.

Zusammenfassung

Eine zunehmende Zahl von Investoren spekuliert auf Zinsdifferenzen, indem sie sich in Tiefzinswährungen verschulden oder in Hochzinswährungen investieren. Die ungedeckte Zinsparität (UZP) besagt, dass Hochzinswährungen abwerten und dass Währungen mit tiefen Zinsen aufwerten, wobei im Durchschnitt Zinsdifferenzen durch gegenläufige Wechselkursbewegungen aufgewogen werden. Falls sich die UZP durchsetzte, würde es sich nicht lohnen auf Zinsdifferenzen zu spekulieren, da langfristig kein Gewinn erzielt werden könnte. Obwohl die UZP auf scheinbar plausiblen Annahmen beruht, liefern empirische Arbeiten umfangreiche Evidenz für systematische Verletzungen. Die Erkenntnis, dass die UZP keine Gültigkeit besitzt, ist weit verbreitet und im Englischen unter dem Begriff “UIP puzzle” bekannt. Die vorliegende Arbeit versucht Erklärungen zu finden, wobei Abweichungen von der UZP als Kompensation für die Übernahme von Risiken interpretiert werden.

Im Einleitungsteil findet sich ein Literaturüberblick über Studien, die die UZP auf ihre Gültigkeit testen. Besonderes Augenmerk wird auf Arbeiten gelegt, die auf Umfragen zu Wechselkurserwartungen beruhen. Es wurden verschiedene Erklärungen für Abweichungen von der ungedeckten Zinsparität vorgebracht. Diese werden vier Kategorien zugeordnet, nämlich Theorien, die Abweichungen von der UZP auf (1) irrationale Märkte, (2) Stichprobenprobleme, (3) heterogene Erwartungen und (4) Währungsrisikoprämien zurückführen.

Im Hauptteil werden Risiko-Rendite Eigenschaften von sogenannten Carry-Trades - eine an Bedeutung gewinnende Form der Spekulation gegen die UZP - analysiert. Es wird dargelegt, dass Carry-Trades während Finanzmarktkrisen hohe Verluste generieren können. Diese Erkenntnis wird durch eine multivariate GARCH-Analyse gefestigt, die aufzeigt, dass Carry-Trades in Zeiten fallender Aktienmärkte äusserst ungünstige Korrelationseigenschaften aufweisen.

Schliesslich wird gezeigt, dass das Capital Asset Pricing Model (CAPM) Abweichungen von der UZP gut zu erklären vermag, sofern man das Modell um einen zweiten Risikofaktor erweitert, der für asymmetrische Markttrenditen entlohnt (Coskewness). Auf Konsumvariablen basierende Preismodelle (C-CAPM) vermögen einen noch höheren Anteil der Gesamtvarianz zu erklären, falls eine langfristige Konsumkomponente verwendet wird. Da Abweichungen von der UZP als Risikoprämien interpretiert werden können, kommen Wetten auf Zinsdifferenzen einem risikoreichen Unterfangen gleich.

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List of Abbreviations

ADF	augmented Dickey-Fuller
AMEX	American Stock Exchange
AR	autoregressive
ARCH	autoregressive conditional heteroscedasticity
BE/ME	book-to-market
BEA	Bureau of Economic Analysis
BEKK	Baba-Engle-Kroner-Kraft
BIS	Bank of International Settlements
CA	current account
CAPM	capital asset pricing model
CBOE	Chicago Board Option Exchange
C-CAPM	consumption-based capital asset pricing model
cdf	cumulative density function
CIP	covered interest rate parity
CPI	consumer price index
CRRA	constant relative risk aversion
CRSP	Center for Research in Security Prices
DCF	discounted cash flow
DDM	dividend discount model
Eidg.	Eidgenössisch
EMU	European Monetary Union
FED	Federal Reserve System
GARCH	generalized autoregressive conditional heteroscedasticity
GDC	general dynamic covariance
GDP	gross domestic product
GLS	generalized least square

GMM	general methods of moments
HML	value minus growth
ICAPM	international capital asset pricing model
IES	intertemporal elasticity of substitution
iid	identically and independently distributed
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
LTCM	Long-Term Capital Management
MSCI	Morgan Stanley Capital International
MV-GARCH	multivariate generalized autoregressive conditional heteroscedasticity
NASDAQ	National Association of Security Dealers Automated Quotation
NIS	news impact surface
NYSE	New York Stock Exchange
OECD	Organisation for Economic Co-operation and Development
OLS	ordinary least square
OTC	over the counter
pdf	probability density function
PPP	purchasing power parity
SDF	stochastic discount factor
SECO	Staatssekretariat für Wirtschaft
SMB	small minus big
SNB	Swiss National Bank
stddev	standard deviation
TED	Treasury-bill minus Eurodollar
US	United States
UIP	uncovered interest rate parity
UZP	Ungedekte Zinsparität
VAR	vector autoregression
VIX	Chicago Board Option Exchange Volatility Index

AUD	Australian dollar
CAD	Canadian dollar
CNY	Chinese renminbi
CHF	Swiss franc
DEM	German mark
EUR	euro
FIM	Finnish mark
GBP	British pound
JPY	Japanese yen
NOK	Norwegian kroner
NZD	New Zealand dollar
SEK	Swedish krona
USD	United States dollar

Chapter 1

Introduction

Interest rates on comparable deposits vary widely across different currencies. Investors could exploit such differences by investing in high-yield currencies or by borrowing in low-yield currencies. The return from such a strategy is not only driven by interest rate differentials but also by currency movements. After all, investors with a stake in foreign currencies need to convert foreign to domestic money or vice versa at some point in time. Take a Swiss investor chasing high-yield deposits in AUD. Since he ultimately consumes in CHF, payoffs need to be reconverted from AUD to CHF at maturity. The return in domestic currency decreases therefore as the CHF appreciates and it increases as the CHF depreciates. If uncovered interest rate parity (UIP) held, it would not be possible to exploit interest rate differentials profitably on average. UIP claims that high-yield currencies depreciate and that low-yield currencies appreciate so that exchange rate movements precisely countervail interest rate differentials. Speculation on interest rate differentials would thus amount to a futile gamble, leaving investors with an excess return of zero in comparison to a deposit in domestic currency.

UIP is based on the rationale that expected excess returns lead to an inflow of capital into high-yield areas and to an outflow of capital from low-yield areas. Since interest rate levels, which reflect the price of capital, are driven by supply and demand forces, such capital flows reduce interest rate differentials and trigger exchange rate adjustments in terms of an immediate appreciation of the high-yield currency and an immediate depreciation of the low-yield currency. Flows should only be suspended when the expected exchange rate adjustment back to equilibrium is equal in size to the remaining interest rate differential. In spite of the logic of this mechanism, UIP fails systematically, which means that it has a tendency to deviate in one and the same direction. Deviation from UIP is empirically well-established and the phenomenon was even given its own name: It is known as the “interest rate parity puzzle” or, for reasons explained in chapter 2, as the “forward rate anomaly”. Dozens of studies even report that exchange rate movements tend to oppose what UIP predicts. In fact, it is often found that high-yield currencies tend to appreciate and that low-yield currencies tend

to depreciate. This implies that investors with a stake in high-yield currencies benefit twice from betting against UIP, viz. from (1) interest rate differentials and from (2) currency movements in their favor. This thesis provides an overview of the broad body of literature on deviation from UIP and proposes explanations for departure from parity.

1.1 Motivation

Although economists have devoted enormous efforts towards finding a solution to the interest rate parity puzzle, we still lack truly convincing explanations.¹ That is troublesome because models of international finance routinely assume that UIP applies. A better understanding of why UIP fails is urgently needed because it would allow researchers to design more realistic models. Whereas ignorance is troublesome for the academic community, it is downright dangerous for investors. This holds, in particular, for the growing number of speculators deliberately betting against UIP. For them, it is of paramount importance to know whether UIP fails due to market inefficiencies as some commentators suggest or whether deviations reflect currency risk premia. In the former case, violations amount to a free lunch, offering handsome profit opportunities, and investors would be foolish not to exploit interest rate differentials. In the latter case, however, deviation arises as a compensation for bearing systematic risks, and speculation consequently loses much appeal.

Recent research suggests that speculation against UIP has risen dramatically of late. We corroborate this hypothesis by providing evidence for a flourishing carry trade activity.² It is also shown that UIP speculators make small profits on average but sustain large and abrupt losses every once in a while. In fact, we argue that carry traders find themselves trapped in veritable loss spirals in times of financial crises. Such distributional abnormalities can hardly be captured by risk management systems and expose investors to uncontrollable market vagaries. The difficulty to properly account for crises episodes, which occur infrequently, suggests that the recent surge in carry trade activity might stem from investors underestimating implied risks.

¹The use of the academic “we” instead of “I” or the elimination of personal pronouns all together is lively debated in academia. I have chosen to keep my dissertation in plural form. There should be no doubt, however, that it is the result of my own independent work and so are all shortcomings.

²The carry trade is a well-known strategy based on speculation against UIP. We refer the reader to chapter 4 for a more thorough definition and a summary of indicators pointing towards a rise in activity.

The purpose of this study is to enhance clarity about the forces driving departure from UIP. More specifically, we examine risk-reward opportunities and try to relate deviation from UIP to systematic risks. Particular emphasis is put on return asymmetries which expose investors to potentially large losses in times of crises. In light of recent market developments, such investigations seem urgently needed.

1.2 Research Idea

Systematic deviation from UIP poses a conundrum because it implies that profit opportunities are not exploited - at least not in sufficient measure - so as to disappear. This so-called UIP anomaly has been extensively analyzed and various solutions have been suggested. Figure 1.1 assigns existing explanations to four categories, each visualized by a circle, where classification is based on underlying assumptions. Existing work hence assumes that investors are either risk-neutral or risk-averse (vertical axis) and that investors are either rational or irrational (horizontal axis).

Risk-neutral agents exhibit a preference for higher expected returns. In such a scenario, agents exploit all known profit opportunities, irrespective of risks involved. Explanations assuming risk neutrality attribute departure from UIP to irrationality or to some form of information inefficiency and are shown in the upper block of figure 1.1. We distinguish between theories based on (1) irrationality, (2) in-sample bias and (3) regime shifts and heterogeneous beliefs. An extensive review of that literature is provided in chapter 3, but we do not deal with these theories any further thereafter.

The truly innovative contributions in the main sections of this thesis are part of the (4) risk premia literature shown on the lower right of figure 1.1. Risk premia proponents substitute risk neutrality for the more realistic assumption of risk aversion, which implies that agents evaluate assets along two dimensions: (a) expected returns and (b) risk. Under risk aversion, deviation from UIP is not a puzzle per se because it might occur as a compensation for bearing risk. A conundrum arises, however, due to the fact that standard asset pricing models such as the capital asset pricing model (CAPM) or the consumption-based asset pricing model (C-CAPM) fail to account for the cross-sectional variation in deviation from UIP. This is precisely where this thesis sets in. We try to relate departure from UIP to asset pricing models originally developed to cope with equity market anomalies such as Mehra and Prescott's (1985) equity premium puzzle. Extended

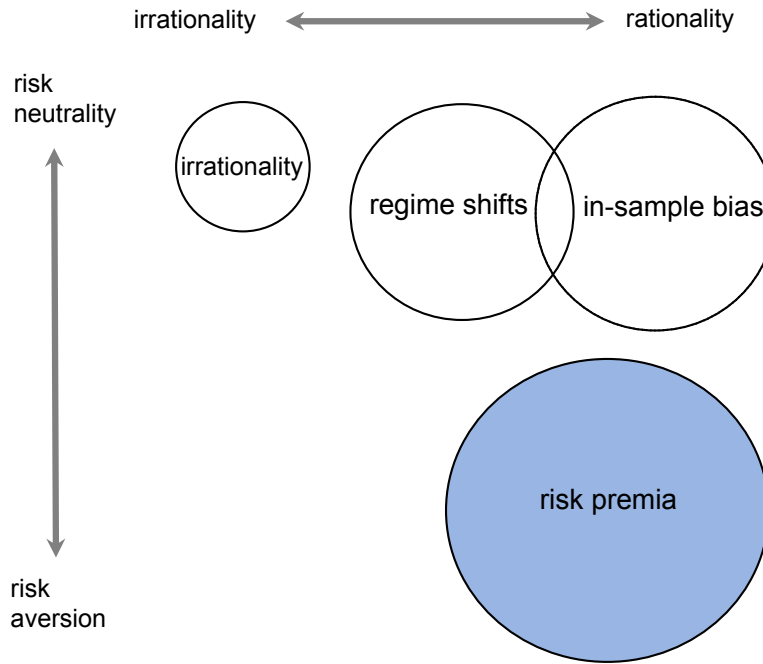


Figure 1.1: Solving the UIP puzzle: Overview

pricing models often perform much better than standard specifications in equity pricing frameworks. It is therefore amazing that these models have barely been applied to the pricing of currency risk. Besides relating currency risk to extended asset pricing settings, we zoom in on risk-return opportunities of strategies betting against UIP where particular emphasis is put on distributional abnormalities. Moreover, contagion and flight-to-quality phenomena are investigated by analyzing deviation from UIP in response to stock market crises. The following outline provides a more detailed overview of what we are contemplating.

1.3 Outline

This dissertation contains seven chapters. Chapter 2 introduces the reader to the concept of UIP and provides an extensive review of empirical work testing for its validity. Particular emphasis is put on investigations based on survey data because these enable us to distinguish whether UIP fails due to systematically biased expectations or due to currency risk premia.

Chapter 3 provides an overview of the large body of literature claiming to solve the UIP puzzle. We cannot convey a complete review because the solutions

proposed are too numerous. However, we strive to provide a representative summary by incorporating major findings from a broad spectrum of theories and by highlighting how the literature evolved over time.

Chapters 4 to 7 can be seen as the main part of this thesis because they contain novel contributions. Although based on ideas presented in the introductory part, these chapters are completely self-contained and can be read independently from each other and independently from chapters 2 and 3. Readers familiar with the concept of UIP can thus directly proceed with chapters 4 to 7.

Chapter 4 analyzes various aspects of carry trades - a popular form of speculation against UIP. We provide evidence for a rise in carry trade activity and analyze risk-reward opportunities. It is found that carry trades expose investors to negative skewness and excess kurtosis. Moreover, we report empirical evidence in support of the loss spiral hypothesis, according to which demand-supply forces cause large carry trade losses every once in a while, usually in times of financial turmoil.

The 5th chapter explores contagion and flight-to-quality phenomena by analyzing correlation dynamics between equity market returns and returns from a carry trade strategy. A multivariate GARCH analysis reveals that correlation increases considerably in response to large stock market shocks. Significant asymmetries emerge, which means that the increase in correlation is particularly pronounced in response to negative as opposed to positive shocks. Our results suggest that carry traders suffer a severe diversification meltdown in times of global stock market downturns.

The 6th chapter introduces the reader to intertemporal asset pricing and analyzes currency risk premia within a consumption-based asset pricing model (CCAPM). Previous research usually failed to relate currency risk to the covariance with consumption. However, we show that a version of Parker and Julliard's (2005) ultimate consumption growth specification captures a surprisingly large fraction of the cross-sectional variation in deviation from UIP. This holds notably if the model is scaled by instruments.

Chapter 7 analyzes departure from UIP within an extended capital asset pricing model (ECAPM) which takes account of covariance and coskewness with market returns. This finer tuned specification generates encouraging results and explains much more than the standard CAPM or a Fama-French extension thereof. Our results suggest that investors speculating against UIP can only do so by taking negative coskewness on board, which exposes their market portfolio to potentially large losses.

Chapter 2

Measuring Deviation from UIP

This chapter introduces the reader to the concepts of covered and uncovered interest rate parity and reviews the broad body of literature testing for their validity. Covered interest rate parity (CIP) is a genuine arbitrage relationship, which implies that it holds at all times. Uncovered interest rate parity (UIP) is found to systematically fail for a wide range of currency pairs and time periods. We put particular emphasis on the literature relying on survey data. The latter allow distinguishing whether deviation from UIP stems from erroneous expectations or whether departure arises as a compensation for risk. This chapter can be seen as setting the stage for the main part of this dissertation, where we analyze why deviation from UIP survives so persistently despite the fact that its exploitation appears to be highly profitable.

2.1 Introduction

Nominal interest rates on otherwise comparable deposits differ widely depending on the currency of denomination. In open capital markets, investors can exploit such differences by allocating funds to high-yield currencies. The return in terms of domestic currency on deposits in foreign currency is not solely driven by interest rate differentials but also depends on currency movements. Due to the volatile nature of foreign exchange markets, unfavorable currency shifts can easily erase profits from interest rate differentials. An investor exploiting interest rate differentials cannot hedge his currency exposure because hedging costs would precisely offset profits derived from the interest rate side. If this were not the case, risk-less profit opportunities would exist. This is ruled out in our investigation because we assume that the no-arbitrage condition holds for the markets subsequently analyzed.

The expected excess return on a deposit in foreign currency corresponds to the expected deviation from uncovered interest rate parity (UIP), which is defined as follows:

$$E_t(\Delta UIP_{t,t+1}) = i_{t,t+1}^f - i_{t,t+1} + E_t(s_{t+1}) - s_t \quad (2.1)$$

where $E_t(\Delta UIP_{t,t+1})$ represents expected deviation from UIP between t and $t+1$, $i_{t,t+1}^f$ is the foreign nominal interest rate and $i_{t,t+1}$ the corresponding domestic rate. s_t denotes the log of the current spot exchange rate, whereas $E(s_{t+1})$ is the log of the expected spot rate for time $t+1$. Throughout this dissertation, exchange rates are defined in direct notation as domestic currency per unit of foreign currency. Except for the expected spot rate, right hand side variables are known with certainty at time t , which corresponds to the settlement day of the deposit contract. Consequently, speculating on interest rate differentials boils down to a bet on $E_t(s_{t+1})$. If UIP held, $\Delta UIP_{t,t+1}$ would be zero, implying that exchange rate movements precisely countervail interest rate differentials. Speculation on interest rate differentials would thus break even because returns on domestic and foreign deposits would be equal once payoffs were converted into a common currency. However, a broad body of literature has shown that UIP fails dramatically. To identify the forces making UIP fail, it is helpful to extend the right hand side of equation 2.1 by $f_{t,t+1} - f_t$. With a bit of reshuffling, one obtains:

$$E_t(\Delta UIP_{t,t+1}) = (i_{t,t+1}^f - i_{t,t+1} + f_{t,t+1} - s_t) + (E_t s_{t+1} - f_{t,t+1}) \quad (2.2)$$

where $f_{t,t+1}$ denotes the logarithm of the forward exchange rate at time t for $t+1$. Expected deviation from UIP can thus be decomposed into two components, viz:

1. deviation from covered interest rate parity (first term) and
2. the difference between expected spot and current forward rates known as the forward rate bias (second term).

There exists an extensive literature testing for CIP and the forward rate bias, which we review in sections 2.2 and 2.3, respectively.

2.2 Deviation from Covered Interest Rate Parity

Let us assume for a moment that CIP fails because $i_{t,t+1}^f - i_{t,t+1} + f_{t,t+1} - s_t > 0$. Attentive investors would then apply for a loan on the domestic money market at a lending rate of $i_{t,t+1}$. The proceeds could be sold on the spot market for foreign currency to be invested on the foreign money market at an interest rate of $i_{t,t+1}^f$. To hedge against unfavorable exchange rate movements, investors could buy forward contracts. The latter enable speculators to reconvert payoffs into domestic currency at the prespecified price of $f_{t,t+1}$ as money instruments mature. Since all prices are known with certainty at time t , such a strategy leads to a riskless profit of exactly $i_{t,t+1}^f - i_{t,t+1} + f_{t,t+1} - s_t > 0$. This illustrates why CIP must permanently hold in efficient markets. The reason is that even minor departures could be profitably exploited without incurring any risk. In other words, CIP is an arbitrage relationship and deviation can only occur if, for some reason, arbitrage is impeded. That would be the case if

1. international capital flows were restricted by law or by prohibitive transaction costs or
2. if there existed a country or political risk premium. A country risk premium could, for instance, arise if countries had different default probabilities.

We subsequently summarize the empirical evidence on deviation from CIP by sorting the literature into three categories, viz. (1) capital flow restrictions, (2) country risk premia and (3) measurement complexities.

2.2.1 Capital Flow Restrictions

A scenario without arbitrage relies on efficient markets, a theoretical concept based on the prerequisite of liberalized capital flows. Frankel and MacArthur

(1988) indeed discover merely minor deviations from CIP, notably if deviations are compared to the magnitude of the forward rate bias. That holds as long as they limit analysis to a set of industrialized countries with free capital movements. By contrast, CIP fails for a set of countries where cross-border capital flows are restricted by law. Frankel (1992) therefore advocates using deviation from CIP as a gauge for international capital mobility. He refers to studies that show a statistically significant decrease in departure over recent years, which he interprets as evidence for ongoing capital flow liberalizations. Gultekin et al. (1989) analyze return differentials between Euroyen investments traded in London and interest rates on comparable yen deposits traded in Tokyo. Since deposits are identical except for their trading location, differentials provide evidence for deviation from CIP. Gultekin et al. report large interest rate differentials between 1977 and 1980, a period during which Japan had capital flow restrictions imposed. Interestingly, differentials quickly disappeared after restrictions were removed in 1981. More recently, Ma et al. (2004) provide evidence for large differentials between Chinese onshore and Chinese offshore interest rates. The latter are calculated from non-deliverable forwards on the Renminbi (CNY) and are traded outside of China. If capital was free to move, such spreads would disappear by force of arbitrage. China, however, maintains a battery of capital flow restrictions, which prevents exploitation of risk-less profit opportunities. For a comprehensive overview of recent changes to Chinese capital control measures, see Liu and Otani (2005).¹

Besides legal restrictions, international capital flows could be discouraged by prohibitive transaction costs. The literature models the latter by defining a band of inaction whose range widens as transaction costs increase. As long as departure from CIP stays within the band's borders, arbitrage is not profitable and CIP follows a random walk. Arbitrage only sets in as departure goes beyond the band so that profit opportunities are large enough to cover transaction fees. Authors taking account of transaction costs attribute high efficiency to money markets. The reason is that deviation from CIP hardly ever leaves the band. In other words, as soon as arbitrage opportunities arise, they are exploited by attentive arbitrageurs. For studies relating deviation from CIP to transaction costs, see, for example, Frenkel and Levich (1977), Fratianni and Wakeman (1982), Clinton (1988) or Balke and Wohar (1998).

¹Liu and Otani (2005), appendix I, page 19 ff.

2.2.2 Country or Political Risk Premia

Deviation from CIP might also arise due to country-specific or political risks (see Aliber, 1973). Accurately speaking, CIP does not really fail in this case because observed deviation arises here as a consequence of investors comparing apples with oranges. Deposits from different countries are not comparable if investors expect the introduction of capital control measures (see Dooley and Isard, 1980) or if a country is expected to default. If investors do not account for differences when comparing deposits, deviation from CIP will be observed. Departure might also arise if investments in certain currencies offer tax advantages, which can be interpreted as “fringe benefits” not reflected in interest rates. Things become very complicated if tax codes do not apply to all investors alike. This results in different perceptions about the “return plus fringe benefit” on the very same asset. Since CIP can never satisfy all perceptions, some departure must occur somewhere.

2.2.3 Measurement Complexities

Minor deviations from CIP might finally occur due to inaccurate data. Agmon and Bronfeld (1975) emphasize difficulties related to bid-ask spreads, whereas Taylor (1987) points to complexities related to contemporaneous sampling. He emphasizes that there are differences between published and actually tradable rates. By carefully sampling high-frequency data from the London foreign exchange market, Taylor finds strong support for CIP.

We can summarize that CIP holds tightly for industrialized countries where deviations move within a narrow band of inaction. Only if countries had capital flow restrictions in place or if investments were subject to country-specific risks, would CIP deviate from zero. This thesis henceforth assumes validity of CIP. That seems an unproblematic assumption because all our empirical investigations are based on data from countries with liberalized capital markets. Moreover, parity relationships are usually calculated on the basis of Euromarket rates. The Euromarket is an interbank money market where trading takes place between large international banks with similar credit worthiness. Since the Euromarket is located in London, it is not much affected by country-specific risks. Therefore, a comparison of Euromarket rates across currencies is neither biased by default spreads nor by differences in country risk premia.

2.3 Forward Rate Bias

Since CIP holds closely for industrialized countries, almost all of the deviation from UIP must stem from the second term in equation 2.2, $E_t s_{t+1} - f_{t,t+1}$, known as the forward rate bias. The forward rate bias is not directly testable because we lack information on the representative investor's expected spot exchange rate, $E_t s_{t+1}$. Empirical work analyzing whether forward rates serve as unbiased predictors for future spot exchange rates manages with plugging in actual realizations for the latter. Dozens of investigations have been conducted on the basis of the following regression:

$$s_{t+1} - s_t = \alpha + \beta(f_{t,t+1} - s_t) + \epsilon_{t+1} \quad (2.3)$$

Since deviation from CIP is insignificant in size, the forward rate premium, $f_{t,t+1} - s_t$, can be replaced by nominal interest rate differentials. Alternatively, various studies therefore run the following regression:²

$$s_{t+1} - s_t = \alpha + \beta(i_{t,t+1} - i_{t,t+1}^f) + \epsilon_{t+1} \quad (2.4)$$

If the parity relationship held on average, β should be one and α zero. This would imply that interest rate advantages were offset by countervailing exchange rate movements on average, so that returns on domestic and foreign deposits were equal in the long run. Since empirical investigations usually rely on s_{t+1} instead of $E(s_{t+1})$, they are based on a joint hypothesis. It is in fact assumed that (1) UIP prevails, which means that there is no risk premium, and that (2) agents form expectations in a rational manner. This combined assumption is sometimes referred to as the “risk-neutral efficient-market hypothesis”. Due to the abundance of empirical literature on deviation from UIP, we can here only cite a representative selection of contributions. The subsequent summary is structured in chronological order because results depend critically on the historical period analyzed.

²The terms forward premium and forward bias are not to be confused. When we talk of a forward premium, sometimes referred to as forward discount, we mean the difference between *current* forward and *current* spot exchange rates. By contrast, the forward bias represents the difference between *current* forward and expected *future* spot exchange rates. Since CIP holds permanently, the latter corresponds precisely to deviation from UIP.

2.3.1 Evidence from the 1970s and 1980s

Bilson (1981) measures deviation from UIP against USD deposits by pooling data across time and across nine major currencies. The hypothesis of β being one is rejected but not the hypothesis that the slope coefficient equals zero. Bilson then divides observations into two subsamples by basing categorization on the size of the forward premium. He reports that the forward rate provides a bad prediction in periods of large forward premia. Generalized least squares (GLS) regressions generate a slightly positive β estimate well below one for the group exhibiting small forward premia and a slightly negative estimate for the group exhibiting large forward premia. Longworth (1981) estimates equation 2.3 for USD and CAD interest rate differentials for different subperiods between July 1970 and December 1978. Due to large standard deviations, he cannot reject the unbiasedness hypothesis for β when looking at the entire sample and that despite the fact that he obtains negative β estimates for all subsamples but one. He concludes that the current spot exchange rate provides a better prediction for future spot exchange rates than current forward rates. Fama (1984) runs estimations of equation 2.3 for nine different currencies against the USD. His data set ranges from August 1973 to December 1982. The slope estimate turns out to be negative and significantly different from one for most subsamples. In a survey on foreign exchange efficiency, Boothe and Longworth (1986) summarize several studies, which all report negative slope estimates. The hypothesis of $\beta = 1$ is typically rejected, but not the alternative hypothesis of β being zero. McCallum (1994) provides overwhelming evidence against UIP in an analysis of USD/DEM, USD/GBP and USD/JPY exchange rates. His data set includes observations from January 1978 to July 1990. He obtains β coefficients in the vicinity of minus three with all coefficients significantly smaller than one. Similar results are reported by Backus, Foresi and Telmer (1995) analyzing data from July 1974 to April 1990. They receive slope estimates in a range between -0.81 and -3.54, depending on the currency investigated. Except for one, all β estimates turn out to be significantly smaller than one.

In summary, we can say that empirical evidence from the 1970s and 1980s unanimously suggests that forward rates provide a poor prediction for future spot rates. The hypothesis of β being equal to one is usually rejected, and some authors even report slope estimates that are significantly lower than zero. A negative β implies that forward markets systematically misprice future spot exchange rates. If, for example, forward rates signal an appreciation, a depreciation is more likely to occur and vice versa if forward rates point towards a depreciation. This

phenomenon is known as the forward rate anomaly or forward rate puzzle and has a counterpart in UIP language, viz. it implies that high interest rate currencies tend to appreciate and that low interest rate currencies tend to depreciate. Investors speculating on high-yield currencies are thus likely to earn a double profit, namely from interest rate differentials as well as from exchange rate movements in their favor.

2.3.2 Evidence from the 1990s onwards

More recently, evidence has emerged that UIP's failure is less dramatic than previously thought. Typically, that is postulated by studies (1) incorporating emerging market currencies or (2) focusing on data from the 1990s. Others show that the bias is less pronounced (3) for long-term interest rate differentials or (4) when expected excess returns are large.

Bansal and Dahlquist (2000) run estimations on a large cross-section of 28 developed and emerging market economies. Slope coefficients are found to be positive for most emerging market economies, which leads them to conclude that the forward rate anomaly is a phenomenon confined to advanced economies. Bansal and Dahlquist show, moreover, that UIP loses vigor in countries with a high per capita income, low inflation rate and moderate inflation volatility. These results are corroborated by Frankel and Poonawala (2006) who reject the UIP hypothesis for developed and developing economies, but show that the forward rate bias is less severe for the latter group of countries. They relate their finding to the fact that exchange rates in developed countries are more difficult to predict than exchange rates in emerging market economies. This argument implicitly draws on the assumption that UIP fails due to biased predictions stemming from irrationality and not due to a risk premium component.

Huisman et al. (1998) examine 15 currencies against the British pound for the period from 1976 to 1996. They obtain a pooled slope coefficient of approximately 0.5. In spite of their encouragingly large estimate, the UIP hypothesis of β being one is still rejected. Flood and Rose (2002) report different results by running a pooled estimation for 23 developed and emerging market countries with data of the 1990s. In contrast to Bansal and Dahlquist (2000), the former cannot identify any relationship between biasedness and income level. The null hypothesis of β being unity is rejected, but Flood and Rose obtain a slightly positive slope estimate. They conclude that UIP seems to have worked better during the 1990s than during earlier periods. That finding is corroborated by Baillie and Bollerslev (2000) who estimate equation 2.3 for DEM/USD exchange rates on a rolling

5-years data window. Whereas they mostly obtain negative slope estimates, β becomes marginally positive at the latest fringe of their sample covering data from the 1990s. Chinn and Meredith (2005), by contrast, find that the forward rate anomaly has not diminished, let alone that it has disappeared. For most currency pairs, a more negative slope estimate is obtained for the sample between 1994 and 2000 compared to previous samples. Frankel and Poonawala (2006) examine monthly data between December 1996 and April 2004 which leads them to strongly reject the UIP hypothesis for most industrialized countries. Out of 21 advanced economies investigated, 16 exhibit a β coefficient significantly lower than zero.

Another recent strand of the literature focuses on long-run deviation from UIP. For instance, Alexius (2001) who studies various government bond yields over the period from 1957 to 2007. She mostly obtains positive slope estimates and concludes rather vaguely that her “results open up the possibility that UIP could hold better for long interest rates than for short interest rates”. Chinn and Meredith (2004) also test long-run deviations on the basis of government bonds. For all currencies under examination, β turns out to be positive and closer to unity than to zero. Similar results are reported by Chinn (2006) for 5- and 10-years government bond yields in major currencies against the USD. Alexius (2001) and Chinn (2006) emphasize that UIP regressions based on government bonds entail various difficulties so that results must be interpreted with care. Long-run analyses, for instance, rely on synthetic government yields of constant maturity, which must be constructed before putting the data to estimation. In contrast to Euromarket rates, which are frequently traded and offshore in nature, government bond yields might exhibit country risk and liquidity premia, which skews regression results. Finally, Chinn (2006) notes that long-term estimates come with large standard deviations, which makes it difficult to draw statistically relevant results.

Sarno, Valente and Leon (2006) advocate accounting for non-linearities in bias regressions. They refer to the “limits to speculation” hypothesis, according to which expected excess returns are only exploited if they exceed a certain threshold level. It is argued that financial institutions do not engage in currency speculation, unless risk-reward opportunities are more favorable than for alternative investment strategies. They therefore propose a non-linear reversion model in which UIP only unfolds as expected risk-reward opportunities increase. Monte Carlo experiments indeed reveal a rapid reversion towards UIP for large Sharpe ratios.

In general, we can conclude that the empirical literature from the 1990s does

not reject UIP so decidedly as previous work. Studies analyzing long-run deviations or emerging market currencies rarely report negative β estimates. The same can be said for contributions focusing on data from the early 1990s, but not for investigations examining more recent data sets. Although there is less evidence for forward rates pointing in the wrong direction, most studies still find a slope coefficient below unity. From a speculator's perspective, a β estimate between zero and one implies that exchange rate movements partly erase excess returns from interest rate differentials. Apparently, speculation against UIP is still profitable but less so than previously thought.

2.4 Exploiting Survey Data

We have shown that UIP can be tested by regressing actual on forward-implied exchange rate depreciation. Such a test is based on the combined hypothesis that there does not exist a risk premium and that agents' expectations are unbiased. Consequently, one can never distinguish whether UIP fails due to systematically biased predictions or due to a risk premia component. Surveys on exchange rate expectations offer a solution because they allow analyzing whether respondents make systematically biased predictions. If an ex-post analysis indeed reveals that predictions routinely deviate from actual exchange rates in one and the same direction, agents must be irrational. In that case, departure from UIP is at least partly due to biased expectations. We subsequently review two commonly applied irrationality tests, viz. tests for (1) unbiasedness and tests for (2) orthogonality. We then demonstrate that the slope estimate in equation 2.3 can be decomposed into a term due to irrationality and a term due to currency risk premia. Before proceeding, it might be helpful to visit table 2.1, which provides mathematical definitions of frequently used terminology.

2.4.1 Unbiasedness

Tests for unbiasedness serve to evaluate whether survey implied expectations provide accurate predictions for future spot exchange rates. That question is closely related to the forces responsible for deviation from UIP. After all, rejecting unbiasedness would imply that at least a minimal part of departure from UIP must be due to erroneous expectations as opposed to currency risk premia. The unbiasedness hypothesis is usually tested by running the following regression:

$$s_{t+1} = a_0 + a_1 E_t(s_{t+1}) + \epsilon_{t+1} \quad (2.5)$$

symbol	description
$s_{t+1} - s_t$	actual depreciation
$E_t(s_{t+1}) - s_t$	expected depreciation
$E_t(s_{t+1}) - s_{t+1}$	expectational error
$f_{t,t+1} - s_t$	forward premium or forward discount
$f_{t,t+1} - s_{t+1}$	forward bias
$f_{t,t+1} - E_t(s_{t+1})$	risk premium

Table 2.1: Terminology

where $E_t(s_{t+1})$ corresponds to the expected survey exchange rate for $t + 1$, and ϵ_{t+1} denotes the error term. Under unbiasedness, expectations are true on average, which implies that $a_0 = 0$ and that $a_1 = 1$. Dominguez (1986) estimates equation 2.5 in first differences by regressing actual against realized depreciation. She strongly rejects the unbiasedness hypothesis for all currencies at all time horizons. In fact, a_1 turns out to be negative for numerous currency pairs, which indicates that the average survey forecast usually points in the wrong direction. Frankel and Froot (1987) compare survey forecasts with actual exchange rate realizations as postulated in equation 2.5. Their data set includes major currencies against the USD and covers data from the early 1980s. It is found that the mean survey respondent systematically underpredicts the USD's appreciation during the period under investigation. Takagi (1990) corroborates these findings by providing an overview of exchange rate surveys. It is generally found that survey measures systematically failed to predict the strength of the USD in the beginning of the 1980s. It was precisely the other way round in the second half of the decade, when survey measures failed to anticipate the dollar's persistent depreciation. Similarly to Dominguez (1986), Ito (1990) runs a regression of equation 2.5 in first difference form. He rejects the unbiasedness hypothesis for the JPY/USD exchange rate, notably for longer forecast horizons. He also analyzes exchange rate expectations sorting answers by industry affiliation and finds "wishful" expectations. More specifically, he provides evidence of a depreciation bias in export-oriented and an appreciation bias in import-oriented industries. Cavaglia et al. (1993) analyze survey data for the second half of the 1980s by regressing equation 2.5 in first differences. It is found that a_0 deviates significantly from zero, whereas a_1 is significantly different from one, usually even negative. Overall, we can conclude that the unbiasedness hypothesis is decidedly rejected. Some authors even find

that survey measures point in the wrong direction.

2.4.2 Orthogonality

Another aspect of rational expectations is orthogonality, which demands that agents use all available information when forming expectations. This implies that forecast errors in $t + 1$ are uncorrelated with all variables in the information set available at time t . Usually, orthogonality is tested by regressing forecast errors on information variables as shown below:

$$E_t(s_{t+1}) - s_{t+1} = a_0 + a_1 X_t + \epsilon_{t+1} \quad (2.6)$$

where $E_t(s_{t+1}) - s_{t+1}$ corresponds to the forecast error at $t + 1$, and X_t denotes the vector of information variables at t . Under orthogonality, a_0 and a_1 would be close to zero, indicating that one cannot extract any forecast information from time t variables. Most studies use one of the three following measures as explaining variable: (1) past forecast errors, (2) forward premia or (3) recent exchange rate movements. Frankel and Froot (1989) regress forecast errors on forward premia. They find a positive value for a_1 in all regressions investigated, usually at statistically significant levels, which signals excessive speculation because predictions seem to systematically overshoot into the direction of the forward rate. Ito (1990) analyzes the JPY/USD exchange rate by regressing exchange rates on past forecast errors, forward premia and recent exchange rate movements separately. For most estimations orthogonality is rejected. Chinn and Frankel (1994) regress forecast errors $E_t(s_{t+1}) - s_{t+1}$ on the survey measure of expected depreciation $E_t(s_{t+1}) - s_t$ and find that predictions overestimate actual exchange rate movements. That agrees with Frankel and Froot (1989), who provide evidence on excessive speculation. Market participants would be better off by moderating their predictions so that they were closer to a random walk. Interestingly, Chinn and Frankel find that the orthogonality hypothesis is not strongly rejected for currencies with high inflation rates. Exchange rate predictability becomes more accurate as inflation differentials increase, which might be due to purchasing power parity (PPP) exerting more influence in high-inflation environments. Note that this finding fits well with the observation by Bansal and Dahlquist (2000) and Frankel and Poonawala (2006), who report that UIP holds better for emerging market economies.

2.4.3 Decomposing Beta

Using survey data, Cavaglia et al. (1994) decompose β from equation 2.3 into a term due to currency risk and a term due to expectational errors. They reformulate β and arrive at:

$$\beta_{t,t+1} = \frac{\text{cov}(\eta_{t,t+1}, f_{t,t+1} - s_t) + \text{cov}(E_t(s_{t+1}) - s_t, f_{t,t+1} - s_t)}{\text{var}(f_{t,t+1} - s_t)} \quad (2.7)$$

where $\eta_{t,t+1}$ denotes the expectational error between t and $t+1$ defined in table 2.1, and $E_t(s_{t+1})$ is the expected spot exchange rate in t for $t+1$. The forward premium can be expressed as follows:

$$f_{t,t+1} - s_t = E_t(s_{t+1}) - s_t + \underbrace{f_{t,t+1} - E_t(s_{t+1})}_{rp_{t,t+1}} \quad (2.8)$$

where $rp_{t,t+1}$ represents currency risk premia. Expressed in words, the forward discount corresponds to a summation of two terms: (1) expected depreciation and (2) currency risk premia. In comparison to forward rates, survey-based exchange rate expectations thus provide a better forecast for future spot exchange rates. After all, forward rates might be polluted by risk premia, whereas survey data are not. Reshuffling equation 2.8 leaves us with the following expression for $rp_{t,t+1}$:

$$rp_{t,t+1} = f_{t,t+1} - s_t - (E_t(s_{t+1}) - s_t) \quad (2.9)$$

Cavaglia et al. (1994) replace $E_t(s_{t+1}) - s_t$ in the second covariance term of equation 2.7 with $f_{t,t+1} - s_t - rp_{t,t+1}$, which follows from equation 2.9. That allows decomposing $\beta_{t,t+1}$ into its components $\beta_{t,t+1}^{re}$ and $\beta_{t,t+1}^{rp}$. We can write:

$$\beta_{t,t+1} = \beta_{t,t+1}^{re} + \beta_{t,t+1}^{rp} \quad (2.10)$$

where

$$\beta_{t,t+1}^{re} = \frac{\text{cov}(\eta_{t,t+1}, f_{t,t+1} - s_t)}{\text{var}(f_{t,t+1} - s_t)} \quad (2.11)$$

and

$$\beta_{t,t+1}^{rp} = 1 - \frac{\text{cov}(f_{t,t+1} - s_t, rp_{t,t+1})}{\text{var}(f_{t,t+1} - s_t)} \quad (2.12)$$

If survey predictions were unbiased on average, $\beta_{t,t+1}^{re}$ should be in the vicinity of zero. This hypothesis is tested by Frankel and Froot (1989) and Cavaglia et al. (1994) in an orthogonality test by regressing forecast errors on forward premia. Both authors reject orthogonality, which leads them to the conclusion that at least part of the forward rate bias must stem from irrationality.³ To understand the second term, assume for a moment that $\beta_{t,t+1}^{re}$ were zero. In that case, the widely established finding of $\beta_{t,t+1} < 1$ would be due to the second term being smaller than one, i.e. $\beta_{t,t+1}^{rp} < 1$. The latter condition could only be fulfilled if risk premia had a positive covariance with forward discounts $f_{t,t+1} - s_t$ which would imply that risk premia exhibited time-variation. In fact, this corresponds to what Fama (1984) finds in a landmark article on the forward rate anomaly discussed in the subsequent section. Cavaglia et al. (1994) evaluate the importance of the risk premium component by regressing expected depreciation on forward discounts. Their regression is shown below:

$$E_t(s_{t+1}) - s_t = a_0 + a_1(f_{t,t+1} - s_t) + \epsilon_{t,t+1} \quad (2.13)$$

Under the null hypothesis that forward discounts reflect expected depreciation on average, one would expect that $a_0 = 0$ and that $a_1 = 1$. For that reason, Cavaglia et al. (1994) interpret their regression as a test for perfect substitutability between forward rates and expectations. Note the similarity between equation 2.13 and the bias regression in equation 2.3. The only difference pertains to the dependent variable, which is here defined as the expected as opposed to the actual exchange rate depreciation. In fact, equation 2.13 can be interpreted as a test for UIP not polluted by irrational expectations. Consequently, a_1 amounts to a direct measure of the importance of the risk premium component, which increases as the slope coefficient, a_1 , becomes smaller than one. The constant, a_0 , is a measure for the average risk premium. The definition of risk premia in equation 2.9 implies that a_1 corresponds to $\beta_{t,t+1}^{rp}$ shown in equation 2.12. Cavaglia et al.'s (1994) estimations strongly reject that a_1 equals one. They therefore conclude that the forward rate bias must be driven by both biased predictions as well as time-varying risk premia. The same regression is run by Frankel and Froot, who find that a_1 is not statistically different from unity. Their results thus suggest that most of the variation in the forward rate bias is driven by expectational errors as opposed to time-varying risk premia. Chinn (2006) reports similar results for long-term exchange rate predictions. His panel regression produces a slope estimate of

³See section 2.4.2 for a discussion of the orthogonality literature.

0.737, which lies well within two standard deviations from unity.

2.5 Fama's Forward Rate Anomaly

We have shown that forward rates systematically deviate from future spot exchange rates. This phenomenon is known as the forward rate bias and is equal in size to deviation from UIP. Such systematic deviations offer statistical profit opportunities, which is why the bias is sometimes referred to as the forward rate anomaly or the UIP puzzle. In an influential paper, Fama (1984) points out that there is another aspect to the conundrum. He shows that risk premia must vary a lot - even more than expectations on exchange rate depreciation. That is an important finding since it implies that successful exchange rate models must capture large variations in currency risk premia. Many models fail to generate that feature as we argue in section 3. Subsequently, we display what Fama (1984) found. His argumentation is based on the following two regressions:

$$s_{t+1} - s_t = \alpha_1 + \beta_1(f_{t,t+1} - s_t) + \epsilon_{t+1} \quad (2.14)$$

$$f_{t,t+1} - s_{t+1} = \alpha_2 + \beta_2(f_{t,t+1} - s_t) + \epsilon_{t+1} \quad (2.15)$$

The first equation corresponds to the above shown bias regression of actual depreciation on forward implied depreciation and reveals information on whether forward markets provide a good prediction for future spot exchange rates. The second equation regresses the difference between forward rates and future spot rates on the difference between forward rates and current spot rates. It follows from equation 2.8 that the forward rate can be decomposed into the expected exchange rate and a risk premium component, i.e. $f_{t,t+1} = E(s_{t+1}) + rp_{t,t+1}$. Fama postulates rational expectations, and he abstracts from problems related to in-sample bias and heterogeneity. That allows him to assume that $E_t(s_{t+1}) = s_{t+1}$, which means that expectational errors are purely random. Regression 2.14 and 2.15 are closely related so that estimates of α_1 and β_1 enable us to determine α_2 and β_2 and vice versa. To see this, note that the summation of the left hand side variables, $s_{t+1} - s_t$ and $f_{t,t+1} - s_{t+1}$, is precisely equal to $f_{t,t+1} - s_t$. The latter corresponds to the regressor, which implies that α_1 and α_2 must sum up to zero, whereas the sum of the slope coefficients β_1 and β_2 must be equal to unity. Equation 2.8 postulates that the forward premium can be decomposed into a risk premium component and a term representing expected depreciation. If that is

kept in mind, and if rationality is assumed, we obtain the following expression for the slope coefficient in equation 2.14:

$$\begin{aligned}\beta_1 &= \frac{\text{cov}(s_{t+1} - s_t, f_{t,t+1} - s_t)}{\text{var}(f_{t,t+1} - s_t)} \\ &= \frac{\text{var}(E_t(s_{t+1}) - s_t) + \text{cov}(rp_{t,t+1}, E_t(s_{t+1}) - s_t)}{\text{var}(rp_{t,t+1}) + \text{var}(E_t(s_{t+1}) - s_t) + 2\text{cov}(rp_{t,t+1}, E_t(s_{t+1}) - s_t)}\end{aligned}\quad (2.16)$$

This result is obtained by replacing $f_{t,t+1} - s_t$ in the first fraction with the right hand side variables of equation 2.8 and by setting $E_t(s_{t+1})$ equal to s_{t+1} . A similar procedure allows us to write the slope coefficient in equation 2.15 in terms of risk-premia and expected depreciation:

$$\begin{aligned}\beta_2 &= \frac{\text{cov}(f_{t,t+1} - s_{t+1}, f_{t,t+1} - s_t)}{\text{var}(f_{t,t+1} - s_t)} \\ &= \frac{\text{var}(rp_{t,t+1}) + \text{cov}(rp_{t,t+1}, E_t(s_{t+1}) - s_t)}{\text{var}(rp_{t,t+1}) + \text{var}(E_t(s_{t+1}) - s_t) + 2\text{cov}(rp_{t,t+1}, E_t(s_{t+1}) - s_t)}\end{aligned}\quad (2.17)$$

Our literature review in section 2.3 reveals that most investigations report a β_1 estimate decidedly smaller than one. Most studies analyzing data from the 1970s and the 1980s even obtain negative estimates. In equation 2.16, the denominator and the variance component of the numerator must be positive so that the negative sign of the slope estimate must stem from $\text{cov}(rp_{t,t+1}, E_t(s_{t+1}) - s_t) < 0$. This is simply a reformulation of the anomaly which we already know from regression analysis, viz. that forward rates tend to point in the wrong direction. This becomes clear if we remember the definition of the risk premium, which is $rp_{t,t+1} = f_{t,t+1} - E(s_{t+1})$. A negative covariance implies that the forward rate tends to point towards an appreciation even though markets expect a depreciation and vice versa if markets expect an appreciation.⁴ Decomposing β_1 and β_2 reveals a second insight. Under the assumption that the correlation between risk premia and expected depreciation is zero, i.e. $\text{cov}(rp_{t,t+1}, E_t(s_{t+1}) - s_t) = 0$, β_1 and β_2 decompose the total variance of $f_{t,t+1} - s_t$ into the fraction due to the variance in $E(s_{t+1}) - s_t$ and the fraction due to the variance in $rp_{t,t+1}$, respectively. Interpretation is not straightforward when $\text{cov}(rp_{t,t+1}, E(s_{t+1}) - s_t) \neq 0$. Note, however, that equations 2.16 and 2.17 differ merely with respect to the first term in the numerator. The slope parameters do therefore still reflect variance proportions. Since empirical studies reveal that β_1 is small or even negative and since β 's must

⁴Fama assumes rationality, which implies that $E(s_{t+1}) = s_{t+1}$.

sum up to 1, β_2 must be large and positive. This implies that the bulk of the variation in $f_{t,t+1} - s_t$ is due to the risk premium component as opposed to the variation in expected depreciation. Consequently, currency models must be capable of generating large variations in risk premia. As we demonstrate below, early models usually fail to account for this feature. Once again, it should be emphasized that Fama's findings are only valid in efficient markets. His derivation is based on the assumption of rational agents who get exchange rate expectations right in the long run. Fama's conclusions are notably not valid under in-sample bias or heterogeneity, two concepts explained in chapter 3.

2.6 Conclusion

UIP demands that interest rate differentials are offset by countervailing exchange rate movements on average and in the long run. There exists, however, ample evidence that the parity relationship fails, which implies that statistical profit opportunities are left unexploited. Empirical investigations from the 1970s and 1980s even report that high interest rate currencies tend to appreciate and that low-yield currencies tend to depreciate, thereby rewarding investors with a double gain, viz. from interest rate differentials and from currency movements in their favor. This phenomenon is commonly known as the forward rate anomaly or the UIP puzzle. The finding of a double gain is more and more challenged in recent work, notably by contributions analyzing long-term interest rate differentials or emerging market currencies. These studies usually find that high-yield currencies tend to depreciate and that low-yield currencies tend to appreciate as UIP predicts but that returns from interest rate differentials are only partly offset by countervailing exchange rate movements. In other words, recent studies reinforce the hypothesis that UIP fails but deviations seem to be less severe than formerly assumed.

Although there exists a plethora of studies providing empirical evidence against UIP, it remains difficult to draw inferences about the forces driving departure. Some authors propose using survey data on exchange rate expectations, which allow distinguishing whether deviation is due to a risk premium or market irrationality. Tests for unbiasedness and orthogonality indeed reveal that exchange rate expectations are inefficient, which implies that market participants make systematic prediction errors. This indicates that the forward rate bias cannot be driven by risk premia alone. In fact, some commentators argue that deviation from UIP is primarily driven by expectational errors as opposed to a risk pre-

mium. However, survey data do not reveal whether forecast errors arise due to market irrationality, in-sample bias or regime shifts. These concepts are explained in section 3 subsequently.

Chapter 3

Explaining Deviation from UIP

International economists have devoted enormous efforts towards finding a solution to the forward rate anomaly. The main purpose of this chapter is to provide a comprehensive and structured overview of the many solutions proposed by assigning existing explanations to four broad categories. The first model category assumes that deviation from UIP stems from irrationality. The second attributes departure to sampling bias, whereas the third relates the anomaly to regime shifts and heterogeneous beliefs. The fourth category is the broadest in terms of research coverage and interprets deviation as a compensation for bearing risk.

3.1 Introduction

UIP appears to draw on empirically sound foundations. After all, attentive investors could exploit statistical profit opportunities resulting from systematic violations by speculating against the parity relationship. We explain in chapter 1 how ensuing capital flows immediately trigger interest and exchange rate adjustments driving UIP back towards parity. In view of the relationship's underlying rationale, it seems puzzling that empirical work overwhelmingly rejects the UIP hypothesis. Dozens of studies have been published claiming to solve the anomaly. In this chapter, we review competing explanations and show how our work relates to the existing body of knowledge.

In order to structure the extensive literature, we suggest sorting explanations on the basis of underlying theory assumptions. The diagram in figure 3.1 serves as a guideline throughout the discussion in this chapter. It shows four different theories, each represented by a circle whose size visualizes its relative importance in terms of research coverage. It can be seen that only few studies propagate (1) irrationality to explain the UIP puzzle. The literature on (2) in-sample bias

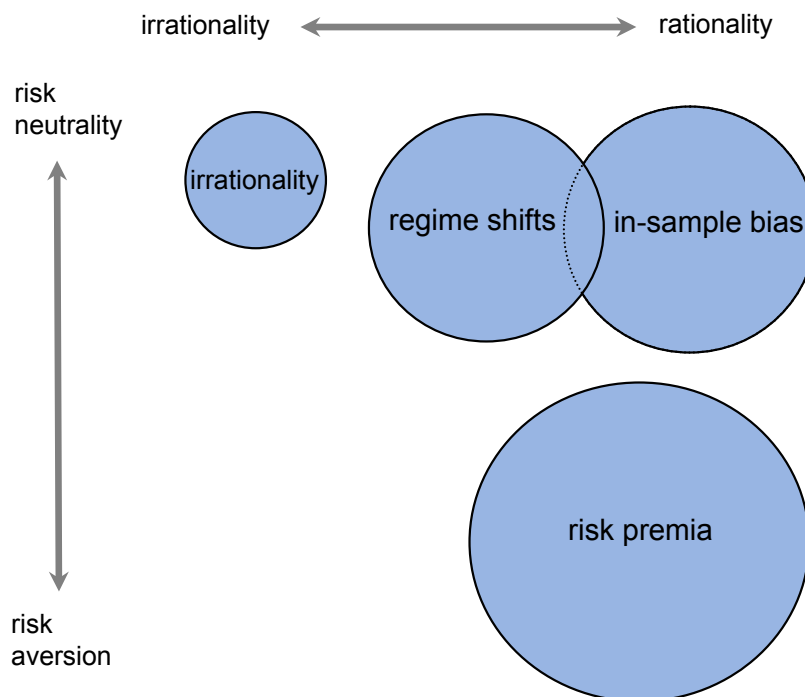


Figure 3.1: Solving the UIP puzzle: Overview

and on (3) regime shifts and heterogeneous beliefs is more widespread, but most authors focus on (4) currency risk premia explanations. Theories or circles gravitate between risk neutrality and risk aversion on the one hand and between rationality and irrationality on the other hand. Risk-averse investors evaluate assets along two dimensions, viz. with respect to expected returns and implied risks. Under risk aversion, departure from UIP does not present a conundrum because deviations could arise as a compensation for risk. By contrast, under risk neutrality, optimization is one-dimensional only, namely with regard to expected returns. Deviation from UIP should theoretically not occur in such settings because risk-neutral agents exploit all available profit opportunities, irrespective of risks involved. In a risk-neutral world, deviation from UIP must thus either stem from irrationality or information inefficiency. That should be kept in mind during the subsequent literature review.

3.2 Irrationality

Theories based on irrationality assume that the forward rate anomaly originates from irrational investors who make systematically biased predictions about future spot exchange rates. A systematic bias arises if forecasts tend to deviate into one and the same direction. This is the case if agents permanently predict an appreciation which markets more often than not fail to deliver. Survey studies usually confirm that expectations are biased by providing evidence for a wedge between expected and actual future spot exchange rates. As we see in section 2.4, survey data enable us to differentiate whether deviation from UIP is driven by a risk premium or whether it is due to some other factor, but surveys stay silent on whether UIP fails due to irrationality, sampling bias or heterogeneous beliefs.

Those claiming that departure from UIP is due to irrationality encounter difficulties to prove their assumption because irrationality does not follow any sensible rule and cannot be modeled. It seems as if irrationality is often advanced by studies arriving at a dead end due to lack of alternative suggestions. Longworth (1981) postulates a simple trading rule by betting on CAD and USD interest rate differentials which proves to be highly profitable. However, he fails to explain why agents refrain from pushing interest rates back towards parity by speculating against UIP. That leads him to conclude that deviation must stem from market inefficiency driven by a shortage of long-term speculative funds which could keep exchange rates in equilibrium. Froot and Thaler (1990) provide an explanation related to irrationality and argue that the forward rate anomaly originates

from slow moving investors. In their setting, agents require time to think before engaging in speculation.

In terms of quantity, the academic literature on irrationality plays a marginal role. Financial practitioners are probably more ardent followers of the irrationality guild. The observed increase in speculative demand for strategies betting against UIP supports this assumption. Although there is no direct evidence on UIP speculation, available indicators suggest that speculation on interest rate differentials is flourishing (see section 4.4). If market participants instead believed that deviation from UIP was driven by a risk premium or an in-sample bias, speculative demand for low- and high-yield currencies would not differ much in size from each other.

3.3 In-Sample Bias

Engel (1996) argues that tests for forward rate efficiency might suffer from an in-sample bias. The latter arises if the information set of the econometrician differs from that of the market. If that was the case, bias regressions could reject the efficiency hypothesis even though it was true and could possibly confirm it even though it was not true. Non-congruency in information sets might happen for one of two reasons: (1) Peso or reverse peso effects and (2) learning effects. (Reverse) Peso effects arise if the econometrician works on a non-representative data sample which leaves him with inferior information in comparison to the market. It is precisely the opposite with learning effects where the econometrician is a step ahead of the market. This might happen if market participants only gradually learn about shifts in fundamentals and hence make biased exchange rate predictions over prolonged periods. Since the econometrician takes an ex-post perspective, he is perfectly informed at the outset of the investigation and might therefore falsely conclude that biased predictions stem from irrationality. As shown in figure 3.2, models based on peso, reverse peso or learning effects usually assume risk-neutral but rational agents. We hereafter discuss these theories.

3.3.1 Peso Effects

From April 1954 to August 1976, the Mexican peso was pegged to the USD at a rate of 0.08 USD per peso. Despite fixed exchange rates, interest rates on Mexican deposits were considerably higher than on comparable deposits in USD. This was due to an expected regime change towards a more expansionary fiscal and monetary policy, triggering a depreciation of the peso. Eventually, the expected

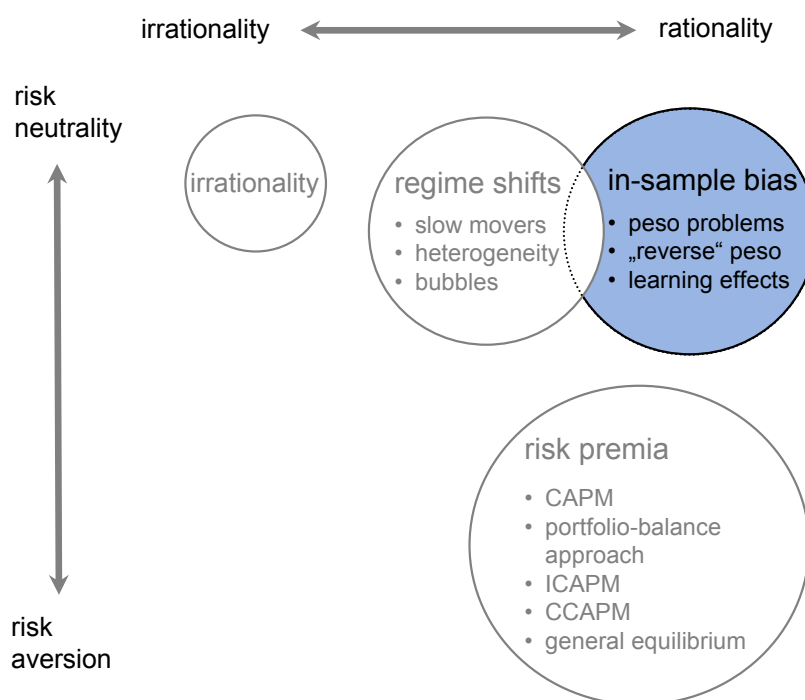


Figure 3.2: Solving the UIP puzzle: In-sample bias

depreciation did occur in August 1976 when the exchange rate plummeted by almost 40% to 0.05 USD per peso. If econometricians thus restrict analysis to the period prior to the devaluation, large and persistent deviations from UIP are observed. Given peso effects, such deviations obviously cannot be interpreted as stemming from market inefficiency. After all, agents were rationally expecting a sizeable devaluation of the Mexican peso, only were they incapable of timing the exchange rate shift. That drove a wedge between forward and expected exchange rates, which lasted for over 20 years. Ever since, the guild of economists has been referring to similar phenomena as “peso effects”. The term is now used in general to describe small sample bias resulting from rare events that potentially cause large and abrupt exchange rate movements. If such shifts do not occur within the econometrician’s sample, departure from UIP will be observed.

Krasker (1980) emphasizes that standard statistics testing for forward market efficiency are deceptive in the presence of peso effects. It is argued that a small likelihood of drastic exchange rate movements leads to fat tails and skewed distributions. Test procedures relying on normality are therefore misleading. Bates (1996) analyzes distributions implied by futures options on foreign exchange. He

shows that exchange rate distributions vary considerably over time, notably with respect to skewness and kurtosis. Although peso effects emerge, he rejects that they were responsible for the observed deviation from UIP between deposits in USD and DEM during the 1980s.

3.3.2 Reverse Peso Effects

On average, forward exchange rates signal an overappreciation of the CHF. Kugler and Weder (2005) relate this phenomenon to the *reverse* peso effect, which is attributed to safe haven qualities of the CHF.¹ Assume an econometrician working on a data set which exclusively covers uneventful periods. His data set is thus missing abrupt appreciations, which would occur in turbulent times as a consequence of the CHF's safe haven quality. Since market participants base foreign exchange rate predictions on the probability that some crisis could hit during the period of the forward contract, a systematic wedge between forward and expected exchange rates emerges. It would be wrong to relate this finding to market irrationality because agents' predictions would prove right in the very long run as some crises is bound to occur eventually.

3.3.3 Learning Effects

In a peso framework, deviation from UIP is driven by uncertainty whether rare events *will* occur or not. By contrast, learning effects describe a situation where markets are doubtful on whether a shift in regime *has occurred* or not, or when markets do not immediately grasp all exchange rate relevant consequences of a policy change. Lewis (1989) argues that the systematic underprediction of the USD's strength in the first half of the 1980s originated from learning effects. She provides evidence that US money demand experienced a considerable increase during the early 1980s. It is argued that the rise in demand was not offset by a commensurate increase in money supplies, leading to a continuous appreciation of the USD. Since markets took time to adapt to an accelerating money demand, exchange rate expectations and forward rates persistently underestimated the USD's appreciation. Learning effects are usually modeled in a regime-switching setting with agents forming exchange rate expectations on a probability-weighted average of two terms. The first term represents exchange rate expectations under the condition that no regime shift has occurred. By contrast, the second term

¹Evidence on safe haven characteristics of the CHF can be found in Kugler (2005) or in Ranaldo and Söderlind (2007).

shows expectations assuming that a shift has occurred. Probabilities are formed by Bayesian updating, which means that they are continuously revised on the basis of information from prior observations. In the absence of new shocks, learning leads to a more or less continuous diminishment of the forward rate bias. That in contrast to peso problems, where deviation from UIP is abruptly eliminated as soon as a shock occurs. Note that learning effects arise as a consequence of incomplete information and not due to irrationality.

3.4 Regime Shifts and Heterogeneous Beliefs

Engel and Hamilton (1990) investigate the USD's strength during the early 1980s and the weakness it subsequently suffered from 1985 to 1988. They argue that exchange rate movements follow long swings, alternating between long-lasting periods of appreciation and depreciation. It is shown that forward rates systematically underpredicted the USD's appreciation from 1980 to 1985. Interestingly, it was precisely the opposite thereafter when forward rate markets underpredicted the USD's weakness. To explain long-lasting swings as well as the forward market's mispricing, Engel and Hamilton propose a model where exchange rate movements follow two different normal distributions. More specifically, they postulate a segmented trends model featuring an appreciating and a depreciating regime. Investors know the parameters of both distributions and whether they are in regime one or in regime two. An important factor obscured to them is at which point in time regimes switch. Since investors are assumed to be risk-neutral, the forward rate is simply a probability-weighted average of regime predictions. Such predictions obviously lead to a systematic misalignment between forward and future spot exchange rates. The resulting bias is an increasing function of the probability of a regime change and of the expected magnitude of the exchange rate shift in case of a switch. Whereas Engel and Hamilton's specification fails empirically, a model extension by Kaminsky (1993) generates more favorable results. He additionally postulates that agents try to forecast a change in regime by evaluating information from announcements of the Federal Reserve Board (FED). Yet another successful approach is proposed by Evans and Lewis (1995) postulating exchange rate jumps when regimes switch. The models of Engel and Hamilton (1990), Kaminsky (1993) and Evans and Lewis (1995) are primarily descriptive and do not aspire to explain why different regimes emerge. Various authors propose theoretical underpinnings for regime-switching processes in foreign exchange. We here categorize these contributions into three subgroups, viz. theories based

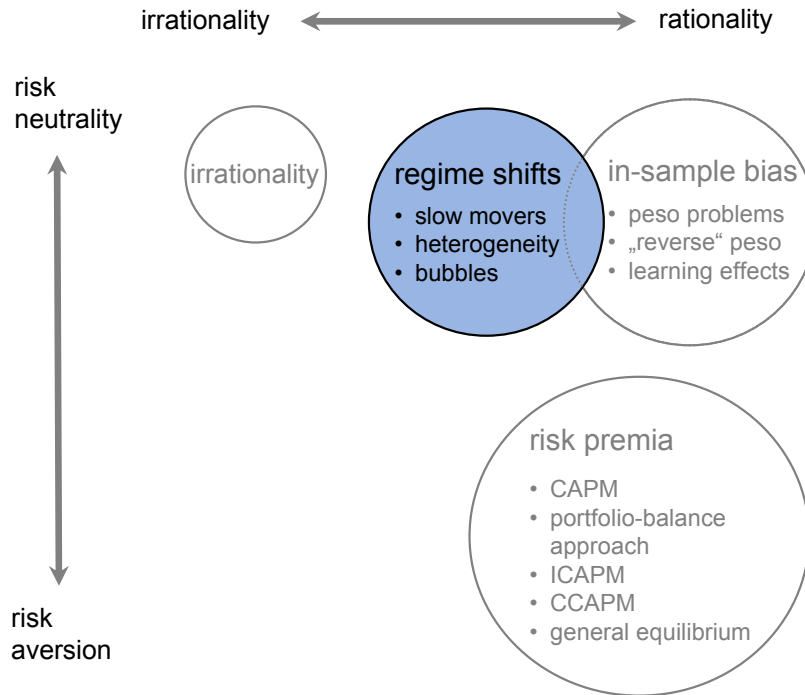


Figure 3.3: Solving the UIP puzzle: Regime shifts and heterogeneous beliefs

on (1) slow movers, (2) heterogeneous beliefs and (3) bubble phenomena.

Regime-change models are often assigned to the peso literature. Remember that peso effects arise due to information asymmetries between econometricians and market participants in a fully rational world. The theories discussed subsequently incorporate, by contrast, at least bits of irrationality. For that reason, we think it more appropriate to include a separate category labeled regime shifts and heterogeneous beliefs, located somewhat to the left of the in-sample bias phenomena in figure 3.3. Note that the two categories are interlinked because learning effects and peso problems can also be modeled in regime-switching settings.

3.4.1 Slow Movers

Froot and Thaler (1990) first noticed that the forward rate bias might arise due to slow-moving investors. To understand their argument, assume a setting where interest rates are equal initially when all of a sudden an unexpected increase in domestic rates occurs. According to UIP, large capital inflows immediately lead to an appreciation of the domestic currency. The new equilibrium is reached when

expected excess returns from interest rate differentials are counterbalanced by an expected depreciation of the domestic currency. In a world with slow movers, however, not all investors react instantly. Some might require time to think before running transactions, whereas others might be restrained by regulations restricting asset reallocation. Capital inflows thus remain insufficient to equilibrate exchange rate adjustments. As a consequence, domestic deposits continue to provide expected excess returns, which gradually lures more and more investors into the domestic market. A continuous appreciation of the domestic currency sets in. The slow mover hypothesis of Froot and Thaler provides an explanation why high interest rate currencies continue to appreciate, whereas low interest rate currencies continue to depreciate over prolonged periods. The framework thereby corroborates Engel and Hamilton's (1990) observation of long-lasting cycles of appreciation and depreciation. Bacchetta and van Wincoop (2005) extend the model by explicitly postulating rationality. In their model, a large fraction of investors is rationally inattentive because they face relatively large costs for information processing and decision taking. The remaining investors, who trade immediately, are risk-averse, which is why they are not willing to fully exploit all profit opportunities. Empirically, Bacchetta and van Wincoop can successfully explain the forward rate anomaly.

3.4.2 Heterogeneous Beliefs

Despite extensive research, there does not exist a structural model providing reliable forecasts for short-term exchange rates. In view of the impossibility to predict exchange rates, it is no surprise that expectations vary widely across survey respondents. That is what Takagi (1990) finds by investigating several surveys on exchange rate predictions. The forecast ability increases somewhat if a long-term perspective is taken. Rogoff (1996) and Kilian and Zha (2002) find, for instance, that long-term exchange rates are influenced by inflation differentials. Evaluating results from a questionnaire survey, Taylor and Allen (1992) report that long-term predictions are indeed formed on the basis of fundamentals such as deviation from purchasing power parity (PPP). However, in the short run investors are found to strongly rely on technical analysis. That is corroborated by Frankel and Froot (1990) who explore how exchange rate expectations are formed using data from various surveys. They distinguish between chartists extrapolating recent trends and fundamentalists assuming that exchange rates converge to some long-term equilibrium.

On the basis of these findings, Ahrens and Reitz (2005) propose a model where portfolio managers are torn between the perspectives of chartists and fundamentalists. Similarly to Engel and Hamilton's (1990) specification, the model postulates two regimes for exchange rate movements. The fundamental regime predicts exchange rate shifts on the basis of deviation from PPP. On the other hand, predictions from the chartist model are based on a trading rule following a simple momentum strategy. Portfolio managers form expectations by a weighted average of the fundamentalists' and the chartists' view. The weight assigned to a certain strategy positively depends on its performance in previous periods. To better understand the model's dynamics, assume that the exchange rate initially is at its long-term equilibrium where all weight is given to the fundamental component. A sudden exogenous shock might lead to an increase of the foreign interest rate, which sparks off an appreciation of the foreign currency. Since fundamentals failed to predict the event, portfolio managers suffered losses. For the next period's forecast, the fundamental weight is downgraded and more weight is assigned to predictions of the chartist model. The latter is based on a simple momentum strategy and thus signals a further appreciation of the foreign currency. Portfolio managers will therefore increase their foreign deposit holdings, which leads to a further appreciation of the foreign currency and, consequently, to a further downgrading of the fundamental weight. A self-fulfilling process sets in, leading not only to deviation from UIP but also to long-lasting depreciation of the domestic currency.

3.4.3 Bubbles

Another possible explanation for systematic deviations from UIP are bubbles which are defined as episodes during which exchange rates depart from fundamentals. Flood and Garber (1980) and Flood and Hodrick (1990) argue that asset price bubbles are not phenomena confined to irrational settings. To see this, note that most pricing models postulate that the current price depends positively on its future expected value. A bubble might therefore persist in spite of full market rationality as long as investors believe that it will continue. Put differently, agents might be fully aware of a misalignment between the level of the current exchange rate and its fundamentally justified value. Even so, they might continue to buy an already overvalued currency if they expect to profit from a further overshooting. At some point in time, the bubble will burst, and the exchange rate will realign with fundamentals. There is a fly in the ointment with this reasoning: One can explain the bubble's continuation but not its origination, at least

not under full market rationality. At least a spark of irrationality is required for a bubble to take off. From a technical perspective, a bubble phenomenon can also be modeled in a regime-switching framework (see, for instance, Blanchard, 1979). Whereas the first state represents the exchange rate's trajectory under the condition of continuation, the second state describes what happens when the bubble bursts. Both states occur with a certain probability, and exchange rate expectations are formed as a probability-weighted average. As long as the bubble remains upward-trending, exchange rate expectations and forward rates systematically underpredict actual realizations. Hence, we can not only explain deviation from UIP but also long up- and downward swings.

The USD's strength in the early 1980s and its subsequent depreciation is sometimes interpreted as a bubble phenomenon. In fact, from December 1980 to February 1985, the USD/GBP exchange rate dropped from 2.39 to 1.08. It then shot up to 1.88 by March 1988. Such pronounced alternations cannot be reconciled with movements in economic fundamentals. That holds all the more, as the USD seemed to move against fundamentals during certain subperiods (see Frankel and Froot, 1991). Investigations by Evans (1986) and Meese (1986) corroborate the bubble hypothesis, whereas Wu (1995) provides evidence against it. Testing for bubbles is not straightforward because it requires a notion of equilibrium exchange rates. After all, bubbles are defined as price discrepancies from fundamentals. Model misspecifications might therefore play havoc with testing procedures. The fact that there does not exist a consensus about fundamental exchange rate drivers does not simplify matters.² To avoid difficulties related to model misspecification and joint hypotheses, Evans (1986) advocates using a sign test. The latter is a purely statistical method, which enables Evans to evaluate whether there are abnormal returns in foreign exchange markets without having to specify an explicit exchange rate model. He defines abnormal returns as systematic deviations from UIP which cannot be explained by coincidence. At closer inspection, his test is not of much help since the null hypothesis might be rejected due to a bubble phenomenon or any other source driving a wedge between forward and future spot exchange rates such as risk premia, peso problems or learning effects.

3.5 Risk Premia

The theories discussed so far assume risk neutrality, which entails that agents exploit all available profit opportunities, irrespective of risks involved. That is

²See Meese and Rogoff (1983), who show that various structural models fail to provide reliable exchange rate forecasts.

unrealistic because real world investors exhibit a great deal of risk aversion, which makes portfolio optimization a two-dimensional concern. In a risk-averse setting, profit opportunities are carefully balanced against implied risks. The risk premia literature therefore investigates whether deviation from UIP arises as a compensation for risk exposure.

Figure 3.4 provides an overview of models relating deviation from UIP to currency risk premia. Successful models must build upon theoretically sound foundations while they must exhibit significant explanatory power. These requirements prove difficult to fulfill because currency risk premia exhibit challenging features from a modeling perspective. First of all, the cross-sectional variation in deviation from UIP is large, which signifies that models must be capable to generate large differences in currency risk premia. Standard asset pricing models usually fail in this regard because risk factors are not volatile enough to produce the required magnitudes. As a consequence, implausibly large values for the coefficient of relative risk aversion must be assumed. Modelers are trying to lower risk aversion coefficients by choosing more variable risk measures or by modifying utility functions so that they react in a more sensitive manner in response to variations in

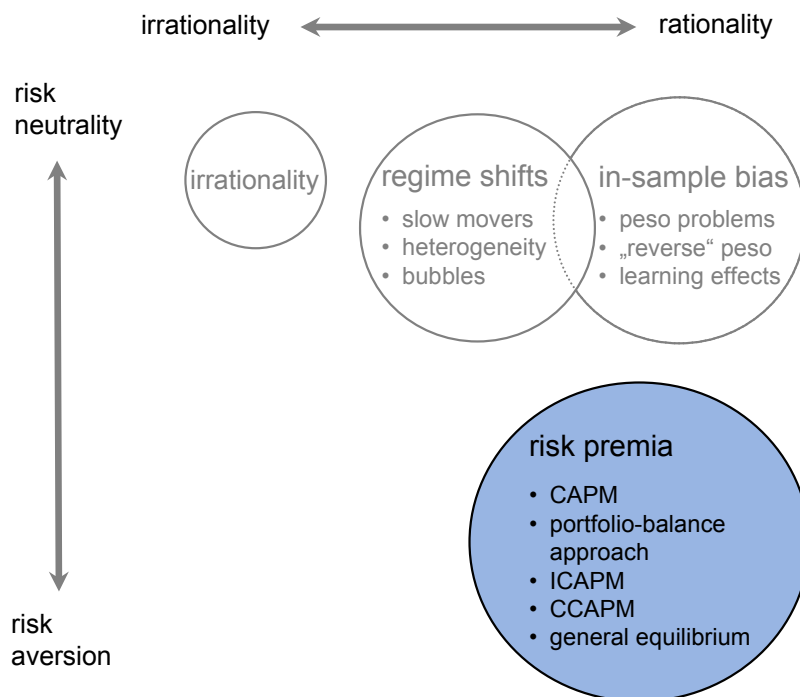


Figure 3.4: Solving the UIP puzzle: Risk premia

underlying risk factors.

Another puzzling feature is the so-called forward rate anomaly, according to which high-yield currencies tend to appreciate instead of depreciate as UIP would predict. Fama (1984) has shown that the forward rate anomaly implies large fluctuations in risk premia. In fact, variation in the risk premium must be even larger than variation in expected depreciation or in interest rate differentials. More recent contributions cope with time-variation by introducing heteroskedasticity to underlying processes or by running conditional estimations. In the subsequent literature review, we put particular emphasis on measures taken to tackle difficulties related to size and time-variation in risk premia. Before going into detail, we start with an empirical analysis of the relationship between national net saving rates and deviation from UIP, which demonstrates that risk aversion really matters.

3.5.1 Net Savings and Deviation from UIP

Agents primarily consume in their respective home currency, which is why foreign investments tend to be more risky than domestic investments. After all, foreign payoffs are subject to exchange rate shifts, whereas payoffs denominated in domestic currency are not. In a hypothetical world characterized by an infinite risk aversion, agents would exclusively hold domestic assets in order to avoid exchange rate exposure. Cross-border capital flows would be insignificant, implying a de-facto segmentation of national capital markets. In such a setting, we are likely to observe deviations from UIP because consumption-induced home bias restricts exploitation of foreign profit opportunities. In each country, the interest rate level, reflecting the price of capital, would settle at the respective country's market clearing rate where total savings correspond to total investments. Accordingly, interest rate levels would be driven by domestic capital demand and supply only. Countries with relatively high saving rates would hence exhibit lower interest rates than countries with relatively low saving rates. In a more realistic setting where risk aversion is lower than infinity, economies can be seen as partially segmented. In such frameworks, the difference between national saving and investment rates, appearing in the current account balance, is most relevant. The latter reveals how much net capital a country needs to import in order to finance trade in goods and services, net factor income and net transfers. It therefore bears information on interest rate pressure originating from the real side of the economy. Let us focus on the trade component of the current account, which is by far its most important driver. A deficit accrues if imports exceed exports, so

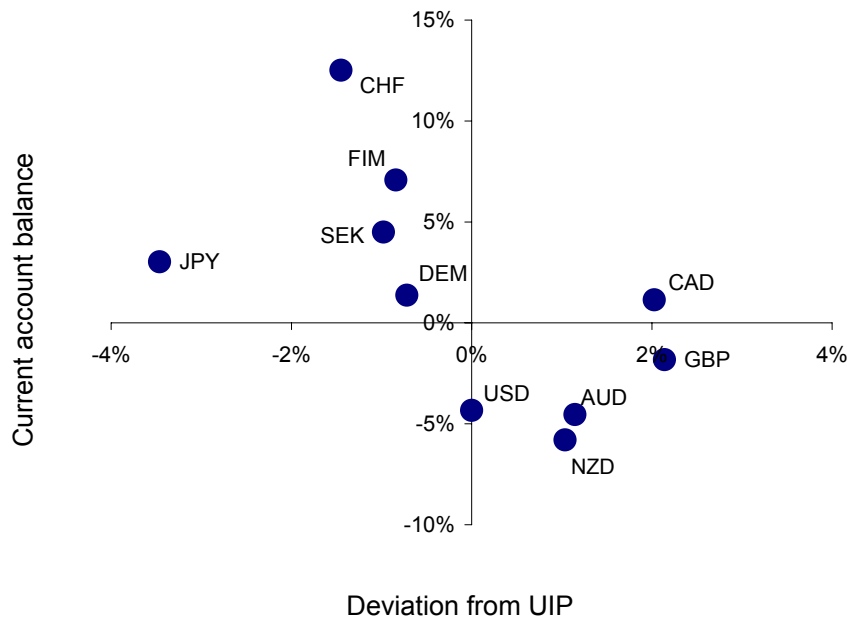


Figure 3.5: Deviation from UIP with respect to the USD (horizontal axis) and current account imbalance (vertical axis) for a selection of countries

that foreigners need to be compensated in domestic assets. A priori, risk-averse foreigners are not willing to invest domestically because this exposes their consumption flow to the vagaries of the foreign exchange market. In order to sustain current account deficits, the domestic country must therefore allure capital by offering attractive yields. The argument is the other way round if the domestic country registers a positive current account balance. In that case, capital must leave the country, but domestic residents are only willing to invest abroad if they are offered attractive compensation.

In light of this argument, we would expect comparatively attractive returns in countries with current account deficits and vice versa in countries with current account surpluses. That is precisely what we observe empirically. Figure 3.5 reveals that there indeed exists a negative relationship between current account imbalances and deviation from UIP. Our calculations are based on averages between 1997 and 2006 from the perspective of an USD investor. The negative relationship implies that there must be some risk aversion around, which results in asset home bias despite of de-jure perfectly open capital markets. This conclusion can be drawn because under risk neutrality, one should not observe a systematic relationship between current account imbalances and deviation from UIP. That is because risk-neutral agents optimize one-dimensionally with respect to expected returns only. Consumption hedging is not even on a risk-averse investor's monitor.

3.5.2 Capital Asset Pricing Model (CAPM)

The capital asset pricing model (CAPM) measures risk exposure in terms of the covariance between returns on some asset i and returns on a broadly diversified market or wealth portfolio. The covariance term is sometimes referred to as un-diversifiable or systematic risk. Assets exhibiting a large and positive covariance with the market portfolio are seen as risky because they expose wealth to large fluctuations. Risk-averse investors thus demand a premium for buying positively correlated assets, whereas they are willing to hold low-yield assets if they exhibit a low or negative correlation with the market. The CAPM boils down to the following risk-reward relationship:

$$E(r_{i,t,t+1}) - r_{rf,t,t+1} = \beta_i [E(r_{m,t,t+1}) - r_{rf,t,t+1}] \quad (3.1)$$

with β_i defined as follows:

$$\beta_i = \frac{\text{cov}(r_{i,t,t+1}, r_{m,t,t+1})}{\text{var}(r_{m,t,t+1})} \quad (3.2)$$

where $r_{m,t,t+1}$ denotes the return on the market or benchmark portfolio between t and $t + 1$, and $r_{rf,t,t+1}$ is the risk-free rate. Equation 3.1 relates expected excess returns for asset i to β_i multiplied by expected excess returns on the market portfolio. β_i captures asset-specific systematic risks and is an increasing function of the covariance between fluctuations in asset i and fluctuations in the market portfolio. The model postulates that excess returns for asset i rise in parallel with risk exposure measured in terms of the covariance with the market portfolio. Equation 3.1 amounts to a general pricing rule and can be applied to all assets, including excess returns on foreign deposits. The left hand side of equation 3.1 could be substituted with deviation from UIP. That is precisely what Bansal and Dahlquist (2000) do in order to test for currency risk premia in a CAPM framework. They calculate deviation from UIP vis-à-vis 27 currencies against the USD. The aggregate US equity index is chosen as benchmark portfolio. Their R-squared is close to zero, which signals that their specification cannot explain the cross-sectional variation in currency risk premia. Bansal and Dahlquist's estimation is based on a constant beta specification and cannot capture time-variation in risk premia. That in contrast to Mark (1988), who incorporates time-variation in β by specifying an univariate ARCH model for the covariance and the variance term. He uses a weighted average of returns on the US, German, Swiss, Japanese and British stock market as the market portfolio. That is a more reliable measure

for the CAPM market factor than aggregate US equity returns since it covers a much larger fraction of the global stock market wealth. Mark does not reject the model, but his test results must be interpreted with care. We argue in chapter 7 that Mark hardly explains any of the variation in currency risk premia. This suspicion is nourished by a similar analysis conducted by McCurdy and Morgan (1991), who report disappointingly low R-squares for their regression. In contrast to Mark, McCurdy and Morgan conduct a multivariate GARCH estimation to obtain time-variation in variance-covariances between market returns and currency returns. Lustig and Verdelhan (2005) obtain more promising results when running a CAPM estimation by using interest rate differentials as instruments. They report an R-squared of up to 36% which means that they can capture almost one third of the total variation in currency risk premia. The reader is referred to chapter 7, where we estimate an extended CAPM incorporating coskewness as an additional risk factor. There we provide a more thorough literature survey.

3.5.3 Portfolio-Balance Approach

Similarly to the CAPM, portfolio-balance models are based on mean-variance optimization. It is assumed that investors maximize the value of their wealth portfolio for a prespecified variance. In mathematical terms, the following maximization problem needs to be solved:³

$$\max U[E(W_{t+1}), \sigma^2(W_{t+1})] \quad (3.3)$$

with

$$E(W_{t+1}) = W_t \lambda_t' E(r_{t,t+1}) + W_t (1 - \lambda_t' \mathbf{1}) r_{rf,t,t+1} \quad (3.4)$$

$$\sigma^2(W_{t+1}) = W_t^2 \lambda_t' \Omega \lambda_t \quad (3.5)$$

where W denotes agents' wealth. The utility function in equation 3.3 increases in the first argument, which represents the expected value of the wealth portfolio at the end of the investment horizon. It decreases in the second argument, which is the variance of the wealth portfolio, denoted by $\sigma^2(W_{t+1})$. Maximization is subject to two restrictions. The first postulates that the expected end-of-period wealth depends on the portfolio vector of expected asset returns $E(r_{t,t+1})$ and a

³Our subsequent notation is close to that presented in Giovannini and Jorion (1989).

term including the risk-free rate $r_{rf,t,t+1}$. λ_t denotes the vector of portfolio weights of risky assets, and $\mathbf{1}$ is a vector of ones. The second restriction shows that the variance of the wealth portfolio is a function of portfolio weights, λ_t , and of the variance-covariance matrix of risky asset returns, Ω . The first order condition of the maximization problem is given below:

$$\lambda_t = (\rho\Omega)^{-1}[E(r_{t,t+1}) - r_{rf,t,t+1}] \quad (3.6)$$

where ρ is the coefficient of relative risk aversion defined as $-2W_t U_2 / U_1$. U_1 and U_2 are the partial derivatives of the utility function with respect to the first and the second argument, respectively. Equation 3.6 shows optimal portfolio weights from the perspective of an investor. As Giovannini and Jorion (1989) note, it can also be interpreted as an equilibrium condition with λ representing the global stock of assets available. With this last interpretation in mind, we can solve for equilibrium excess returns:

$$E(r_{t,t+1}) - r_{rf,t,t+1} = \rho\Omega\lambda_t \quad (3.7)$$

If the model is applied to international bond or money markets and if rational expectations are assumed, the left hand side corresponds to deviation from UIP. The equilibrium condition thus postulates that deviation from UIP is an increasing function of the representative agents' risk aversion ρ . If agents were risk-neutral ($\rho = 0$), no deviation from UIP would occur. In a risk-neutral world, capital flows react perfectly elastically to profit opportunities, irrespective of risks involved, making investments in different currencies perfect substitutes. If only the smallest departure from UIP emerged, massive capital flows would immediately eliminate all deviation. UIP is also an increasing function of Ω which represents the variance-covariance matrix. The reason is that positively correlated assets lead to larger fluctuations in total wealth. That is undesirable from the perspective of a risk-averse investor worrying about the aggregate portfolio. He thus demands compensation in terms of positive deviation from UIP in order to hold positively correlated deposits. On the other hand, assets exhibiting a low or a negative correlation with most other assets offer large diversification benefits. Investors are willing to acquire such positions despite their expected underperformance. An increase in the global stock of assets, λ_t , finally leads to rising excess returns because the additional asset supply must be met with a commensurate increase in asset demand, which depends positively on expected returns. The hypothesis that returns are driven by the forces of supply and demand is

corroborated in section 3.5.1, where we show that current account surpluses are negatively related to deviation from UIP.

A number of studies apply portfolio-balance theory to deviation from UIP, usually with sobering results. Frankel (1982) estimates an unconditional version of the model. In contrast to the framework presented previously, his model is specified in real terms. This leads to the following extension of equation 3.7:

$$E(r_{t,t+1}) - r_{rf,t,t+1} = \rho\Omega(\lambda_t - \alpha) \quad (3.8)$$

where α represents a vector of consumption shares allocated to different countries. In equation 3.8, equilibrium excess returns additionally depend on α which bears a negative sign. That reflects the attractiveness of asset holdings denominated in the same currency as consumption expenditure. Frankel shows that investors exhibiting extreme risk aversion hold assets in precisely the same currency proportions as they consume. He cannot reject the null hypothesis of ρ being zero, which would imply that bond investments are perfect substitutes and that there does not exist any risk premium. Whereas Frankel estimates a static model, assuming a constant variance-covariance matrix Ω , subsequent studies usually account for changing variance-covariances. These studies take account of *time-variation* in risk premia and expected returns, which is a crucial ingredient for currency risk pricing. Lyons (1988), for instance, uses currency option prices to plug out a time-varying measure for the implied volatility. He finds little support for the model, and his estimates for the coefficient of relative risk aversion bear the wrong sign. Moreover, Lyons regresses deviation from UIP on asset shares which he measures as a function of gross public debt outstanding. According to equation 3.7, one would expect average excess returns to rise as asset shares increase. By contrast, Lyons reports a negative relationship between deviation from UIP and government debt. Giovannini and Jorion's (1989) model is also based on time-varying variance-covariances. Unlike Lyons, second moments are not derived from implicit option price volatilities but from a GARCH process. The estimated coefficient of relative risk aversion is insignificantly different from zero, and the model's overidentifying restrictions are rejected. Giovannini and Jorion argue that rejection does not necessarily mean that the mean-variance optimization cannot explain anything. Rejection might also be due to the use of an inefficient benchmark portfolio. Thomas and Wickens (1993) therefore propose to enlarge asset classes by testing the portfolio-balance model by including bonds as well as equities. They incorporate more relevant markets than previous studies, viz. US, Japanese, UK and German assets in order to cover a larger fraction of

total financial wealth. Despite these innovations, they reject their static as well as their time-varying variance-covariance specification.

Much of the mean-variance literature assumes that investors care exclusively about returns in USD. These papers are based on the implicit assumption of permanent validity of purchasing power parity (PPP). If PPP held at all times, inflation differentials between home and foreign countries would be offset by countervailing exchange rate movements. As a consequence, perceptions about the real return of a certain asset would not depend on the price deflator used. In such a world, real returns would be the same, irrespective of nationality. That is an unrealistic scenario because PPP is violated at short horizons and holds at best in the very long run. In fact, there exists a voluminous empirical literature showing that deviation from PPP is large and cyclical.⁴ The portfolio-balance model of Frankel (1982) accounts for PPP violations by introducing different consumption patterns across nations. As a consequence, investors are subject to different inflation processes and balance their portfolios accordingly. If all investors were highly risk-averse ($\rho = \infty$), they would try to fully hedge consumption risk by holding assets in consumption currency only. Frankel obtains global asset demand by a weighted aggregation of country demands where weights correspond to a nation's wealth. Kim and Salemi (2000) propose a more sophisticated model by explicitly modeling income and inflation processes in a multi-country setting. Their asset demand function does not only depend on risk aversion, variance-covariances and expected excess returns as in equation 3.6 but additionally on covariances between excess returns and real incomes and excess returns and inflation. These covariance terms enter because agents want to hedge against real income as well as inflation shocks. Kim and Salemi account for investor heterogeneity by postulating country-specific income and inflation processes, which leads to different hedging motives across countries. They also include ARCH effects in covariance structures in order to capture time-variation in risk premia. Kim and Salemi obtain a highly significant coefficient of risk aversion of reasonable size.

3.5.4 International CAPM

The standard CAPM is not a truly international model since it implicitly assumes identical consumption baskets as well as validity of PPP. Both these assumptions are strongly rejected in practice. In fact, agents exhibit a strong preference for locally produced goods and services, whereas PPP holds at best in the long run. The international CAPM (ICAPM) provides a framework for asset pricing in an

⁴See, for instance, Rogoff 1996 or Taylor and Taylor 2004.

international context without imposing such restrictive assumptions. However, the model's conceptual advantage entails a considerable increase in complexity as we will demonstrate hereafter.

Similarly to the standard CAPM, the ICAPM relates excess returns to market risk premia. In the international framework, excess returns are in addition driven by multiple currency risk premia components. The principal pricing formula driving the ICAPM is derived in De Santis and Gérard (1998). They obtain the following expression for excess returns on some asset i :

$$E(r_{i,t,t+1}) - r_{rf,t,t+1} = \delta_m \text{cov}[E(r_{i,t,t+1}) - r_{rf,t,t+1}, E(r_{m,t,t+1}) - r_{rf,t,t+1}] + \sum_{c=1}^L \delta_c \text{cov}[E(r_{i,t,t+1}) - r_{rf,t,t+1}, \pi_{c,t}] \quad (3.9)$$

where $\pi_{c,t}$ denotes nominal inflation rates in country c measured in terms of the reference currency. δ_m and δ_c are prices for market and inflation risk exposure, respectively. The total risk premium is thus driven by the covariance with the market portfolio - as in the standard CAPM - and by a summation term capturing L different inflation risk premia. The summation component arises because consumers demand compensation for unfavorable exposure to their respective country's inflation rate. The CHF consumer, for instance, demands compensation for assets exposing his personal consumption basket to purchasing power risk. He demands a positive (negative) excess return for assets yielding below (above) average returns in times of high inflation. The EUR investor demands a different premium for the very same asset. After all, he consumes a different basket and is therefore exposed to a different inflation process. In the aggregate, the total inflation premium is obtained by summing up all inflation terms, where L denotes the number of countries or consumption baskets.

All variables in the inflation covariance term are measured in terms of a reference currency. To simplify matters, empirical studies usually assume non-stochastic local inflation so that changes in $\pi_{c,t}$ are exclusively due to exchange rate movements. For that reason, the inflation covariance term is sometimes referred to as the currency instead of the inflation risk premium. Assuming that the local inflation rate is zero, we can write:

$$E(r_{i,t,t+1}) - r_{rf,t,t+1} = \delta_m \text{cov}[E(r_{i,t,t+1}) - r_{rf,t,t+1}, E(r_{m,t,t+1}) - r_{rf,t,t+1}] + \sum_{c=1}^L \delta_c \text{cov}[E(r_{i,t,t+1}) - r_{rf,t,t+1}, s_{c,t+1} - s_{c,t}] \quad (3.10)$$

where all variables are defined as before with the exception of the second covariance term. The latter now captures currency instead of inflation risk. In analogy, δ_c denotes compensation for currency instead of inflation risk exposure. The price for exposure to the market portfolio, δ_m , is restricted to be positive, whereas the sign of δ_c depends on a nation's wealth and on the average risk aversion of its citizens.

The ICAPM is usually applied to systems of assets including equity and money or bond market positions. The left hand side of equation 3.10 corresponds precisely to deviation from UIP if money market deposits are priced. The ICAPM has been extensively tested. For instance, by Dumas and Solnik (1995) who estimate the model using a conditional general methods of moments (GMM) approach and scale moments with instruments. The instrumental variable approach leads to time-variation in risk premia and expected returns, which is what we need in order to cope with Fama's (1984) forward rate anomaly (see section 2.5). It is found that currency risk premia play a statistically significant role, and that the ICAPM outperforms the standard CAPM. De Santis and Gérard (1998) provide more evidence on the significance of currency risk. Besides conditioning risk prices, they augment the model with GARCH-in-mean effects to account for time-variation in the variance-covariance matrix which leads to a specification where prices, δ_t , and risk exposures, cov_t , bear time-subscripts. Similarly, Cappiello, Castrén and Jääskelä (2003) estimate a conditional ICAPM using a multivariate GARCH-in-mean methodology. In contrast to previous studies, their analysis is conducted from the perspective of an EUR investor, and they focus on deviation from UIP as opposed to risk premia on equities and bonds. They find statistically significant prices for market and currency risk and notably report that European investors pay a premium for money market deposits in USD. European investors seem to hedge against fluctuations in the USD because their consumption basket includes a considerable fraction of goods and services from the US. That finding is corroborated by De Santis, Gérard and Hillion (2003) in an ICAPM analysis focusing on the importance of EMU compared to non-EMU currency risk.

3.5.5 Consumption-Based Asset Pricing Model (C-CAPM)

Agent's utility is ultimately driven by consumption of real goods and services. The theoretical underpinnings of the CAPM and ICAPM presented previously are therefore debateable. These models assume that agents maximize a somehow defined wealth portfolio, usually a national or a global equity market index. It is implicitly assumed that the equity index provides a good proxy for aggregate

consumption. That is disputable for at least two reasons:

1. Aggregate wealth is much broader than stock market capitalization since it additionally includes real estate as well as human capital.
2. The fraction of total wealth spent on consumption is time-varying and might, for instance, depend on the outlook for the economy.

Consumption-based models directly relate asset prices to consumption growth. From a theoretical perspective, these settings are clearly preferable to CAPM-like specifications. Empirical estimations are, however, more difficult than in CAPM-like frameworks due to lack of high-frequency data on consumption. We try to convey the general idea of consumption-based asset pricing and present results from empirical work relating the model to deviation from UIP.

In an arbitrage-free world, there exists a stochastic discount factor, which consistently prices all traded payoffs, returns and excess returns (see Cochrane, 2001). The following pricing formula can therefore be seen as a general pricing rule driving all intertemporal asset pricing models:

$$0 = E_t(m_{t+1}x_{t+1}) \quad (3.11)$$

where m_{t+1} is a strictly positive variable, known as the stochastic discount factor (SDF) or the pricing kernel, and x_{t+1} denotes an asset's stochastic excess return at time $t + 1$. In a consumption-based setting, m_{t+1} corresponds to the marginal rate of intertemporal substitution. Under power utility, the SDF boils down to the following expression:

$$m_{t+1} = \beta \left(\frac{c_t}{c_{t+1}} \right)^\rho \quad (3.12)$$

where ρ denotes the coefficient of relative risk aversion, and β is the time preference rate. The pricing kernel corresponds to the inverse of the risk-free rate, which is why equation 3.11 can be reformulated as follows:

$$0 = \frac{E_t x_{t+1}}{r_{rf;t,t+1}} + cov_t \left(x_{t+1}, \beta \left(\frac{c_t}{c_{t+1}} \right)^\rho \right) \quad (3.13)$$

For assets whose returns are uncorrelated with consumption growth, the covariance term on the right hand side is zero. Such assets precisely yield the risk-free rate. Similarly to the CAPM, risk premia stem from the covariance term between

asset returns and pricing kernels. Risks rise as the covariance between asset returns and consumption growth increases. A positive covariance with consumption growth makes the covariance term negative and demands that $E_t x_{t+1}/r_{rf;t,t+1} > 0$. The underlying rationale is simple to comprehend. Positive covariance means that assets do well in times of affluence but fare poorly in times of recession or during periods of sluggish consumption growth. Such a procyclical payoff stance is undesirable because it exposes investors' total consumption to large fluctuations. As a consequence, investors demand a premium for taking assets with procyclical payoff patterns on board. On the other hand, investors are willing to settle for a return below the risk-free rate for assets exhibiting negative correlation with consumption growth implying that $E_t x_{t+1}/r_{rf;t,t+1} < 0$. After all, negatively correlated assets do well in times of deprivation when payoffs are most wanted.

Various authors relate deviation from UIP to the C-CAPM - usually with sobering results. Mark (1985), Hodrick (1989) and Modjtahedi (1991) estimate the model under the assumption of time-separable preferences, which means that utility is driven by current consumption alone. Their results are representative insofar as they obtain implausibly large values for the parameter of relative risk aversion ρ . Aggregate consumption growth apparently is too smooth and cannot explain departure from UIP. More recent contributions suggest various ways to cope with the magnitude problem. Some abandon time-separable utilities for more sophisticated preference structures with the goal to enhance the utility function's sensitivity in response to consumption growth shocks. The literature propagating habits, which postulates that utility depends on current as well as on past consumption, belongs to that category. Others object that aggregate consumption is the wrong risk measure. Proponents of that strand argue that the consumption volatility of the representative investor is much larger than what aggregate consumption suggests. The reason is that individuals are subject to idiosyncratic shocks against which they cannot hedge due to market incompleteness. In other words, it is argued that there exist idiosyncratic risks amplifying pricing kernels. Again others propose to incorporate durable as well as non-durable consumption or to base analysis on long-term consumption growth as risk measure.

Empirical investigations pricing currencies as opposed to equities is confronted with a second intricacy: time-variation in currency risk premia (see Fama, 1984). Since the C-CAPM is usually estimated in a generalized methods of moments setting (GMM), time-variation can be incorporated by postulating time-variation in variance-covariances or by scaling moments with instruments. Instruments are thought to bear information about the future state of the economy and must be

chosen according to economic theory. The conditional GMM estimator augmented by instruments is explained in chapter 6.6.

Backus, Gregory and Telmer (1993) investigate currency risk under habit utility. Habit formation implies that agents' well-being does not only depend on current consumption levels but also on current relative to past consumption levels. Campbell and Cochrane (1999) indeed show that habits can account for a variety of equity and bond price phenomena where the standard power utility fails. A similar finding is reported by Backus, Gregory and Telmer (1993) who demonstrate that habit utility can account for much more of the total variation in currency risk premia than models based on time-separable utility. Unfortunately, their model does not produce enough variability and it fails to replicate positive autocorrelation in forward premia. Sarkissian (2003) obtains more promising results by postulating consumption heterogeneity across countries. More specifically, he uses a model with two risk factors: (1) world consumption growth and (2) consumption dispersion across countries. The latter enters despite its idiosyncratic nature because consumption dispersion cannot be diversified. For that reason, variation in world consumption alone is not sufficient to describe consumption volatility. Consumption dispersion does indeed lower the value for the coefficient of relative risk aversion and can account for up to 20% in the total cross-sectional variation in currency risk premia, compared to merely 2% for the standard C-CAPM. A much better fit is obtained by Lustig and Verdelhan (2007) by sorting foreign currency returns into portfolios on the basis of interest rate levels. The first portfolio contains deposits in the lowest-yielding currencies, whereas the last portfolio contains deposits in the highest-yielding currencies. Portfolios are continuously rebalanced and change their composition as currencies move up and down interest rate level rankings. Lustig and Verdelhan claim that Yogo's (2006) durable consumption growth model can account for almost 87% of the total cross-sectional variation in portfolio returns. Note that their sorting amounts to conditioning information on the basis of interest rate levels, which serve as instruments. Their investigation meets with severe criticism from Burnside (2007), who argues that the durable consumption specification cannot explain any of the variation in currency risk premia. He attributes Lustig and Verdelhan's positive assessment to estimation errors. A more detailed discussion of the C-CAPM and its application to currency risk is given in chapter 6 where we conduct our own C-CAPM estimations based on a long-term consumption growth measure.

3.5.6 General Equilibrium Model

The C-CAPM solely focuses on the consumption side of the economy. That is the reason why consumption-based models are sometimes referred to as being partial equilibrium in nature. That in contrast to general equilibrium settings, which model the consumption as well as the production side. In general equilibrium settings, the pricing kernel corresponds to the consumption-based first order condition, precisely as in the C-CAPM but consumption is not simply given exogenously. Instead, it is related to the production side of the economy.

Since general equilibrium models are heterogeneous in design, we can here only convey an intuitive understanding of the mechanics typically governing such models. Equation 3.13 serves as starting point. It can be interpreted as a general pricing rule for excess returns in intertemporal frameworks. If x_{t+1} is written in terms of excess returns on foreign deposits, we obtain:

$$0 = \frac{E_t(r_{t+1}^f \Delta s_{t,t+1} - r_{t+1}^d)}{r_{rf;t+1}} + cov_t \left(r_{t+1}^f \Delta s_{t,t+1} - r_{t+1}^d, \beta \left(\frac{c_t}{c_{t+1}} \right)^\rho \right) \quad (3.14)$$

where $\Delta s_{t,t+1}$ represents exchange rate movements between t and $t + 1$, r_{t+1}^d is the domestic interest rate, r_{t+1}^f the corresponding foreign rate and $r_{rf;t+1}$ the risk-free rate. According to equation 3.14, agents demand a higher risk premium for foreign investments when the covariance term decreases. Note that a negative covariance implies that the foreign currency depreciates in times of recession and that it appreciates in boom periods. Such a procyclical payoff stance is undesirable from the perspective of a risk-averse investor, which induces him to demand a risk premium. We now turn attention to the production and money side of the economy. Our goal is to extend the pricing equation by incorporating endowment processes.

Most studies investigating currency risk within a general equilibrium setting assume a Lucas (1978) two-country economy. In a Lucas world, each country is endowed with a different fruit tree yielding a stochastic crop at certain points in time. Fruit is perishable and must either be consumed or exported at short notice. Payment is effected in a cash-in-advance manner in the currency of the producing country. Domestic and foreign citizens exhibit identical preferences and receive money from central banks who inject liquidity. Due to the fact that fruit is non-storable, total consumption, c , is a function of real shocks. These are modeled as time-varying endowment flows and reflect fluctuation in fruit harvests. Besides endowments, equation 3.14 is subject to shocks from the money

side, which enter via exchange rates. Under constant expenditure shares, exchange rate depreciation is driven by relative money supplies as shown below:

$$E_t(\Delta s_{t,t+1}) = E_t[(mo_{t+1}^d - mo_t^d) - (mo_{t+1}^f - mo_t^f)] \quad (3.15)$$

where mo_t^d and mo_t^f denote the logarithm of money supply in the domestic and in the foreign country, respectively. In accordance with PPP, the home currency experiences a depreciation when domestic liquidity growth exceeds liquidity growth abroad and vice versa if domestic liquidity growth is lower. We are now fully equipped to reformulate equation 3.14 by replacing depreciation, $\Delta s_{t,t+1}$, and the inverse of consumption growth, c_t/c_{t+1} , with relative money supplies and endowments. After a bit of reshuffling, one obtains:⁵

$$\begin{aligned} r p_t \equiv f_t - E_t(s_{t+1}) = & -0.5 \cdot [Var_t(mo_{t+1}^d) - Var_t(mo_{t+1}^f)] \\ & + \alpha(1 - \gamma)Cov_t(mo_{t+1}^d - mo_{t+1}^f, y_{t+1}^d) \\ & + (1 - \alpha)(1 - \gamma)Cov_t(mo_{t+1}^d - mo_{t+1}^f, y_{t+1}^f) \end{aligned} \quad (3.16)$$

where y_t^d and y_t^f denote the logarithm of domestic and foreign endowments, respectively. γ is the coefficient of relative risk aversion, α corresponds to the share of total consumption spent on domestic fruit, whereas $(1 - \alpha)$ denotes the corresponding share spent on foreign produce. Equation 3.16 states that the risk premium is driven by the correlation between money shocks and real shocks. Assume, for instance, that the domestic central bank acts in a more procyclical manner than its foreign counterpart. This implies that the domestic currency depreciates when the global economy is running well and that it appreciates in periods of sluggish growth. From a portfolio optimization perspective, such a procyclical stance is highly appreciated because it implies that domestic assets increase in value when wealth is most needed. Since we assume risk aversion (i.e. $\gamma > 1$), the last two terms in equation 3.16 must be negative leading to $f_t - E_t(s_{t+1}) < 0$. In this simple setting, a more procyclical policy stance at home thus results in an underperformance of domestic money market deposits.

Engel (1992) argues that standard versions of the Lucas model cannot explain risk premia. In fact, it is shown that the covariance on the right hand side of equation 3.16 is far too small to account for return differentials, unless one assumes implausibly large values for the coefficient of relative risk aversion. Bekaert (1996) attacks Fama's (1984) volatility puzzle by incorporating time-nonseparable

⁵See Engel, 1996 for the derivation.

utilities and time-varying uncertainties in fundamentals. More specifically, he augments the model with durable goods and habit preferences, which are known to generate more variable pricing kernels, and he accounts for time variation in the conditional variance of market fundamentals. That is done by specifying a constant correlation GARCH process for money supplies and fruit endowments which captures time-variation in expected excess returns and conditional covariances of asset prices. Bekaert's model is indeed better suited to tackle Fama's volatility conundrum. A simulation exercise generates risk premia which are far more volatile than in standard C-CAPM specifications, even though still smaller than what one observes empirically. Bekaert, Hodrick and Marshall (1997) extend the foreign exchange rate model and additionally include equity and bond markets. They stick to time-separability in utility and to homoscedastic driving processes for fundamentals but abandon Von Neumann-Morgenstern preferences. Instead, they postulate that agents exhibit first-order risk aversion, which makes them extremely risk-averse. In such a setting, small shocks to expected consumption have a relatively large impact on pricing kernels and therefore on expected returns. Their model generates sizeable risk premia, but it is not capable to properly account for excess returns. More recently, Alvarez, Atkeson and Kehoe (2007) propose a general equilibrium model based on segmented asset markets. In their framework, the consumption flow of the representative investor is more variable than aggregate consumption, whose variance is set to zero. The model generates time-varying risk premia, and it can account for Fama's forward rate anomaly.

3.6 Conclusion

The UIP puzzle has been extensively analyzed by international economists and dozens of solutions have been proposed. We present a framework which categorizes competing explanations on the basis of underlying theory assumptions. Solutions proposed rely on assumptions which differ along two dimensions, viz. (1) with respect to the degree of risk aversion and (2) with respect to the degree of irrationality. That insight allows us to identify four broad categories, which are shown in figure 3.1.

In terms of research coverage, explanations based on (1) irrationality are of marginal importance only. Proponents of the irrationality strand argue that agents are missing out on potentially lucrative profit opportunities. For lack of convincing explanations, they conclude that the parity relationship's failure must stem from irrationality. Explanations based on (2) in-sample bias attract more sci-

entific attention. The latter arises due to information asymmetries or due to a measurement bias stemming from a non-representative data set. The in-sample bias solution might bear importance during exceptional time periods, but we do not believe that it provides a solution for permanent UIP violations. After all, information asymmetries should level off as time passes because rational agents continuously improve their predictions. The in-sample bias literature is closely related to explanations which attribute the anomaly to (3) regime shifts and heterogeneous beliefs. These theories cannot only account for systematic deviation from UIP but also for long-lasting swings of exchange rate appreciation and depreciation. The data show that such cycles occasionally emerge. Finally, the (4) risk premia literature claims that deviation from UIP arises due to exposure to systematic risks. Risk is usually measured in terms of the covariance with equity market returns or consumption growth. That literature is based on the assumption that agents exhibit risk aversion. Studies relating deviation from UIP to risk premia come in various forms and range from CAPM and C-CAPM settings to portfolio-balance and general equilibrium models. Early contributions based on risk premia usually failed because risk drivers were not volatile enough to explain the cross-sectional variation in deviation from UIP. More recent studies advocate innovative preference structures and can account for time variation in risk prices, which generates better results.

Chapter 4

Carry Trade Activity and Risk-Reward Opportunities

Various commentators claim that carry trade activity has risen at a rapid pace in recent years. This surge in activity might have led to a dramatic rise in risks incurred by carry traders. Recent research indeed suggests that excessive speculation triggers sharp carry trade losses in periods of financial turmoil, which sometimes leads to veritable loss spirals. We present indicators on carry trade volumes and analyze risk-reward opportunities of carry trade strategies. Particular emphasis is put on distributional abnormalities such as negative skewness and excess kurtosis. Risk reversals reveal that investors expect sharp carry trade losses in times of distress on financial markets, which reinforces the loss spiral hypothesis.

4.1 Introduction

An increasing number of investors seems to exploit interest rate differentials by borrowing in low-yield currencies such as the CHF or the JPY in order to invest in high-yield target currencies. We argue that excessive borrowing in CHF and JPY, henceforth referred to as funding currencies, causes safe haven attributes, which makes these currencies appreciate in times of financial crises. That ought to be worrisome for carry traders because an appreciation in funding currencies inflates debt positions which results in large carry trade losses. This chapter examines interactions between carry trade activity, return asymmetries and loss spirals by shedding light from various angles.

First, we provide evidence that the CHF and the JPY play a prominent role on the short side of the carry, where the importance of the latter seems to have risen disproportionately since the year 2003. There does not yet exist a readily available statistic on carry trade activity. Section 4.4, however, presents a variety of indicators such as net open futures positions or statistics on global bank claims from which we can draw inferences on volumes involved.

Section 4.5 analyzes risk-reward opportunities of carry trade strategies. On the one hand, it is found that a broadly diversified carry trade scheme generates higher Sharpe ratios than global equity market investments. On the other hand, diversified carries seem to exhibit negative skewness and excess kurtosis, thereby exposing investors to potentially large losses.

Section 4.6 provides economic intuition for the hypothesis that excessive speculation triggers loss spirals from time to time. The alleged relationship is tested by analyzing how expected currency return distributions change in response to looming currency crises. It is shown that market participants assign a large probability to severe CHF and JPY appreciations during turbulence on financial markets, which corroborates the loss spiral hypothesis.

A truly novel contribution of our work is the use of risk reversals. The latter are calculated on the basis of option-implied currency volatilities and reveal information about underlying exchange rate distributions. Risk reversals respond in a highly sensitive manner to looming crises. This makes them a more adequate object of examination than exchange rates, on which previous studies usually rely on.

4.1.1 Definition

Unfortunately, the literature does not provide an unique definition for carry trades, which has led to some confusion. We try to enhance clarity by relating our work to alternative carry trade definitions. Narrowly defined, carry trades can be seen as taking a short position in some low-yield currency to invest the proceeds in a comparable deposit in some high-yield currency. Under this definition, a carry trader exploits interest rate differentials between (1) comparable assets in (2) different currencies. Such a strategy provides a profit if exchange rates remain unchanged. Losses occasionally occur when funding currencies sharply appreciate or when target currencies sharply depreciate so that the interest rate advantage is more than nullified by unfavorable exchange rate movements. The narrow carry trade definition, henceforth referred to as "classical" carry trade, boils down to a pure bet on exchange rate movements. It comes with a third characteristic, (3) leverage, because long positions are financed by incurring debt in low-yield markets. Some authors have a slightly broader definition in mind when they refer to carry trades because they only retain two of the three characteristics mentioned above, viz. leverage and currency speculation. A strategy with a short position on the CHF money market and a long position in equities or bonds in some high-yield currency thus classifies as a carry trade in that framework. Carry trades in the sense of this definition do not correspond to pure foreign exchange speculation. In fact, the return of such a strategy is, for example, also driven by changing default spreads or stock market shifts. The literature knows even broader definitions. Take, for instance, Béranger et al. (1999), who additionally sacrifice the currency speculation aspect. They define any long-short strategy as a carry trade, among others a scheme exploiting return differentials along the US yield curve. Again others abandon the leverage but retain the currency aspect. In practice, Japanese investors buying higher yielding AUD deposits are, for instance, often referred to as carry traders.

4.2 Related Literature

The broad setting of this chapter brings us in touch with two aspects of the existing literature, viz. with studies evaluating the importance of carry trade activity and with work exploring carry trade implied risk-return opportunities. This section reviews existing contributions and shows how our work relates to the existing body of knowledge.

4.2.1 Carry Trade Activity

The bulk of the literature presented subsequently dates from 2006 or 2007, and many contributions have only been published in working paper series as yet. This shows that academic interest in carry trades is a rather recent phenomenon which might itself be an indication that carry trade activity has become more important of late. In fact, there do not exist readily available statistical data directly revealing carry trade volumes, and we rely on indirect measures. Galati et al. (2007) draw inferences from statistics from the Bank of International Settlements (BIS) on cross-border bank liabilities. McGuire and Upper (2007) and Nishigaki (2007) evaluate carry trade volumes on the basis of “non-commercial” net futures contracts, whereas Galati and Melvin (2004) extract information from turnover volumes in foreign exchange markets. All these indicators point towards burgeoning carry trade activity. Gagnon and Chaboud (2007) propose to exploit funding currency specific return patterns in order to gauge carry trade volumes. They report that the JPY exhibits sharp appreciations against the USD from time to time, which is what one would expect from popular funding currencies (see section 4.6). This leads Gagnon and Chaboud to the conclusion that carry trade activity in JPY has gained in importance recently. Section 4.4 complements most of these studies with own data for funding activity in CHF and JPY. We then contribute to the literature by examining how carry funding currencies respond to changes in carry-to-risk ratios and by inferring information from risk reversals.

4.2.2 Risk-Reward Opportunities

Although carry speculation has increased dramatically over the last couple of years, only few studies analyze risk-reward opportunities of such strategies. An exception is Burnside et al. (2006), who find Sharpe ratios between 0.5 and 0.63, which is much more than what they report for the US stock market. Sharpe ratios drop, however, if transaction costs are taken into account. A closely related study by Burnside et al. (2007) analyzes Sharpe ratios for carry trade strategies based on developed and emerging market currencies. Emerging markets are found to boost Sharpe ratios considerably. In section 4.5.2, we calculate our own Sharpe ratios for a broadly diversified carry trade strategy. It turns out that diversification lowers risks considerably, leading to favorable risk-reward opportunities. The Sharpe ratio reduces risks to the standard deviation, which is appropriate as long as profit distributions remain symmetric. Various commentators argue though that carry trades exhibit asymmetric payoff patterns, exposing investors to nega-

tive skewness. According to Cavallo (2006), for example, carry funding currencies depreciate slowly as more and more traders jump on the carry trade bandwagon. The opposite pattern is observed for carry target currencies, which gradually appreciate as carry exposure builds up. In times of financial crisis, carry traders rush to the exit at the very same time. That leads to an exceptionally sharp appreciation of carry funding currencies and to a severe depreciation of target currencies, bringing about huge losses for carry traders. Gagnon and Chaboud (2007) corroborate the asymmetric return hypothesis by investigating carry exchange rates between 1990 and 2006. They find that the number of sharp JPY/USD appreciations was much larger than the number of equally sharp JPY/USD depreciations, whereas it is the other way round for the AUD/USD. Gyntelberg and Remolona (2007) calculate third and fourth moments for daily returns on selected carry trade strategies and report that distributions exhibit negative skewness and fat tails. Cairns, Ho and McCauley (2007) regress exchange rate movements on changes in global volatility. They find that the CHF, the EUR and to a lesser extent the JPY tend to appreciate vis-à-vis the USD in times of heightened volatility, whereas most other currencies tend to depreciate. A cross-sectional comparison of volatility estimates reveals that the sensitivity with respect to volatility increases as interest rate levels rise. This finding fits well with the hypothesis that carry trades trigger sharp appreciations in funding currencies in times of crises. Ranaldo and Söderlind (2007) therefore argue that carry trade is the mirror image of safe haven. Plantin and Shin (2006) develop a dynamic pricing model for carry returns, which successfully captures asymmetric exchange rate patterns. Section 4.6 contributes to the existing literature on asymmetries in carry trade return distributions by providing economic intuition for the loss spiral hypothesis and by running an empirical analysis of risk reversal dynamics.

4.3 Data

We work with a data set recorded from April 1st, 1992, to September 25th, 2007, where different time granularities were chosen depending on investigation.

The composite carry index examined in section 4.5 is based on monthly Euro-market interest rates and on exchange rate data. It exploits several carry trade relationships simultaneously and amounts to a broadly diversified carry trade strategy.¹ The index is based on data from nine developed markets, viz. Australia, Canada, Euro zone, Japan, New Zealand, Norway, Switzerland, United King-

¹We would like to thank Willy Hautle from the Cantonalbank of Zurich for kindly proposing the following construction procedure for the carry trade index.

dom and the United States. First, all possible market combinations are formed, which leaves us with $n!/((n-k)!k!)$ market pairs, where n denotes the number of markets, and k corresponds to the group size. In our case, n is nine and k is two because pairs of currencies are formed, which results in 36 currency combinations. A separate carry trade strategy is run on each market pair by incurring debt in the currency of the country with the lower interest rate level and by taking a long position in the currency of the country with the higher interest rate level. Our investment strategy is dynamic in the sense that long and short positions are conditioned on time t interest rate differentials. Positions thus flip sides whenever the interest rate differential changes its sign. An aggregate carry trade index is eventually obtained as an equally weighted average across profits and losses from all 36 carry trade strategies. Positions are rebalanced on a monthly basis and all calculations are conducted in terms of the USD.

A daily frequency is chosen for the risk reversal analysis in section 4.6, which leaves us with a total of 4040 observations. A risk reversal shows the difference in implied volatilities between an out-of-the-money call option and a directly opposite out-of-the-money put option. The JPY/USD risk reversal shows, for instance, the difference in implied volatilities of a JPY call/USD put option minus a JPY put/USD call option. In a world characterized by normally distributed exchange rate returns, such implied volatilities are the same so that the price of a risk reversal amounts to zero. However, if exchange rates suffer from asymmetric return distributions such as skewness, directly opposite call and put options exhibit different implied volatilities. In other words, risk reversals bear information on how markets perceive exchange rate distributions. In addition to the JPY/USD risk reversal just defined, we make use of the JPY/EUR, the CHF/USD and the CHF/EUR risk reversal, which are all constructed as buying a call and selling a put in JPY or CHF. Our calculations are based on 1-month 25-delta risk reversals because these are the most frequently traded. Although the Dickey-Fuller test leads to a strong rejection of the unit root hypothesis, we first-difference risk reversal time series before running regressions. The reason is that we find evidence that risk reversals exhibit structural breaks (see section 4.4.5).

Option-implied currency volatilities were used to calculate carry-to-risk ratios in section 4.4. The latter serve as a gauge for carry trade attractiveness and are obtained as the ratio between 3-months Euromarket interest rates divided by option-implied standard deviations of currencies. The carry-to-risk ratio is an ex-ante proxy of the better-known Sharpe ratio, which is calculated ex-post by dividing realized excess returns by realized standard deviations. To evaluate the

importance of carry trade activity, we study net open futures positions on non-commercial traders. That series is a proxy for speculators' net exposure to certain currencies and is explained in detail in section 4.4.2.²

4.4 Quantifying Carry Trade Activity

Carry trades are commonly thought to be flourishing. Some commentators even relate recent episodes of sharp JPY appreciation to large scale unwinding of carry trade positions. They thereby implicitly assume that carry trade volumes are so important that they can fuel prices of large currencies. In spite of the supposedly burgeoning activity and its dire implications for implied risks, academic evidence quantifying carry trade activity is surprisingly rare. This section summarizes the existing literature and provides supplementary evidence for the importance of the CHF and the JPY as carry funding currencies.

4.4.1 Profitability

Carry trade activity must be positively related to its expected profitability after taking account of risk adjustments. For that reason, we first analyze whether carry trades have become more profitable or less risky in recent times. We express risk-reward opportunities by dividing expected profits by option-implied exchange rate volatilities. This leaves us with an expression closely related to the well-known Sharpe ratio.

To understand how expected profits are derived, note that carry trade returns arise from two sources, viz. (1) from interest rate differentials and (2) from exchange rate movements. Meese and Rogoff (1983) demonstrate that in the short run, exchange rates roughly obey a random walk, which means that current spot rates provide a good prediction for future spot rates. Accordingly, we assume constant exchange rates on average. That allows us to approximate expected carry trade profits by interest rate differentials. Since the latter are known with certainty at the very beginning of the investment horizon, all carry trade uncertainty stems from the exchange rate side. We thus measure risk in terms of exchange rate volatility (i.e. standard deviations) which we plug out from currency option prices. Finally, an expression known as the carry-to-risk ratio is obtained, by dividing interest rate differentials by standard deviation. The results are presented in the upper panel of figure 4.1 for both USD/JPY and USD/CHF carry trades.

²Data on risk reversals along with option-implied volatilities was kindly provided by Citigroup. All other time series were obtained from Datastream.

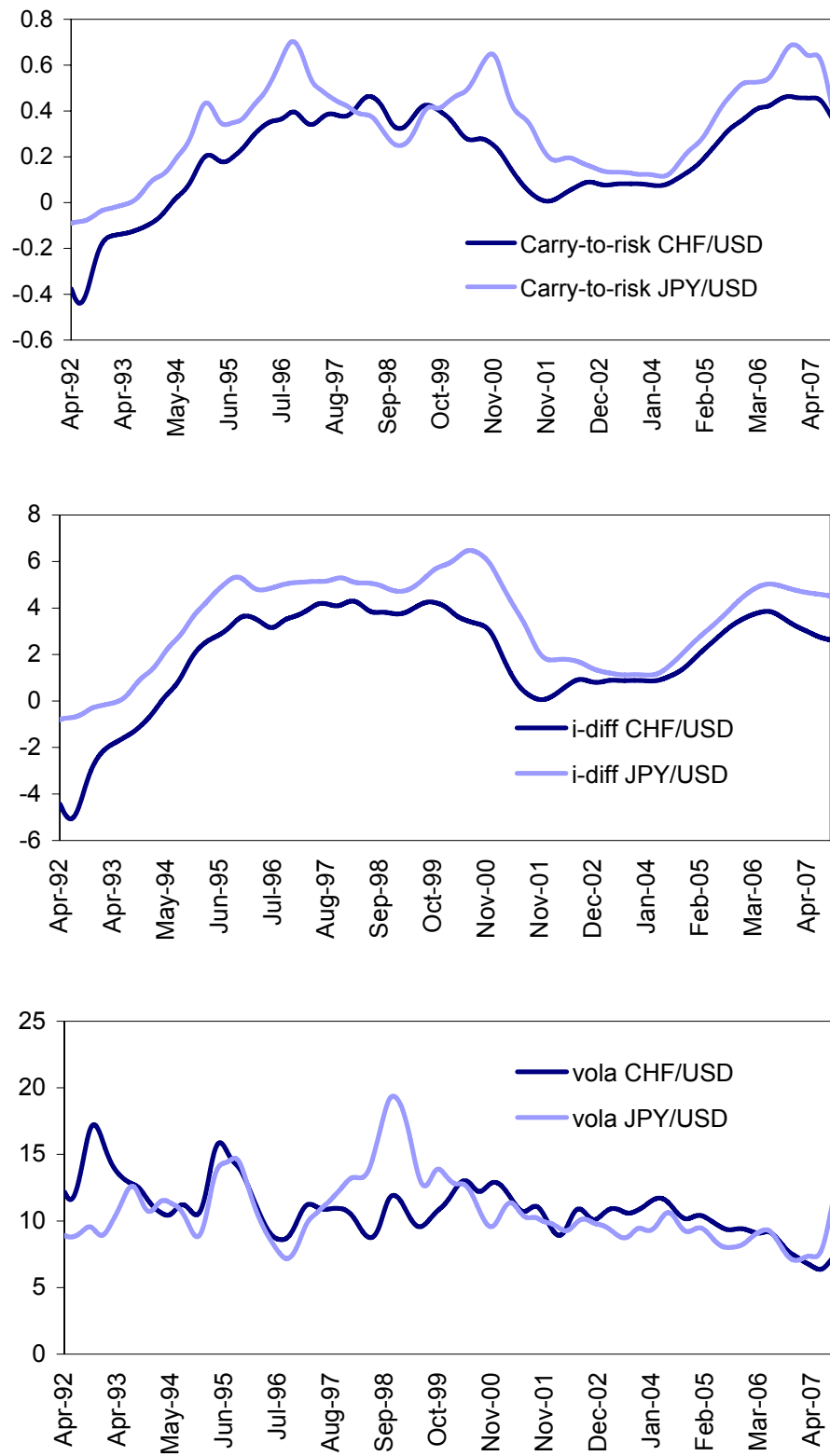


Figure 4.1: Carry-to-risk ratios for JPY/USD and CHF/USD carry trades

Risk-reward opportunities improved considerably between 2002 and 2007 for these strategies. Although the presence of profit opportunities does not proof anything, this finding fits well with the hypothesis of a rising carry trade activity. It gives at least reason to believe that a growing number of investors could have been lured into carry trade schemes of late. At the beginning of the current decade, profitability suddenly dropped. This might be related to the bursting of the dot-com bubble in March 2000. Carry-to-risk ratios for other strategies such as AUD/JPY carry trades have also improved recently (see Galati et al., 2007).

Interesting insights can be gained by analyzing interest rate differentials and volatilities separately. The middle panel in figure 4.1 shows that 3-months inter-bank interest rates have been lower for deposits in JPY than for comparable deposits in USD. Interestingly, there are considerable fluctuations, which appear to be closely related to business cycle conditions. Interest rate differentials widened between 2004 and the beginning of 2007 when the FED moved towards a more restrictive monetary policy stance. At the latest fringe, differentials have fallen again as the US subprime crisis threatens to wreak havoc. Expected profits from carry trades are apparently quite volatile and strongly depend on business cycle conditions. Although differentials are substantially smaller on average, a similar pattern emerges for USD versus CHF deposits.

The lower panel in figure 4.1 shows that currency volatilities have moderated considerably since the year 2000. That holds not only for movements in JPY/USD and CHF/USD exchange rates but also for a wide range of other currency pairs not shown here. This is a further indication that carry speculation has become less risky with hindsight, which might have induced traders to exploit already minor interest rate differentials. We cannot identify a business cycle pattern for the volatility series, which suggests that the downward trend is of a more persistent nature. It remains to be seen whether the most recent spike triggered by the subprime crisis has put an end to the low volatility period or whether volatilities return to their moderate levels we have grown accustomed to.

A comparison of JPY/USD and CHF/USD strategies reveals that the former generally exhibits a larger carry-to-risk ratio than the latter. That holds throughout the entire sample except for the period around the LTCM crisis in 1998 and for the ongoing credit crises. During that recent episode, JPY/USD volatilities have increased by much more than CHF/USD volatilities, which gives rise to the belief that JPY short holdings become disproportionately risky in times of crises.

4.4.2 Net Open Futures Positions

A classical carry trade denotes a strategy where traders run into debt in low-yield currencies to invest the proceeds in high-yield currencies. Instead of engaging in credit markets, exposure can alternatively be gained by trading currencies on forward or futures foreign exchange markets. A futures or forward contract corresponds to an obligation to sell a currency for some other at a prespecified date in the future. Whereas forwards trade over the counter (OTC), futures are on offer at exchange places such as the Chicago Mercantile Exchange, which compiles transaction data on futures trading. A much-noted series is net open futures positions, whose compilation requires all market participants to identify themselves as being “commercial” or “non-commercial” traders. “Commercial” traders are typically non-financial institutions trading for hedging purposes. Hedge funds and banks, by contrast, classify as “non-commercial” players since they usually participate as speculators. Net open futures positions are then compiled for each group separately, and the results are published on a weekly basis.³ “Commercial” positions correspond to the precise mirror image of “non-commercial” positions because every short position must be covered by a long position, which is why an aggregation over both groups adds up to zero.

Figure 4.2 shows net open positions in JPY/USD and CHF/USD futures for “non-commercial” traders or speculators. The series is calculated as the number of long minus short futures contracts and has been available on a weekly basis since March 1995. It can be seen that speculative positions plunged to the minus region towards the end of the year 2004. Since then, JPY/USD and CHF/USD futures contracts have been on net supply. This might stem from carry trade activity because it indicates that speculators do not expect the JPY or the CHF to appreciate by so much as uncovered interest rate parity predicts. Note that the number of net futures positions in JPY/USD is much more negative than its CHF/USD counterpart. That does not come as a surprise if one considers that the JPY is a much larger market than the CHF. A longer perspective reveals that net open futures positions have been on historically low levels until very recently. Speculators’ appetite weakened only with the emergence of the credit crunch in August 2007. “Non-commercial” net open futures positions seem to be correlated with the above presented carry-to-risk ratio. Figure 4.2 suggests that speculators tend to short the JPY and the CHF when carry trades provide favorable risk-reward compensation and vice versa when carry schemes lose attractiveness.

³See Klitgaard and Weir (2004) for a more detailed description of net open futures positions in foreign exchange.

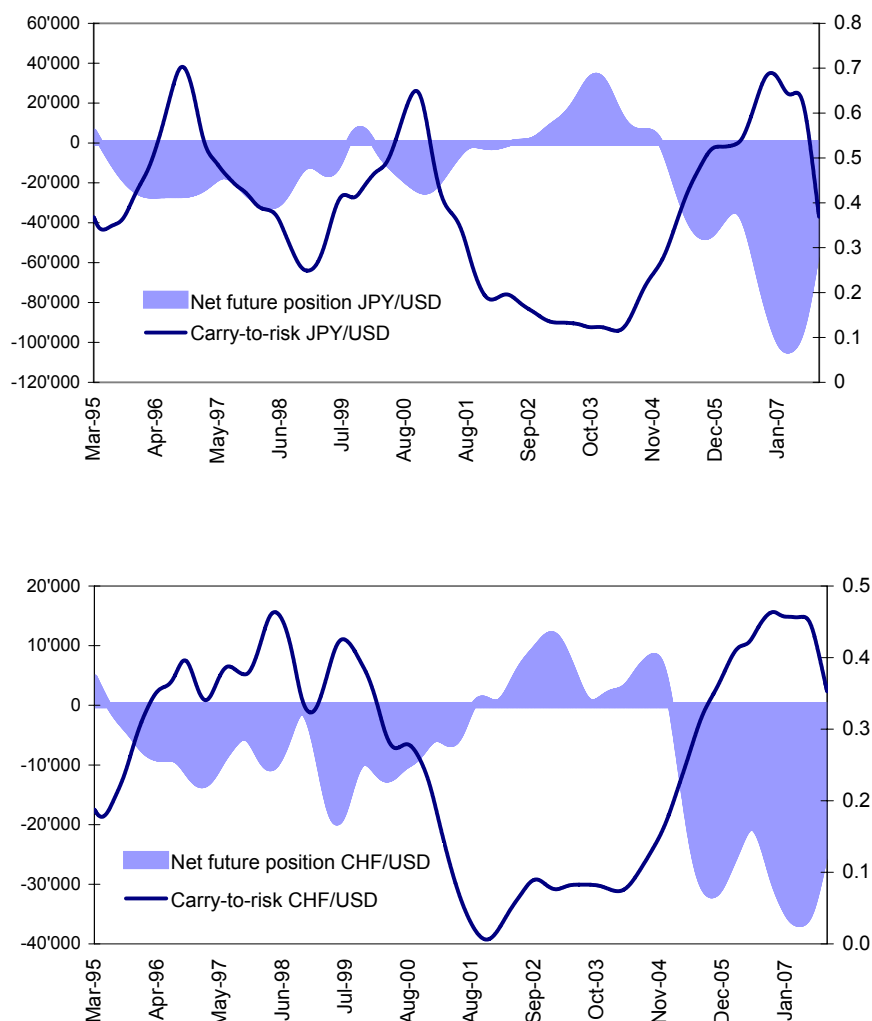


Figure 4.2: Net open positions in JPY/USD and CHF/USD futures of “non-commercial” traders

“Non-commercial” traders’ net open futures positions signal that investors became bearish for the JPY and the CHF towards the end of 2004. That finding fits well with our hypothesis of a recent increase in carry trade activity. Obviously, net futures positions cannot be directly related to carry trade volumes and provide at best an indication for speculative carry trade activity. After all, only a small fraction of total carry volumes is executed via futures contracts. The reason is that the bulk of forward trading is done over-the-counter and not over exchanges, and that traders might alternatively use the credit- or currency option market to get exposure to carry trade schemes. Moreover, speculation in currency futures might have various other causes not stemming from carry trade activity.

4.4.3 International Banking Statistics

Galati et al. (2007) investigate BIS International Banking Statistics and report an increase in global bank claims in JPY and CHF. They show that non-banks in Caribbean financial centers such as the Cayman Islands have been borrowing disproportionately in JPY. That finding is related to the large number of hedge funds located in these places which are thought to be heavily exposed to carry trade schemes. Statistics also reveal that banks in the Euro area register a sharp increase in CHF denominated claims on banks in Croatia, Poland and Hungary. That is interpreted as evidence that households in Eastern Europe have been borrowing heavily in CHF lately due to the latter's low interest rate level. A similar finding is shown by Epstein and Tzanninis (2005), who identify an explosive growth in foreign currency denominated debt of Austrian households where the largest fraction is denominated in CHF. Nils Bernstein (2007), Governor of the National Bank of Denmark, provides more evidence for excessive borrowing in CHF. He argues that CHF denominated net loans to the Danish private sector have been rapidly increasing since 2001.

Similarly to net open futures positions, BIS International Banking Statistics only serve as a rough indicator for carry trade activity. Galati et al. emphasize, for instance, that their analysis is restricted to on-balance sheet positions while carry exposure is often incurred via derivative markets, which are off-balance sheet in nature. Banking statistics on net claims do, moreover, not reveal whether positions really arise from carry trade activity. After all, net claims might accumulate for a variety of alternative reasons. If someone acquires a short position in CHF, for example, we would expect someone else to acquire a long position. If Galati et al. (2007) locate positive net claims in CHF for the European banking sector, we would thus assume a corresponding negative entry somewhere else because net claims should eventually sum up to zero in the global aggregate - that holds at least if we abstract from current account imbalances. International banking statistics are therefore only valuable to the extent that they can be related to a convincing story such as hedge fund activity in Caribbean off-shore centers.

4.4.4 Carry-to-Risk Dynamics

It might make more sense to focus on prices instead of volumes in order to gauge carry trade activity. That all the more since it is difficult to interpret and to collect volume data while price data is readily available from exchanges. In this section, we study the dynamics of carry trade currencies in response to changing

risk-reward ratios. It is assumed that carry trade currencies respond in a highly sensitive manner to shifts in carry-to-risk ratios if carry trade activity is of any relevance. This hypothesis is tested on the basis of the following regression:

$$\begin{aligned} \text{FxChange}_t = & \alpha + \beta_1(\text{CriskChange}_t \times \text{d92}) + \\ & + \beta_2(\text{CriskChange}_t \times \text{d03}) + \epsilon_t \end{aligned} \quad (4.1)$$

where FxChange_t is the logarithmic currency change, and CriskChange_t denotes the absolute change in the carry-to-risk ratio. Carry-to-risk ratios are interacted with dummy variables, viz. d92 and d03 . The former has been set to unity from April 1992 to December 2002 and corresponds to zero otherwise. It is precisely the other way round for the d03 -dummy, which has been set to one from 2003 onwards. Table 4.1 shows that β_1 and β_2 turn out to be positive and highly significant for the currency pairs investigated. This indicates that the JPY and the CHF tend to depreciate (appreciate) against the USD when carry-to-risk ratios rise (fall). That is what we would expect from carry funding currencies and signifies that carry trade activity matters. β_2 is generally larger than β_1 , which demonstrates that sensitivity with respect to movements in carry-to-risk ratios has increased since 2003. That corroborates our hypothesis of a surging carry trade activity. A comparison across regressions reveals that β 's are larger for the JPY/USD than for the CHF/USD exchange rate, which suggests that the importance of the JPY has grown disproportionately as carry funding currency in comparison to the CHF.

	JPY/USD	JPY/EUR	CHF/USD	CHF/EUR
α	0.0000 (-0.4656)	0.0000 (0.0540)	-0.0001 (-0.6895)	0.0000 (-0.5922)
β_1	0.0586 (4.8608)	0.0520 (3.5326)	0.0518 (2.9419)	0.0109 (3.9192)
β_2	0.0901 (7.9087)	0.1125 (5.7089)	0.0551 (2.9663)	0.0182 (3.5996)
R^2_{adj}	0.0383	0.0217	0.0089	0.0139

Table 4.1: Regression of carry trade funding currencies on carry-to-risk ratios

4.4.5 Hedging Demand

A carry trader cannot fully hedge against exchange rate risk because hedging costs would precisely offset interest rate differentials, which would end in a profit of zero. That follows from the no-arbitrage condition because otherwise interest rate differentials could be profitably exploited without incurring any risk. Some carry traders, however, buy protection against extreme outcomes such as a severe appreciation in funding currencies. A trader betting on interest rate differentials between USD and JPY deposits could buy a JPY call/USD put option with a strike price well below the current spot rate. If the JPY experienced a sharp appreciation, the trader could buy JPY at the prespecified price. This enables him to close the short position at strike price, leaving him with a limited loss only.

Carry traders are thought to insure against large losses by buying far out-of-the-money options. Since these are relatively cheap, only a small fraction of the interest rate differential must be sacrificed for protection. If many traders were interested in buying far out-of-the-money JPY calls/USD puts, demand forces would leave their mark in option-implied volatilities. More specifically, a so-called “volatility skew” would emerge with far out-of-the-money JPY calls/USD puts trading at higher volatilities or prices than directly opposite far out-of-the-money JPY puts/USD calls. Some commentators therefore suggest using risk reversals as a gauge for carry trade activity (see Gagnon and Chaboud, 2007). We calculate average risk reversals for various currency pairs by running the following regression:

$$\text{RRlevel}_t = \alpha_1 + \alpha_2 \times \text{d03} + \epsilon_t \quad (4.2)$$

where RRlevel_t represents risk reversals in levels at time t , and d03 denotes a time dummy set to zero before January 2003 and to unity thereafter. The so specified regression measures average risk reversals between April 1992 and December 2002 (α_1) and between January 2003 and September 2007 ($\alpha_1 + \alpha_2$). Table 4.2 shows that average risk reversals have been significantly positive, irrespective of the currency pair or subperiod analyzed, which indicates that there is indeed an excess demand for protection against sharp appreciation in JPY and CHF. Such a demand pattern might arise from carry trade speculation with traders trying to hedge against extreme losses. Note that α_2 is positive for risk reversals involving the JPY, which we interpret as evidence that hedging demand has increased since 2003. By contrast, α_2 is negative for CHF risk reversals, which suggests

	JPY/USD	JPY/EUR	CHF/USD	CHF/EUR
α_1	0.670 (9.679)	0.485 (7.382)	0.257 (7.210)	0.336 (11.619)
α_2	0.261 (2.518)	0.252 (2.582)	-0.089 (-1.777)	-0.113 (-2.766)
R^2_{adj}	0.018	0.020	0.008	0.020

Table 4.2: Average risk reversals

that demand for insurance against substantial CHF appreciations has decreased of late. Risk reversals on JPY have been considerably larger than risk reversals on CHF, reinforcing the hypothesis that the JPY is carry traders' premier choice of funding.

Although our regression results fit well with the hypothesis of burgeoning carry trade activity, results must be interpreted with care. Risk reversals might trade at non-zero prices for a variety of reasons. Take the CHF, for example, which some commentators claim to appreciate sharply in times of geopolitical turmoil. Such safe haven attributes induce investors to pay a premium for CHF calls over CHF puts, leading to a positive price for risk reversals. In general, investors always favor calls over puts or vice versa if they expect asymmetries in underlying exchange rate distributions. That insight is used in section 4.6, where risk reversals are exploited to infer information on skewness in return distributions of carry trade funding currencies.

4.5 Risk-Reward Opportunities

It is well-established that UIP fails in a statistically significant sense, but only few studies explore whether deviations matter economically. In view of the rising exposure to carry trade schemes and other forms of UIP speculation, an investigation of risk-reward opportunities is urgently needed. This section contributes to fill this gap by analyzing how much money can be gained from carry speculation and by shedding light on implied risks. Particular emphasis is put on the examination of whether carry trade profit distributions exhibit negative skewness. That is what we would expect if carry traders indeed experienced large losses every once in a while as recent research suggests.

4.5.1 Profit Trajectories

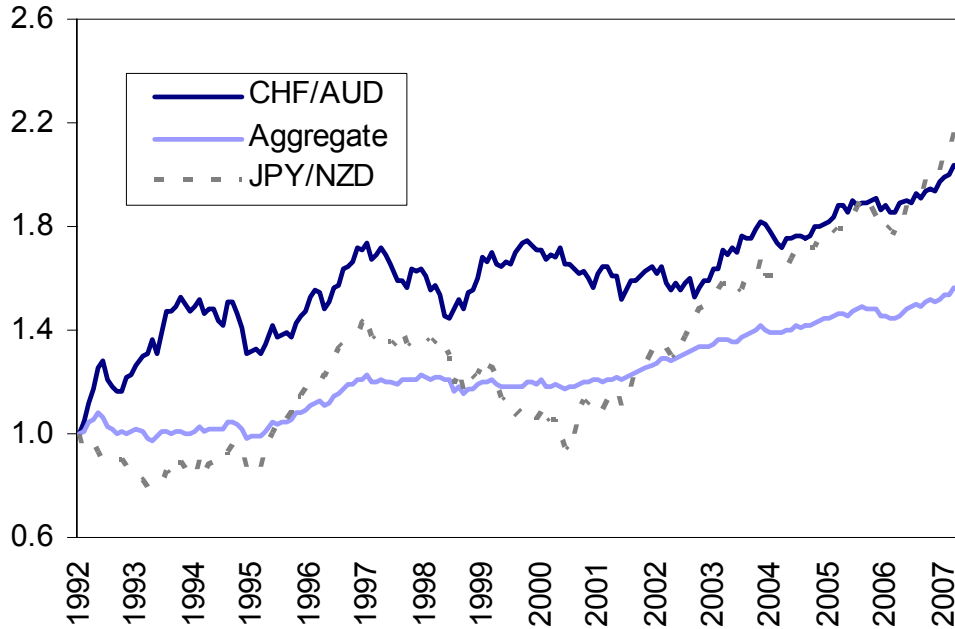


Figure 4.3: Return indices in USD for various carry trade strategies

This section analyzes investment strategies based on different carry trades. The main goal is to show that diversification enhances risk reward opportunities considerably. For that purpose, a broadly diversified carry index, henceforth referred to as composite, is engineered. Its construction is described in section 4.3.

Figure 4.3 illustrates profit trajectories for selected carry trade strategies. We assume that one USD is at stake at each point in time, which implies that traders are forced to rebalance positions on a monthly frequency. Profit trajectories are obtained by aggregating monthly carry trade profits and losses across time. The trajectory for the AUD/CHF carry trade strategy climbed from one in April 1992 to 2.03 in August 2007. That does not tell us anything about implied returns. The reason is that classical carries are debt-financed and do not require any upfront or seed payment, which is why we cannot calculate returns on the latter. It can only be said that an initial credit of one USD on April 1990 eventually led to a capital of slightly more than two USD by August 2007, leaving the investor with a profit of approximately one USD after interest payment. In fact, all 36 carry trade strategies analyzed have ended up in the profit region (i.e. above one) by August 2007, which indicates that carries work reliably across a wide range

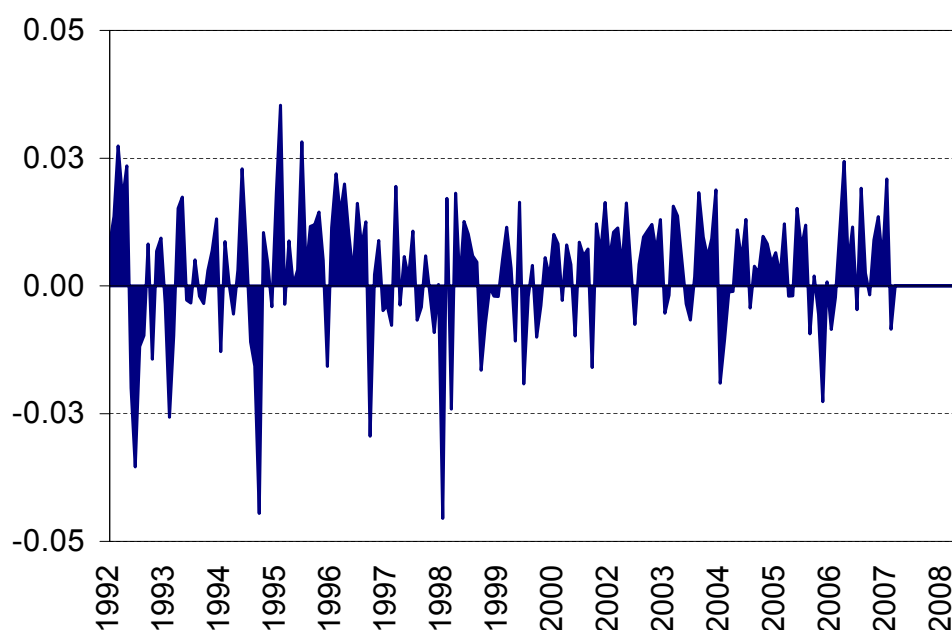


Figure 4.4: Comparing periods of carry trade profits and carry trade losses in terms of USD

of currencies. Figure 4.3 shows that the composite carry index rose from one to 1.55 over the horizon analyzed. Its profit trajectory evolves in a much smoother manner than a bet on the AUD/CHF or the JPY/NZD carry trade. Whereas the aggregate carry index exhibits a gradual increase, individual strategies fluctuate greatly. Traders betting on JPY versus NZD deposits experienced prolonged loss periods. Their index decreased by approximately 40% between April 1997 and October 2000 when it dropped from 1.37 to 0.84. In summary, it can be said that aggregation entails large diversification benefits which results in much smoother profit trajectories.

Figure 4.4 shows monthly profits and losses for the composite carry trade index. For most months, outcomes turn out to be positive - we count 136 months with profits against only 75 months with losses. Sometimes, however, losses turn out to be quite large. So, for instance, in October 1998 when the composite carry generated a loss of 4.6 cents per USD at stake, despite its broad diversification. In general, there were more large downward spikes than large upward spikes which is a first indication that traders experience large losses from time to time. The next section takes a more systematic look at risk-reward opportunities by examining profit distributions and their moments.

4.5.2 Summary Statistics

Table 4.3 shows summary statistics on profit and loss distributions for all 36 carry trade strategies sorted by Sharpe ratios. The first strategy exploits AUD/USD interest rate differentials and generates a Sharpe ratio of 0.78, followed by carries exploiting interest rate differentials between EUR and USD deposits. The last row of the table shows summary statistics for the Datastream world equity market total return index. It is interesting that certain carry combinations commonly thought of as being highly profitable merely occupy mediocre or lower ranks. That holds, for example, for carries with a short position in JPY and a long position in AUD or CAD. On the other hand, it comes as a surprise that the CHF/EUR carry is located somewhere in the middle. After all, the latter strategy exhibits an interest rate differential of only 1% on average. These seemingly anomalous results are due to the standard deviation component, which is exceptionally high for the JPY/AUD and the JPY/CAD carry trade strategy, while it is lowest for CHF/EUR trades. Conventional wisdom seems to put too much weight on the interest rate differential component, while risks involved are not taken into account appropriately. In addition, carry trade rankings crucially depend on the observation period investigated. In fact, the JPY/AUD and the JPY/CAD strategy are indeed relatively attractive if observations are restricted to more recent periods.

The third row from the bottom shows that investors gain 3.66 cents on an annualized basis and on average over all carry trades. The average standard deviation, given in the third column, amounts to 9.82 cents, which leads to an annualized Sharpe ratio of 0.37. Whereas the composite carry generates the same profit on average (3.66 cents), it comes with a much lower standard deviation of only 4.25 cents. This indicates that aggregation entails substantial diversification benefits. The reason is that losses on some currency pairs are compensated by gains somewhere else, which results in a considerable reduction in aggregate volatility. In view of these findings, it is not surprising that the composite index generates a much higher Sharpe ratio (0.86) than individual carry trade strategies. The Sharpe ratio of the composite index is also higher than that provided by the world equity index.⁴ The existence of such favorable risk-reward opportunities seems puzzling - at least at first sight. After all, one would expect speculators to drive UIP back towards parity. Asymmetries in profit distribution, which are discussed subsequently, might bring us a step nearer to a solution of the conundrum.

⁴For comparison, see Sharpe (1994), who conjectures that the annualized Sharpe ratio for US stock market investments amounts to approximately 0.4 in the long run.

	mean	stddev	skew	kurt	SR	JB
USD/AUD	7.23	9.32	-0.30	2.76	0.78	0.15
EUR/USD	7.11	9.36	-0.28	3.41	0.76	0.00
CHF/NZD	6.61	11.13	-0.28	3.25	0.59	0.24
JPY/NZD	7.24	12.27	-0.35	3.64	0.59	0.04
GBP/NOK	4.84	8.25	0.06	3.72	0.59	0.04
CHF/CAD	6.48	11.48	-0.16	3.32	0.56	0.91
CAD/NZD	5.08	9.10	-0.21	3.24	0.56	0.45
CHF/AUD	6.71	12.60	-0.26	3.15	0.53	0.53
AUD/NZD	3.55	6.79	-0.15	3.16	0.52	0.73
NOK/USD	4.97	9.76	-0.09	3.14	0.51	0.07
USD/NZD	4.73	9.65	-0.46	3.42	0.49	0.01
USD/JPY	5.37	11.21	-1.08	7.58	0.48	0.00
USD/CAD	2.75	6.07	-0.26	3.12	0.45	0.24
EUR/NZD	4.37	10.01	-0.24	3.17	0.44	0.19
GBP/JPY	4.88	12.28	-1.24	7.29	0.40	0.00
NOK/JPY	4.50	12.22	-0.95	4.94	0.37	0.00
CHF/NOK	2.37	6.54	-0.36	3.78	0.36	0.01
JPY/AUD	4.57	13.18	-0.49	4.15	0.35	0.00
EUR/CAD	3.38	10.29	-0.11	3.13	0.33	0.37
CHF/GBP	2.75	8.42	-0.60	6.33	0.33	0.00
EUR/AUD	3.28	11.37	0.04	2.81	0.29	0.54
CHF/EUR	1.04	3.65	-0.27	3.32	0.29	0.73
EUR/JPY	3.17	11.22	-0.89	6.17	0.28	0.00
GBP/AUD	2.98	10.86	-0.23	3.54	0.27	0.02
CAD/JPY	3.04	12.38	-0.87	6.92	0.25	0.00
GBP/CAD	2.25	9.75	-0.56	4.98	0.23	0.00
EUR/GBP	1.73	7.51	-0.56	4.68	0.23	0.00
GBP/NZD	2.25	10.30	-0.56	4.02	0.22	0.00
NOK/CAD	2.20	10.26	-0.30	3.04	0.21	0.21
GBP/USD	1.69	8.61	-0.90	6.30	0.20	0.00
EUR/NOK	0.96	5.24	-0.32	4.45	0.18	0.00
CHF/JPY	1.93	11.20	-0.67	5.18	0.17	0.00
CHF/USD	1.69	10.57	-0.52	3.34	0.16	0.01
NOK/NZD	1.57	10.73	0.06	3.52	0.15	0.01
NOK/AUD	1.55	11.49	0.06	3.17	0.14	0.29
CAD/AUD	0.99	8.42	0.16	2.77	0.12	0.59
Average	3.66	9.82	-0.39	4.11	0.37	-
Carry index	3.66	4.25	-0.92	5.23	0.86	0.00
MSCI WLD	8.93	13.33	-0.79	4.22	0.67	0.00

Table 4.3: Summary statistics on carry trade returns

The previously discussed Sharpe ratio reduces risk to standard deviations and fails to account for fat tails and skewness. However, columns 4 and 5 in table 4.3 reveal that carry profits exhibit distinct asymmetries. We obtain a value of more than three for the kurtosis of almost all carry trades investigated, which signals that distributions have fatter tails than under normality. Investors dislike fat tails because they reflect that positions are subject to large fluctuations. To make matters worse, carry trade profits exhibit negative skewness, which means that distributions reach more into the loss than into the profit region. Negative skewness is another unfavorable characteristic, for which investors demand a supplementary risk premium. That is shown in chapter 7 where deviation from UIP is related to coskewness with equity market returns. Diversification does not mitigate asymmetries. The composite carry comes with a kurtosis of 5.23 and a skewness of -0.92, which is worse compared to what we obtain for individual carry trades on average or for the world equity portfolio. Consequently, the Jarque-Bera test rejects the null hypothesis of normality for most individual carry trade strategies and most distinctively for the composite carry trade index. For the latter, the p-value of the Jarque-Bera test, shown in column 7, is almost zero. Diversified carry trades thus provide higher Sharpe ratios than world equity market investments. On the other hand, carry trade profit distributions are more negatively skewed and exhibit more kurtosis. That corroborates the hypothesis that carry speculators find themselves trapped in loss spirals from time to time - a phenomenon more closely analyzed subsequently.

4.6 Loss Spirals

In this section, we try to provide an intuitive explanation for the loss spiral hypothesis. Theory is then endorsed with empirical evidence where we explore movements in CHF and in JPY risk reversals. These currencies are chosen because they seem to play a prominent role on the short side of the carry trade (see section 4.4).

4.6.1 Mechanics of Loss Spirals

Every now and then, carry traders fall prey to self-reinforcing loss spirals for whose initiation they are paradoxically responsible themselves. To understand how carry trade activity can trigger such damage, it is crucial to analyze interactions between carry trade borrowers and carry trade lenders in times of financial distress.

Carry traders' long positions are financed by incurring debt in some low-yield currency. Own funds are merely required as a deposit of margins, which serve as collateral to the lender. Leverage boosts expected returns by magnifying profits, but it also amplifies losses. Leveraged structures must therefore be seen as risky ventures in general. That alone is scarcely fatal because professional carry traders should be aware that they are exposed to a leveraged scheme. According to Gagnon and Chaboud (2007), disaster looms if total carry trade exposure reaches volumes whose simultaneous unwinding has an impact on prices. To see that, assume a sharp appreciation of the funding currency, for instance, the JPY. Consequently, carry traders suffer a loss on their short position, which induces lenders to increase collateral requirements. To meet rising margin calls, some traders might be forced to sell long positions in order to exit from the short side of the trade. Since traders are likely to hold similar stakes, many might seek to close at the very same time. In case manoeuvred volumes become so bloated that they can move prices, long currencies will depreciate further, while short currencies will experience an appreciation. That leads to yet more losses and again higher margin calls, and we are left with a feedback mechanism leading to ever larger losses.

In the previous example, loss spirals originate from a fierce appreciation of the JPY. There exist many other potential triggers. Everything inducing traders to simultaneously unwind large carry trade positions might lead to disaster. Assume, for instance, that currency markets become more volatile. This leads to even fatter tails in profit distributions and amounts to a rise in implied carry trade risks. Again, this might lead to an increase in margin requirements and hence to a simultaneous foreclosure of carry trade positions. Moreover, traders might be forced to reduce exposure in order to comply with internal risk control requirements. After all, banks constantly assess their risk exposure by using "value at risk" and similar models. In times of rising volatility, traders might be urged to reduce positions, which results in a simultaneous unwinding of large volumes.

4.6.2 Empirical Evidence

In this section, we try to provide empirical evidence for the loss spiral hypothesis. In line with our reasoning above, we analyze how CHF and JPY risk reversals behave in response to rising exchange rate volatility and funding currency appreciation.

Carry funding currencies such as the JPY exhibit negative skewness due to the sporadic occurrence of abnormally sharp appreciations. Such return asymmetries

leave their mark in option-implied volatilities, so that options on carry currencies should exhibit “crooked smiles”. More specifically, the JPY/USD risk reversal defined as buying a far out-of-the-money JPY call/USD put and selling a directionally opposite far out-of-the-money JPY put/USD call should exhibit positive volatility. Indeed, as shown in section 4.4.5, that corresponds to what we observe on average. We explore here risk reversal dynamics in periods of rising exchange rate volatility and in the aftermath of funding currency appreciation. The probability of a sharp appreciation of the JPY increases during such episodes, which should translate into widening JPY/USD risk reversals. After all, that is what we would expect if carry trade-related loss spirals were of any relevance.

Anecdotal evidence indeed corroborates our hypothesis. JPY/USD risk reversals have risen dramatically during the recent credit crunch starting in August 2007 when many hedge funds found it increasingly difficult to obtain refinancing. A similar spike can be observed in the aftermath of the LTCM crisis in October 1998. During that period, hedge funds faced similar refinance difficulties as banks tightened lending standards. These episodes correspond well with our hypothesis that return distributions become more negatively skewed in periods when carry trade players run into trouble. During both crises, the spike in risk reversals was accompanied by a sharp appreciation of the JPY. In fact, risk reversals and exchange rates are highly correlated. We obtain a correlation coefficient of 0.36 between movements in JPY/USD risk reversals and movements in JPY/USD exchange rates. The question might arise why our analysis is based on risk reversals and not simply on exchange rate data. After all, most market participants primarily care for exchange rate movements. The reason is that exchange rates do not capture all safe haven properties. If a loss spiral is on the verge but does not materialize, exchange rates do not send any signal. Risk reversals, by contrast, react immediately because they reflect return distributions and accordingly capture *actual* as well as *latent* safe haven quality.

Subsequently, we regress risk reversals on factors thought to proxy for carry trade profitability. We focus on analyzing whether hedging demand against severe appreciations in funding currencies increases during and in the immediate aftermath of events having a potentially damaging effect on carry trades. This would be the case if market participants feared that the harmful effect could develop into a fully fledged loss spiral. It was argued above that loss spirals could be set off by an increase in currency market volatility. The reason is that rising volatility makes carry trade positions increasingly risky, which might result in a simultaneous unwinding of positions in order to reduce exposure. To capture

this effect, we include implied volatilities obtained from currency option prices in our subsequent regression. Appreciation in carry funding currencies constitutes another threat, which could potentially trigger a loss spiral. We account for exchange rate shifts by including a factor measuring daily exchange rate movements in percentage. The following measures were taken to avoid simultaneity problems arising from feedback mechanisms between dependent and independent variables. First, the volatility factor is constructed as the first principal component of the logarithmic change in option-implied volatilities across a wide range of currency pairs. Thereby, attention was paid not to include implied volatilities of the currency pair in the regressand. The regression with the JPY/EUR as dependent variable is, for instance, based on CHF/EUR, CHF/GBP, CHF/USD, JPY/GBP, JPY/USD and USD/GBP but not on JPY/EUR volatilities. Second, the exchange rate regressor is included with a lag, which means that risk reversals today are explained by exchange rate movements yesterday. That leaves us with the following expression:

$$\begin{aligned} \text{RRChange}_t = & \alpha + \beta_1(\text{FXChange}_{t-1} \times \text{d92}) + \beta_2(\text{FXChange}_{t-1} \times \text{d03}) \\ & + \beta_3(\text{FXVolChange}_t \times \text{d92}) + \beta_4(\text{FXVolChange}_t \times \text{d03}) + \epsilon_t \end{aligned} \quad (4.3)$$

whereas RRChange_t denote absolute changes in risk reversals and FXChange_{t-1} are %-movements in foreign exchange in $t - 1$. FXVolChange_t corresponds to the first principal component of the logarithmic changes in volatilities in t obtained from option prices. All regressors, bar the constant, are interacted with dummy variables d92 and d03 , which enable us to evaluate whether sensitivities have changed more recently.

Equation 4.3 is estimated for various risk reversals using ordinary least squares (OLS) while test statistics are based on Newey-West autocorrelation and heteroskedasticity consistent covariance estimates. Table 4.4 displays the results. β_1 and β_2 turn out to be negative and highly significant, which indicates that risk reversals in t widen in response to an appreciation of carry funding currencies in $t - 1$. That effect emerges clearly in all regressions and for both estimation periods. t -statistics gravitate between -5.09 for the recent JPY/EUR and -13.08 for the recent CHF/USD estimation. The effect is not only highly significant but also economically relevant. An appreciation of the JPY against the USD by 1 percent in $t - 1$ reduces the JPY/USD risk reversal by approximately 0.1. That is quite large once one considers that the JPY/USD risk reversal usually trades within a range between 0 and 2. A comparison of β_1 with β_2 leaves us with con-

	JPY/USD	JPY/EUR	CHF/USD	CHF/EUR
α	0.0002 (0.0719)	0.0006 (0.3387)	-0.0003 (-0.2273)	0.0000 (-0.0086)
β_1	-11.1574 (-12.0320)	-6.8156 (-9.0801)	-5.1175 (-8.7804)	-7.4412 (-6.2630)
β_2	-9.5791 (-11.1551)	-8.9960 (-5.0949)	-6.2753 (-13.0878)	-5.3836 (-6.2062)
β_3	0.0229 (3.6615)	0.0102 (3.4522)	0.0012 (0.4993)	0.0050 (2.4097)
β_4	0.0472 (9.2933)	0.0224 (7.8227)	-0.0006 (-0.1646)	0.0031 (4.1739)
R^2_{adj}	0.1974	0.1281	0.0938	0.0578

Table 4.4: Regressing risk reversals on movements in exchange rates and on currency volatilities

tradictory signals depending on the regression analyzed. Whereas the CHF/USD and the JPY/EUR risk reversal have reacted in a more sensitive manner to foreign exchange rate shifts since 2003, sensitivity has decreased somewhat for the JPY/USD and the CHF/EUR example. Risk reversals increase also in response to rising currency volatility. That can be seen from β_3 and β_4 , which turn out to be positive and highly significant, except for the recent CHF/USD regression. Note that the sensitivity with respect to implied volatilities has grown for risk reversals involving the JPY. That can be seen from β_4 , which is larger than β_3 . We interpret that finding as evidence that the JPY plays an increasingly prominent role as carry funding currency. In summary, it can be said that investors' demand for call options on carry funding currencies increases indeed during and in the aftermath of events with a harmful impact on carry trades. That is interpreted as fear that initial damage could trigger a feedback mechanism leading to ever larger losses.

4.7 Conclusion

This chapter provides circumstantial evidence on volumes involved in carry trade activity and evaluates risk-reward opportunities. Particular emphasis is put on asymmetries in profit distributions and on loss spirals triggered by excessive carry trade speculation.

Various indicators point towards a flourishing carry trade activity. Funding

in CHF and in JPY, which are both notorious low yielders, seems particularly widespread. Most indicators suggest that the importance of the JPY on the short side of the carry has risen considerably in recent years.

It is then shown that a diversified carry trade strategy provides exceptionally favorable risk-reward opportunities. In fact, the composite carry index provides a much higher Sharpe ratio than an undiversified carry trade strategy or investments into the MSCI world equity index. The balance of risk and reward worsens, however, when third and fourth moments are taken into consideration. In fact, carry trade profit distributions usually exhibit negative skewness and excess kurtosis. Diversification does not help to reduce these anomalies.

The finding of burgeoning carry trade activity combined with negative skewness leads us to more closely analyze the loss spiral hypothesis proposed by Cavallo (2006) and Gagnon and Chaboud (2007). It is argued that excessive carry trade activity triggers loss spirals every once in a while as traders rush to the exit at the very same time. We propose an empirical test based on risk reversals to test the hypothesis and find strong support.

Chapter 5

Carry Trades: Analyzing Correlation Dynamics

This chapter examines contagion and flight-to-quality phenomena between carry trades and global equity markets. The main message is that carry trading amounts to a risky venture which exposes speculators to a diversification meltdown in times of financial turmoil. More specifically, this chapter investigates conditional as well as unconditional correlation between global equity market returns and profits derived from different carry trade strategies. Correlation dynamics are modeled within a multivariate GARCH framework taking account of asymmetries. It is found that unconditional correlation between carry trade profits and stock market returns is positive on average. To make matters worse, correlation rises considerably in response to equity market downturns. This implies that carry traders face particularly unfavorable correlation in periods when diversification would be most needed. These findings are corroborated by an analysis of asymmetry in exceedance correlation. Exceedance correlation is defined as the correlation in the tails of a bivariate distribution. It turns out that correlation for joint downward shocks in carry trade and equity markets is larger than correlation for joint upward shocks, which is another indication that correlation patterns change unfavorably in times of stock market downturns.

5.1 Introduction

Nominal exchange rates sometimes deviate to a great extent from what is thought to be a fair value. Carry speculators borrowing cheaply in currencies with relatively low interest rates and lending at higher rates elsewhere are often blamed for causing such decoupling. The critics argue that carry traders run large risks. After all, unexpected currency movements might quickly erase profits implied by interest rate differentials. The latter are relatively small in comparison to the magnitude of fluctuations in foreign exchange markets. In this chapter, we focus on yet another carry trade risk exposure, viz. on correlation spillovers, which are sometimes referred to as contagion. More specifically, we analyze the variance-covariance dynamics between carry trades and nominal returns on world stock markets in a multivariate GARCH (MV-GARCH) as well as in an exceedance correlation framework. A thorough understanding of variance-covariance spillovers obviously is of crucial importance for international investors. Not taking account of time-variation in second moments is likely to result in an over-investment in high-yield currencies. This makes investors prone to an unexpected diversification meltdown in times of financial crisis.

As a matter of fact, the standard carry trade strategy boils down to a double speculation against uncovered interest rate parity (UIP) where investors hope to profit twofold from risk premia in their favor. First, carry traders speculate that a default-free investment in some high-yield currency outperforms a comparable default-free investment in domestic currency. Since interest rates are known at the beginning of the contract period, the carry trader is solely exposed to uncertainty in exchange rate movements. He would incur a loss on his foreign deposit if the domestic currency experienced an unexpected sharp appreciation. Instead of investing in foreign money markets, investors can alternatively lock in interest rate differentials by entering a forward contract which promises delivery of domestic currency at some future date. Assuming rational expectations, the difference between forward rates and future spot exchange rates is known as currency risk premium and is precisely equal in magnitude to deviation from UIP. That is due to covered interest rate parity, which must hold permanently by virtue of arbitrage.¹ In contrast to the forward premium, measuring the difference between forward rates and current spot rates, the currency risk premium captures the difference between forward rates and future spot rates and is only known ex-post. The second speculation concerns borrowing costs and might be interpreted as

¹Subsequently, we use the expressions (currency) risk premium and deviation from UIP synonymously.

a bet against UIP with reversed sign. By borrowing in low-yield markets, carry traders hope to end up with lower borrowing costs than for a comparable loan in domestic currency. As before, interest rates are known at the time of entering a credit agreement, and uncertainty is merely due to foreign exchange rate movements. The carry investor would now incur a loss on his foreign loan if the domestic currency experienced a sharp depreciation. Again, low foreign interest rates could alternatively be locked in via forward markets by promising to deliver foreign currency at some future date.

For some currencies, risk premia are surprisingly persistent, which implies that forward rates systematically under- or overpredict future spot exchange rates. The Swiss franc (CHF), for instance, is a notorious low performer, usually leaving investors with a negative currency risk premium. By contrast, money market deposits in commodity currencies such as the Australian dollar (AUD), the Canadian dollar (CAD) or the New Zealand dollar (NZD) have performed relatively well recently. For that reason, our analysis is based on carry strategies where investors incur debt in CHF and invest the proceeds in commodity currency deposits. So does a persistent forward premium - a phenomenon sometimes referred to as the forward rate puzzle - make certain currencies a foolproof prey for carry traders? A note of caution is advisable, after all, deviation from UIP is probably not simply the result of market irrationality. Evidence is rising that deviation from UIP can be partly explained by exposure to systematic or non-diversifiable risk (see, for instance, Sarkissian, 2003 or Lustig and Verdelhan, 2005). In virtually all asset pricing models, systematic risk is driven by a covariance term between payoffs or returns and some explicit or implicit measure of utility. The CAPM, for instance, postulates that the risk premium arises due to positive covariance between returns on some asset i and returns on the market portfolio, where the latter is seen as a proxy for agents' total wealth. In this chapter, we demonstrate that there exists a relationship between the sign and magnitude of currency risk premia on the one hand and correlation between currency risk premia and returns on global equity markets on the other. Whereas we initially take a static perspective in the sense that correlation is calculated as a sample average, the chapter's main focus lies in analyzing time-varying correlation within both a MV-GARCH and an exceedance correlation framework. In the MV-GARCH section, we explore changes in correlation between returns from carry investments and returns on global equities in response to shocks in stock markets. Besides analyzing the aggregate effect, it is revealing to decompose the carry into two separate bets against UIP. This enables us to study the correlation dynamics of

low- and high-yield currencies separately. The MV-GARCH analysis leaves us with illustrative news impact surfaces (NIS), which displays the impact of past asset price shocks in a three-dimensional graph. The results from MV-GARCH estimations do, however, not directly reveal whether movements in correlation are large in a statistically significant sense. For that purpose, we additionally calculate exceedance correlations, which are defined as correlations in the tails of a bivariate distribution. A test statistic for asymmetry allows us to determine whether exceedance correlations are significantly different in times of joint positive market shocks as opposed to times of joint negative market shocks.

Our analysis shows that unconditional correlation conceals the true magnitude of correlation exposure. In fact, in volatile market environments and particularly during market downturns, correlation between equity markets and commodity currency deposits increases considerably. Intuitively, the rise in correlation is due to investors avoiding procyclical currency positions in periods of market turbulence. In other words, carry traders' long positions exhibit exceptionally unfavorable correlation exposure in times of general market downturns. It is in these periods precisely when diversification is most desirable. To aggravate matters, correlation dynamics are the other way round on the borrowing side of the carry. We assume that carry traders borrow on the Swiss franc (CHF) money market. In contrast to commodity currencies, the CHF moves against the cycle, which means that it has a tendency to appreciate during global market downturns and to lose strength in boom periods. That is one reason why the CHF is sometimes referred to as being a safe haven currency. A carry trader holding a short position in CHF does not appreciate countercyclicality because it leaves him with a larger debt burden in times of stock market downturns. If correlation is conditioned on past asset price shocks or exceedance levels, borrowing in CHF loses even more appeal. Our analysis reveals that the correlation between CHF deposits and equity markets grows considerably more negative in bear markets as opposed to bull markets. Intuitively, that is what one would expect from a safe haven currency, which is in particularly high demand in times of turmoil as investors run for protection. In short, we can conclude that carry traders face unfavorable correlation exposure on their long as well as on their short position. Moreover, risk exposure deteriorates considerably in times of financial crises. Not taking account of that, is likely to result in over-frivolous carry speculation.

5.2 Related Literature

Our analysis is part of a broad body of literature on contagion, which explores dispersion of financial crises across assets and markets. As noted by Pericoli and Sbracia (2003), there does not exist an unambiguous definition of contagion yet. Some authors propose to measure contagion as the probability of a shock conditional on a shock in some other market. Others define contagion as comovements in asset prices that are not justified by changes in economic fundamentals. Again others focus on volatility rather than asset price spillovers. Our study is in accordance with this latter literature which defines contagion as a rise in correlations in response to crises. Crises are usually defined as times of large market downturns or as periods of exceptionally high volatility. Alternatively, some authors define crises exogenously by major geopolitical events such as the war in Iraq or September 11th, 2001. Empirical research on variance-covariance spillovers is usually conducted in a MV-GARCH framework.

One of the earliest studies in this field is by Longin and Solnik (1995), who examine variance-covariance spillovers between national stock market indices. Introducing dummy variables to a bivariate constant correlation model, Longin and Solnik report an increase in correlation between national stock markets in times of above average volatility in the US equity market. They do not find much evidence for asymmetric effects. In their study, equity market correlations hence do not depend on whether the US stock market suffers a positive or a negative shock. Longin and Solnik's investigation is representative for the bulk of the contagion literature which analyzes spillover effects within the same category of assets. The focus is usually on covariance dynamics across national stock market indices. We are interested in spillover effects across asset classes, viz. between movements in global stock markets and foreign currency money market deposits. Research focusing on variance-covariance dynamics across asset classes is surprisingly rare. One example is a paper by Hartmann, Straetmans and DeVries (2001), who investigate spillovers between stock and bond markets. They do, however, not base their investigation on a MV-GARCH analysis but on a conditional probability measure which captures the probability of a crash given a downturn in another market. It is found that the probability of a bond market crash during a stock market crash is relatively low. Cappiello et al's (2003) MV-GARCH study on correlation dynamics between national stock and bond markets is similar to our investigation. Like most studies on contagion, Cappiello et al. report a rise in correlation between national equity markets during times of crises. In addition, they provide evidence for a flight-to-quality phenomenon between stock and bond markets. In contrast

to contagion, flight-to-quality is defined as a decrease in asset price covariance or correlation in response to market downturns. Divergence in asset prices is a consequence of investors reallocating capital from risky to safer assets in times of turbulence. Cappiello et al's MV-GARCH specification accounts for asymmetric effects, which enables them to differentiate between positive and negative asset price shocks. The inclusion of asymmetries proves to be crucial because contagion and flight-to-quality not only depend on the magnitude of a shock but also on the shock's sign. The latter effect is possibly even more important. Baur and Lucey (2006) do a similar study and find that the correlation between stock and bond markets has considerably fallen in the aftermath of the Asian crisis in October 1997 and also in response to the Russian crisis in June 1998. From a methodological viewpoint, our study is closely related to those of Cappiello et al. and Baur and Lucey. In line with their research, we also investigate covariance spillovers across asset categories and base analysis on an asymmetric MV-GARCH framework. Additionally, by analyzing covariance dynamics between commodity and safe haven currencies, we also obtain contagion and flight-to-quality effects. The main difference concerns the subject of examination. Whereas Cappiello et al. and Baur and Lucey focus on spillover effects between equity and bond markets, our analysis explores correlation dynamics between equity and foreign exchange markets. To the best of our knowledge, there does not exist any such study yet. Tastan (2006) runs, however, a MV-GARCH analysis between movements in exchange rates and stock market returns. Since the bulk of the variation in currency risk premia is due to exchange rate movements, Tastan's study is closely related to ours. He finds significant GARCH effects and concludes that average covariance measures conceal that conditional covariances vary considerably over time. In contrast to our analysis, Tastan does not focus on safe haven currencies, nor does he incorporate asymmetric effects.

The theory around exceedance correlation offers an alternative framework for the analysis of contagion and flight-to-quality phenomena. Judging by the number of studies, the exceedance correlation literature is overshadowed by MV-GARCH analyses. In contrast to MV-GARCH analyses, it notably provides a simple framework to test whether asymmetric effects are of statistical significance.

Exceedance correlation is based on extreme value theory and measures how correlation changes as one moves towards the outer tails of a multivariate - usually bivariate - distribution. In a landmark paper, Longin and Solnik (2001) study conditional correlations between international stock markets. They focus on asymmetric effects by distinguishing between correlation in bull as opposed to correlation

in bear markets. It is found that a bivariate normal distribution provides a good description of correlation in bull markets but that it underestimates correlation during market downturns. Ang and Chen (2002) investigate correlation dynamics between US aggregate equity markets and sub-portfolios sorted by characteristics such as size and book-to-market. They conclude that correlation is much larger for extreme downside moves as opposed to upside moves of the same magnitude. Similarly to Longin and Solnik, they report that downside correlation is larger than what a normal distribution would imply. A key innovation of their paper is that they develop a procedure which enables them to test whether exceedance correlations differ in a statistically significant sense from correlations implied by some prespecified distribution. The drawback is that their procedure demands to calculate theoretical exceedance correlations of multivariate distributions. These can only be obtained by diving into extreme value theory. Besides the fact that closed-form calculations are rather cumbersome, there remains the difficulty of choosing an appropriate benchmark distribution. Fortunately, Hong et al. (2003) suggest an alternative test for asymmetry which circumvents both difficulties and thereby renders the exceedance correlation framework more accessible.² In section 5.6, we study exceedance correlations between profits on carry trade strategies and returns on world equity markets where we make use of Hong et al.'s (2003) test procedure.

5.3 Data

Our data set contains weekly observations from April 11th, 1997, to December 29th, 2006, which leaves us with a total sample size of 508 observations. A weekly frequency was chosen because GARCH effects are found to level off at longer frequencies such as monthly or quarterly time intervals. In fact, it is well possible that a daily granularity leads to even more distinctive results, but since we use data from various market places, a daily or even shorter time span would complicate timing calibration enormously.

We use the world equity market total return index provided by Datastream to calculate logarithmic returns on the global market portfolio. The excess market return is obtained by subtracting the USD Euromarket rate for 1-week deposits from world market returns. Euromarket rates are obtained from the Financial Times and exchange rate data are from Reuters. Deviation from UIP is calculated as follows:

²See, for instance, Michayluk et al. (2006) who investigate exceedance correlation between US and UK securitized real estate markets.

$$uip_{t,t+1} = i_{t,t+1}^f - i_{t,t+1} + \ln(s_{t+1}/s_t) \quad (5.1)$$

where $uip_{t,t+1}$ denotes deviation from UIP between t and $t+1$. $i_{t,t+1}^f$ is the foreign 1-week Euromarket rate, $i_{t,t+1}$ denotes the corresponding domestic rate and s represents the exchange rate. Note that all returns are expressed in logarithmic form. As mentioned previously, a carry trade boils down to a double speculation against UIP where investors hold a long position in a high-yield currency and a short position in a low-yield currency. The returns on the carry trade investment are obtained by summing up currency risk premia from long and short positions. Since $uip_{t,t+1}$ measures deviation from UIP in logarithmic terms, we must run a transformation to obtain discrete returns. Only then can we perform a cross-sectional summation. With deviation from UIP defined as in equation 5.1, we can write:

$$r_{ij,t,t+1} = \ln(1 + e^{uip_{i,t,t+1}} - e^{uip_{j,t,t+1}}) \quad (5.2)$$

where r_{ij} denotes the logarithmic return on a carry trade investment with a long position in the high interest rate market i and a short position in the low interest rate market j . We calculate three carry strategies with investors holding a short position on the CHF and a long position in either the AUD, the CAD or the NZD money market. In the main text, analyses usually refer to the case of an USD investor, which means that all returns are expressed in USD. The appendix contains additional uncommented results from the viewpoint of an EUR and a GBP investor. DEM series are used prior to the launch of the EUR on January 1st, 1999.

5.4 Preliminary Analysis

Figure 5.1 shows a scatter plot with average currency risk premia on the vertical axis and correlations between returns on foreign currency deposits and returns on global equities on the horizontal axis. All returns are calculated from the perspective of an USD investor. Note that the scatter cloud is upward-sloping. In other words, currencies generating a positive risk premium on average are exposed to a higher correlation with world equity markets compared to currencies exhibiting a low or even a negative risk premium. This observation is in contradiction to the literature blaming deviation from UIP to market anomalies and investor

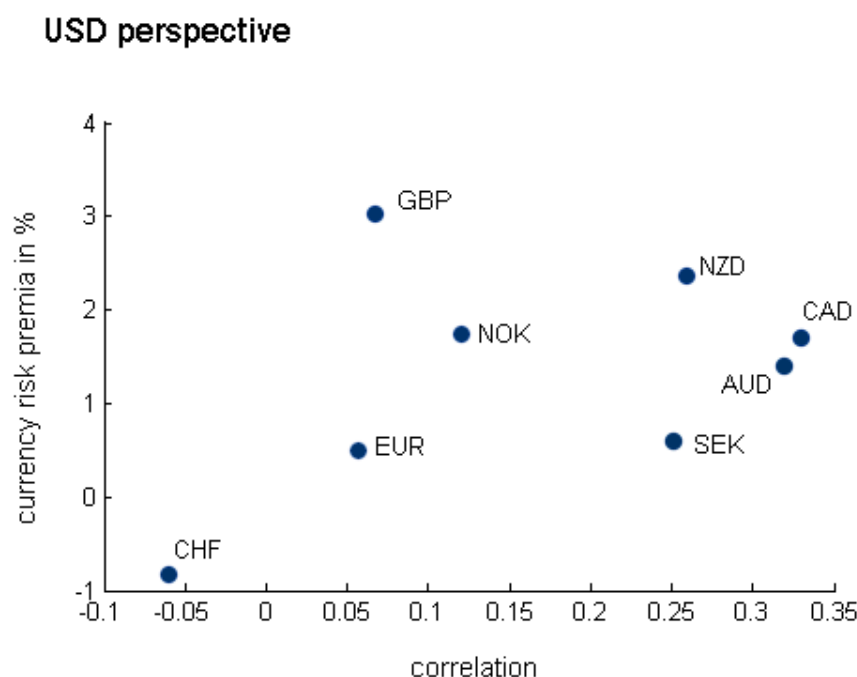


Figure 5.1: Deviation from UIP and its correlation with equity market returns (USD)

irrationality. Figure 5.1 suggests, by contrast, that differences in currency risk premia may be (partly) explained by differences in exposure to systematic risk. The latter is measured in terms of a more or less favorable correlation exposure to global equity markets.

Over the last couple of years, deposits in AUD, CAD or NZD have shown a better performance than comparable deposits in USD. For that reason, we base our analysis on carry trades with a long position in either AUD, CAD or NZD deposits, which are commonly referred to as commodity currencies. That is because they stem from countries where exports of raw materials account for a large fraction of total GDP, which makes these currencies prone to fluctuations in commodity prices and hence to the state of the global economy.³ On the other hand, the CHF money market seems predestined for borrowing because CHF interest rates have been much lower on average than in most other countries. In fact, there exists an extensive body of literature exploring the phenomenon of the so-called Swiss interest rate island (see, for example, Buomberger, Höfert and van Bergeijk, 2000 or Kugler and Weder, 2004). Thus, even after accounting for

³See, for instance, Djoudad et al. (2000) or Chen and Rogoff (2002) for an analysis of the relationship between commodity prices and fluctuations in the AUD, the CAD or the NZD.

currency movements, loans in CHF would have been much cheaper than loans in almost any other currency.

We subsequently assume that carry traders take a short position on the CHF money market to invest the proceeds in either AUD, CAD or NZD deposits. The return of such a zero fund investment is obtained by aggregating the two resulting currency risk premia as shown in equation 5.2.⁴ Interest rate levels in commodity currencies are relatively high in comparison to comparable investments in other currencies, which renders them attractive for carry trade long positions. From April 1997 to December 2005, 1-week Euromarket rates were 6.1% and 5.1% on average for weekly deposits in NZD and AUD, respectively. Deposits in CAD provided 3.7%, deposits in USD 3.9% and deposits in EUR 3.0%. At the very bottom of the league were investments in CHF yielding 1.3% and investments in JPY with an average return of 0.2%. Due to their notorious low interest rate level, CHF and JPY money markets provide advantageous financing conditions which makes them attractive from a carry trade perspective.

Interest rate differentials alone do not allow us to evaluate carry trade profitability. Returns are also driven by fluctuations in foreign exchange rates. This second factor seems crucial because currency movements are usually larger in size than interest rate differentials. Table 5.1 aggregates profits stemming from exchange rate movements and interest rate differentials by showing average deviation from UIP on an annual basis. Between 1997 and 2006, all carry trade strategies contemplated generated a positive return on average ranging from 1.6% for the AUD/CHF to 2.6% for the NZD/CHF carry trade. Standard deviations are, however, much larger so that t-statistics are far from significant. This provides some first evidence that carry trade speculation is a high risk venture. Moreover, table 5.1 reveals that all carry trade investments exhibit negative skewness. Negative skewness implies asymmetrically distributed returns in the sense that investors face an exceptionally high probability of making a large loss.⁵ To make matters worse, summary statistics show that carry trade strategies have fatter tails than what a normal distribution would imply. This can be seen from the val-

⁴It is not entirely correct to talk of returns when referring to carry trades. After all, the latter are zero fund investments, which means that, bar margin calls, they do not require any upfront payment. Accurately speaking, it would be more adequate to talk of profits in USD terms, thereby assuming that the carry trader has an exposure of 100 USD on the long as well as on the short side of the trade. However, for better comparability with interest rate levels and returns from UIP speculation, the terms profit and return are applied synonymously hereafter.

⁵The reader is referred to chapter 7 for a thorough analysis of the relationship between skewness and departure from UIP.

USD	AUD/CHF	CAD/CHF	NZD/CHF
mean	1.6%	1.7%	2.6%
stddev	12.0%	10.7%	12.4%
t-stat	0.13	0.15	0.21
skew	-0.56	-0.57	-0.44
kurt	5.38	4.13	3.99
JB-test	144.78	53.34	36.20
cor equity	0.34	0.27	0.30

Table 5.1: Summary statistics on carry trade returns (USD)

ues for kurtosis which would correspond to 3 under normality. Kurtosis is much higher for our carry strategies with values between 3.99 for the NZD/CHF and 5.38 for the AUD/CHF carry. Given these anomalies in third and fourth moments, it is not surprising that the Jarque-Bera test rejects the null hypothesis of normality for all our strategies.⁶ The last row displays unconditional correlation between the respective strategy and world equity markets. It can be seen that all trades exhibit strong procyclicality, generating profits during general market upturns and losses in bearish market environments. Risk-averse investors usually try to avoid positive correlation schemes because these expose their total wealth to large fluctuations.

As mentioned before, a carry trade boils down to a double speculation against UIP and can be decomposed into two components, viz. a currency risk premium from a long position in a commodity currency and a currency risk premium from a short position in CHF. In order to gain insight into a carry trade's underlying dynamics, table 5.2 reports statistics separately on each of these components. We limit explanations to the perspective from an USD investor, but similar results would be obtained from the viewpoint of an EUR or GBP investor. The first column of table 5.2 shows statistics on deviation from UIP with respect to CHF deposits, whereas columns to the right contain summary statistics with respect to commodity currencies. To emphasize the difference between CHF and commodity currency deposits, all returns are based on long positions.

Results for long positions in CHF (second column) are pretty much the mirror image of those reported for long positions in commodity currencies. It can be seen that an USD investor would have outperformed a corresponding domestic investment by holding commodity currency deposits, whereas he would have un-

⁶See Jarque and Bera (1980) for a description of the test.

USD	CHF	AUD	CAD	NZD
mean	-0.8%	1.4%	1.7%	2.3%
stddev	10.3%	11.0%	6.7%	11.6%
t-stat	-0.08	0.13	0.26	0.20
skew	0.11	-0.20	-0.02	-0.28
kurt	2.88	3.34	3.38	3.40
JB-test	1.35	5.46	2.93	9.82
cor equity	-0.06	0.32	0.33	0.26

Table 5.2: Summary statistics on deviation from UIP (USD)

derperformed by taking a long position in CHF. An investment in the AUD money market, for example, would have brought an outperformance of 1.4%, while comparable CHF investments underperformed by -0.8%. However, the CHF seems to compensate for its low yield by providing a hedge against stock market downturns. In fact, CHF deposits exhibit a slightly negative correlation with returns on global equities. That is precisely what we would expect from a safe haven currency, providing protection in turbulent times. The correlation between returns on commodity currency deposits and returns on world equities is strongly positive, which reflects the procyclical stance of commodity markets. Note as well that the currency risk premium on CHF deposits exhibits positive skewness, whereas departure from UIP with respect to commodity currencies shows a negative skew. In other words, a money market investment in CHF entails a higher probability of making a large gain than of making a large loss and vice versa for an investment in commodity currencies. Deviation from UIP with respect to commodity currency investments, moreover, suffers from excess kurtosis, whereas the probability of large fluctuations in the value of the CHF deposit is slightly smaller than what a normal return distribution would imply. An isolated analysis of commodity currency and CHF deposits generates, however, less distinctive anomalies in third and fourth moments than carry trade investments combining long commodity and short CHF strategies. For that reason, the Jarque-Bera test generally does not reject the null of normality for plain vanilla money market investments.

We have studied unconditional correlation so far. It is argued below that the latter conceals the true magnitude of correlation exposure. We show that carry trade correlation with equity markets deteriorates markedly in times of financial crises, which is precisely when diversification is most desirable. To see that, we need to switch from an unconditional to a more realistic conditional correlation framework that allows accounting for time-variation in second moments.

5.5 Multivariate GARCH Analysis

Autoregressive conditional heteroscedasticity (ARCH) models were originally developed in the first half of the 1980s by Engle (1982) and were later extended by Bollerslev (1986) to the more flexible GARCH framework. GARCH models enable econometricians to forecast the conditional variance of a time series by an autoregressive moving average structure where variances are driven by past asset price shocks and autoregressive variance components. Variances are, however, not only driven autoregressively as univariate GARCH specifications suggest. There, moreover, exist significant variance-covariance spillovers across assets, which can only be captured in a multivariate GARCH (MV-GARCH) framework. The latter serves to model second moments of systems containing several assets, which results in a process for the entire variance-covariance matrix. Obviously, contagion and flight-to-quality are spillover phenomena, which can only be modeled in multivariate settings. Technically, these are considerably more complex than their univariate counterparts. After all, the dynamic of every element in the variance-covariance matrix needs to be modeled. As the system is extended to more and more assets, elements of the variance-covariance matrix multiply to the square, which results in an explosion of free parameters boding trouble for estimation. To avoid parameter explosion, the econometrician needs to restrict the number of assets. Alternatively, he must choose a model using parameters parsimoniously. That usually comes at the cost of losing model flexibility. We restrict here analyses to a two-asset-system and only include global equity market returns and a carry trade profit time series. Consequently, we will not suffer from parameter explosion, irrespective of which MV-GARCH model is chosen. Our choice of model is merely restricted by the requirement that it should account for asymmetric effects. After all, contagion and flight-to-quality phenomena predominantly emerge during bear as opposed to bull markets. Models geared towards capturing asymmetries therefore postulate that the conditional variance-covariance matrix is not only a function of a past shock's magnitude but also of its sign.

From the scores of MV-GARCH models, we choose Engle and Kroner's (1995) BEKK specification in its complete form.⁷ In comparison to the widely applied diagonal BEKK model, the full-fledged version is richer in parameters. Since we deal with a bivariate system only, we are not much affected by parameter explosion so that we can easily cope with the full-fledged specification. The latter brings the advantage that it enhances model flexibility, thereby exposing more detailed insights of the dynamics of the variance-covariance matrix. The BEKK

⁷The acronym BEKK is due to an unpublished draft by Baba, Engle, Kraft and Kroner.

specification is based on a quadratic form, which brings the additional advantage of positivity of the variance-covariance matrix. Within the framework of their general dynamic covariance (GDC) model, which can be seen as a more general version of the BEKK specification, Kroner and Ng (1998) propose to include asymmetric effects. In analogy, we also incorporate asymmetric effects in our specification. Moreover, the BEKK model has been chosen because we encountered difficulties in estimating the dynamic conditional correlation model introduced by Engle (2002) and recently upgraded to an asymmetric version by Cappiello et al. (2003). It is found that the estimation results of Cappiello et al.'s model crucially depend on the choice of start parameters.

The BEKK MV-GARCH(1,1,1) model is defined as follows:

$$r_t = \mu + \epsilon_t \quad (5.3)$$

where r_t is a vector of excess returns. In our analysis, r_t is a bivariate vector denoting excess returns on the global equity index and returns resulting from a carry trade strategy betting on commodity currency versus CHF interest rates. The term μ denotes the corresponding vector of expected returns, which we assume to be constant. Given the information set Ω_{t-1} , we assume that the error term ϵ_t follows a normal distribution. In mathematical terms, ϵ_t is written as follows:

$$\epsilon_t \mid \Omega_{t-1} \sim N(0, H_t) \quad (5.4)$$

with

$$H_t = C \cdot C' + A' \epsilon_{t-1} \epsilon_{t-1}' A + B' H_{t-1} B + G' \eta_{t-1} \eta_{t-1}' G \quad (5.5)$$

where H_t denotes the conditional variance-covariance matrix. C , A , B and G are $n \times n$ parameter matrices with C being lower triangular. Expressed in words, the variance-covariance matrix is driven by a constant term denoted as $C \cdot C'$, previous return shocks ϵ_{t-1} , an autoregressive variance-covariance component H_{t-1} and η_{t-1} . The $n \times 1$ vector η_{t-1} is the asymmetric innovation term which corresponds to the value of ϵ_{t-1} if the latter is negative and is equal to zero otherwise. In mathematical terms, η_{t-1} is defined as follows:

$$\eta_{t-1} = \min(0, \epsilon_{t-1}) \quad (5.6)$$

The model is estimated in a two-step procedure. First, ϵ_t is obtained by demeaning r_t (see equation 5.3). Second, ϵ_t are plugged into the cumulative log-likelihood function given by:

$$\ln L(\theta) = -\frac{tn}{2} \ln(2\pi) - \frac{1}{2} \sum_{t=1}^T \ln |H_t| - \frac{1}{2} \sum_{t=1}^T \epsilon_t' H_t^{-1} \epsilon_t \quad (5.7)$$

where t is the total number of observations, n is the number of assets, and $|H_t|$ denotes the determinant of matrix H_t . We subsequently estimate bivariate MV-GARCH systems using Newton's interior-reflective method to maximize the log-likelihood function.⁸ As shown in section 5.4, the Jarque-Bera test leads to a rejection of the null hypothesis of normality for all carry strategies. For that reason, we apply the quasi-maximum likelihood estimator, which enables us to compute valid standard errors in spite of distributional abnormalities (see Bollerslev and Wooldridge, 1992).

5.5.1 Results

Table 5.3 displays estimation results for our three bivariate systems. Each section of the table reports on a different carry trade strategy, always from the perspective of an USD investor.⁹ The estimates c_{ij} , a_{ij} , b_{ij} and g_{ij} denote elements of the matrices C , A , B and G in equation 5.5. Since these matrices enter in quadratic form, each estimate influences several elements of the variance-covariance matrix, which renders interpretation of estimation outputs difficult. To see that, take estimate a_{22} in the NZD/CHF example, which has a value of 0.249 and a highly significant t-statistic of 3.84. The a -estimates correspond to the elements of the A -matrix, which capture the impact of past shocks on asset prices. Due to the quadratic form of the BEKK model, a_{22} influences the variance of the return on the carry investment as well as the covariance between returns on the carry trade and returns on global equities. As a consequence, we cannot determine one-to-one whether past shocks have a significant influence on variances, covariances or on both.

⁸See Matlab's Optimization Toolbox documentation and the references therein for a description of Newton's interior-reflective optimization procedure.

⁹The appendix contains estimation output from the perspective of an EUR and GBP investor. Results turn out to be very similar. For that reason, we leave them uncommented.

MSCI world - Carry AUD/CHF				MSCI world - Carry CAD/CHF				MSCI world - Carry NZD/CHF			
	params	stddev	t-stats		params	stddev	t-stats		params	stddev	t-stats
c(11)	0.0104	0.0028	3.65		0.008	0.003	2.73		0.004	0.002	1.83
c(21)	-0.0033	0.0039	-0.85		-0.010	0.003	-3.68		0.004	0.003	1.27
c(22)	0.0000	0.0006	0.00		0.001	0.023	0.02		0.004	0.002	2.05
a(11)	-0.0036	0.1325	-0.03		0.031	0.183	0.17		0.050	0.114	0.44
a(12)	0.1029	0.0908	1.13		0.028	0.169	0.17		-0.086	0.091	-0.94
a(21)	-0.2114	0.2022	-1.05		0.268	0.172	1.56		0.021	0.054	0.38
a(22)	0.1297	0.0819	1.58		0.006	0.023	0.25		0.249	0.065	3.84
b(11)	0.5449	0.2944	1.85		0.644	0.126	5.10		0.941	0.049	19.12
b(12)	-0.2012	0.0693	-2.90		0.105	0.051	2.07		-0.035	0.037	-0.93
b(21)	0.4686	0.2539	1.85		0.543	0.153	3.54		-0.032	0.059	-0.54
b(22)	0.9524	0.0643	14.80		0.641	0.181	3.53		0.878	0.081	10.89
g(11)	0.2523	0.1395	1.81		0.204	0.083	2.45		0.198	0.085	2.32
g(12)	0.3674	0.1267	2.90		0.241	0.094	2.57		0.294	0.086	3.41
g(21)	0.4211	0.3233	1.30		0.453	0.216	2.09		0.318	0.104	3.07
g(22)	0.0072	0.2316	0.03		-0.054	0.067	-0.80		0.006	0.035	0.18

Table 5.3: Results of a GARCH(1,1,1) estimation for three bivariate systems, each based on returns from a carry trade and returns on global equity markets (USD)

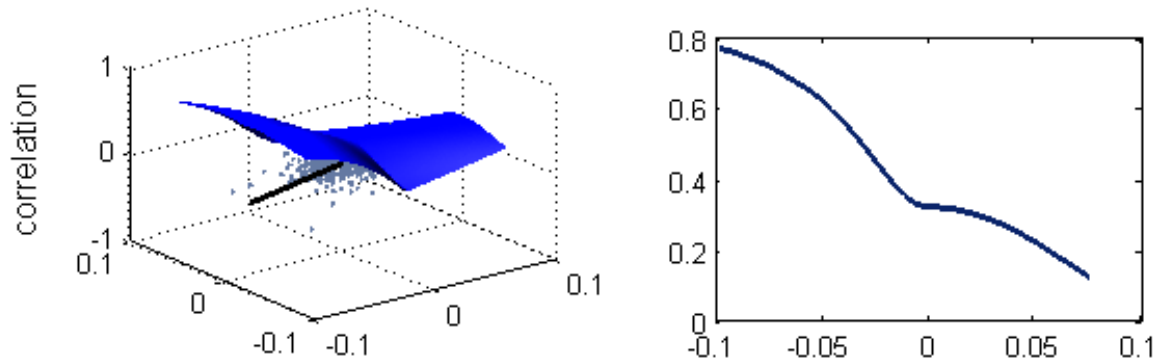
Nevertheless, table 5.3 allows drawing some conclusions. b_{11} and b_{22} are, for instance, highly significant in virtually all estimations, which is an indication for autocorrelation in variance-covariance dynamics. Furthermore, all g -estimates bar one are positive in sign, which provides evidence for an increase in variance-covariances in response to downturn movements in returns. Most asymmetry parameters have a t -statistic of at least 2, showing that the inclusion of an asymmetric component is important. By contrast, we cannot reject the null hypothesis for most a -estimates. This indicates that the absolute magnitude of past shocks does not matter once asymmetries are taken into account.

A better notion of the dynamics of the variance-covariance matrix, H_t , can be gained by investigating news impact surfaces (NIS). We therefore plot correlation surfaces between returns on global equity markets and returns on carry trades, where we assume a long position in a commodity currency and a short position in CHF money markets. Introduced by Kroner and Ng (1998), NIS are three-dimensional graphs which plot conditional variances, covariances or correlations against past asset price shocks. We choose a range of -3 to $+3$ standard deviations for return shocks to global equity markets and carry trade positions, which results in a grid of shock combinations. The elements of the variance-covariance matrix are then obtained by plugging generated shock combinations into equation 5.5. The conditional variance-covariance matrix at time $t-1$, H_{t-1} , is kept constant at unconditional levels. Since we take an interest in correlation dynamics, conditional covariances, $H_{12,t}$, are divided by the product of conditional standard deviations, $\sqrt{H_{11,t}H_{22,t}}$. Eventually, conditional correlations can be plotted against generated shock combinations which leads to the correlation surface shown on the left hand side of figure 5.2. The top panel on the left presents the correlation surface of an AUD/CHF carry trade strategy, whereas the middle and the lower panels show correlation surfaces of the CAD/CHF and of the NZD/CHF carry trade scheme, respectively. The panels on the right are explained below and show “average” correlation responses to equity market shocks.

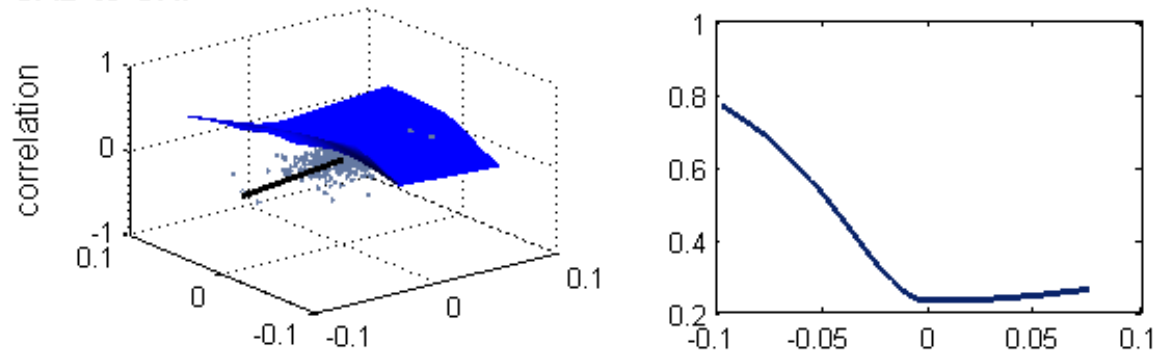
It can be seen that the shape of the correlation surface is very much the same for all carry trade strategies. All graphs exhibit a considerable increase in correlation in response to a negative shock to global equity markets. In other words, an investor with a stake in carry investments and a stake in global equities experiences a diversification meltdown in times of stock market crises when diversification is most desirable. By contrast, positive stock market shocks scarcely lead to a change in correlation. This accentuates the importance of including asymmetric effects in GARCH specifications. Note as well that correlation surfaces are mostly lo-

USD perspective

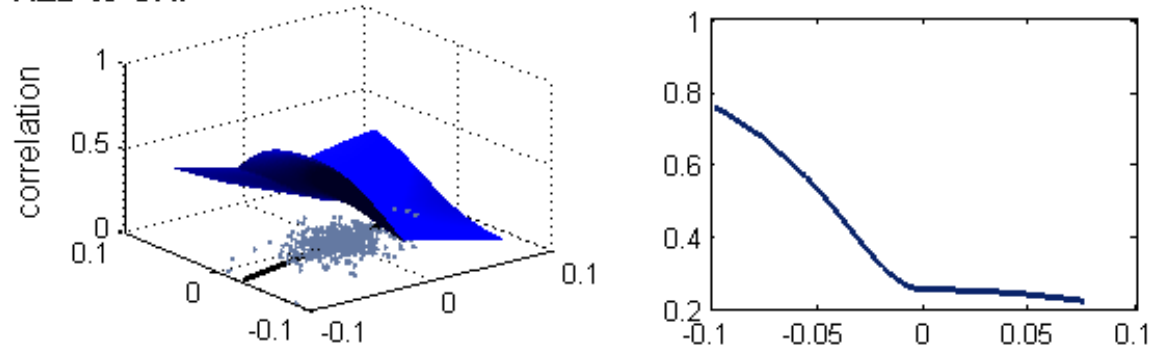
AUD to CHF



CAD to CHF



NZD to CHF



carry trade shock

stock market shock

stock market shock

Figure 5.2: Correlation surfaces for returns from a carry trade and returns on equities (USD)

cated in positive territory, which reflects the fact that unconditional correlation between carry trade and global equity market returns is positive on average (see section 5.4).

Unfortunately, NIS stay silent about the occurrence probability of shock combinations in equity and carry trade markets. If one falsely assumed equal occurrence probability of every dot on the grid, a strongly distorted correlation perspective would be obtained. To enhance explanatory power, we thus extend NIS by a scatter plot revealing how shock combinations occurred historically. Since we work with demeaned data, the bulk of the scatter dots are located around the center of the grid. That is not surprising, after all, small shocks are more likely to occur than large ones. There emerges an additional pattern, viz. negative shocks in global equities predominantly occur in times of negative shocks on carry trade investments and vice versa for positive shocks. As a consequence, the scatter clouds are upward pointing, which is what we would expect given the positivity of unconditional correlation estimates. Whether there is an upward or downward slope can be clearly seen when putting a regression line through the scatter cloud. The regression line can be interpreted as showing the “average” carry trade shock given a global equity market shock of certain magnitude. To accentuate “average” correlation dynamics, we cut the correlation surface along the regression line. The result is shown in the panels to the right of the NIS. It clearly emerges that “average” correlation increases in times of equity market downturns. That pattern holds for all carry trade strategies. The difference between the correlation at the center and the correlation in response to large stock market downturns is relatively large. In the CAD/CHF example, “average” correlation is slightly more than 0.2 at the center and increases to almost 0.8 on the very left of the graph, i.e. when the stock market experiences a drop of three standard deviations. In contrast, correlation barely changes in response to positive stock market shocks. That is at least true for the CAD/CHF and the NZD/CHF carry trade example. For the AUD/CHF strategy, we even obtain a decrease in correlation in response to a positive shock.

Decomposing carry trades into two currency risk premia components leads to separate NIS for commodity currency and CHF money market investments. Whereas figure 5.3 displays correlation surfaces for shock combinations on CHF deposits and global equity markets, figure 5.4 shows corresponding surfaces for commodity currencies and equities. For ease of comparability, we assume here long positions in both CHF and commodity currency deposits. Notice the shape of the NIS for the conditional correlation between returns on CHF money market

USD perspective

UIP vs CHF

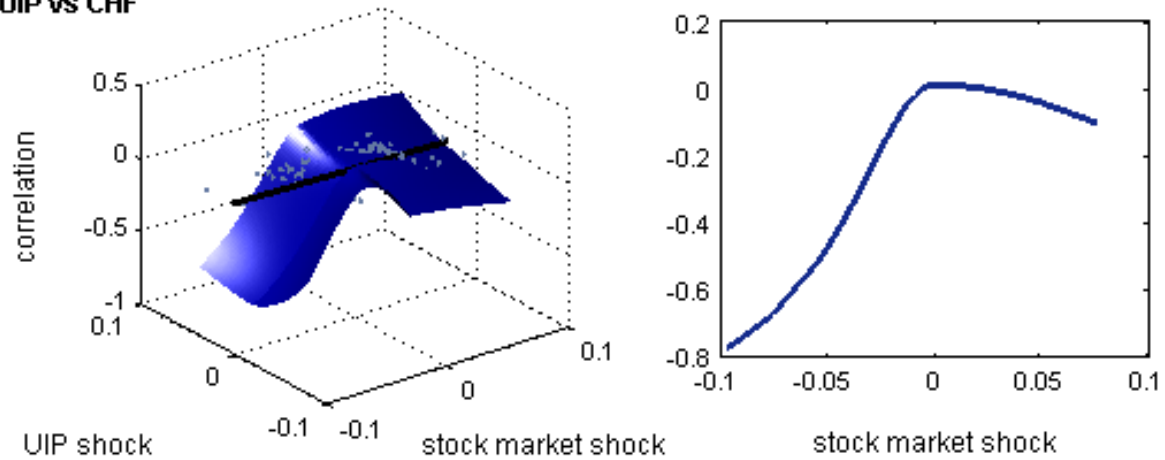


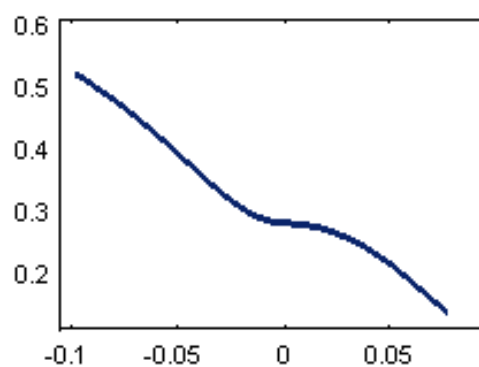
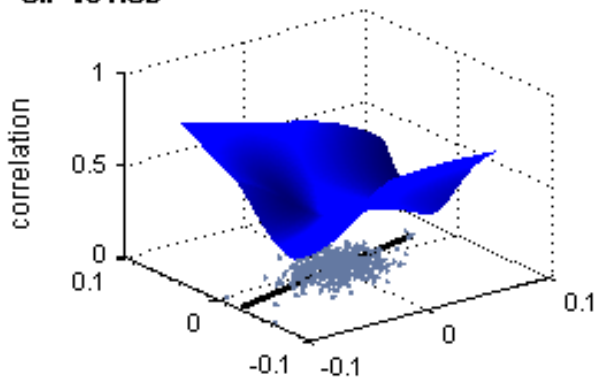
Figure 5.3: Correlation surface for returns on a CHF deposit and returns on equities (USD)

deposits and returns on global equity markets. Conditional correlation is negative on average, and it decreases sharply in response to a negative stock market shock. Apparently, the CHF lives up to its reputation as safe haven currency and develops beneficial diversification attributes in times of market downturns. The shape of the NIS suggests that asymmetries matter greatly, after all, the surface's response depends very much on whether equity markets are hit by a positive or by a negative shock. Conditional correlation decreases more in the aftermath of negative as opposed to positive stock market shocks. Note that movements in correlation are fairly small if we keep stock market shocks constant and move along the money market axis. Hence, correlation surfaces are primarily driven by stock market movements and not by disturbances on money markets.

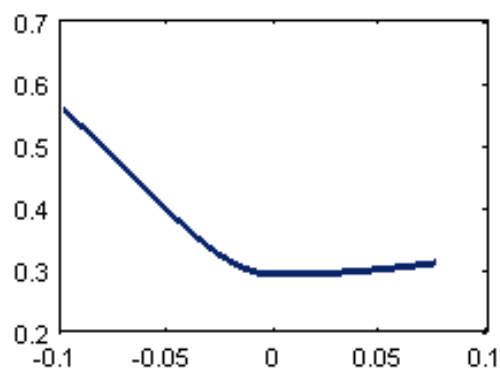
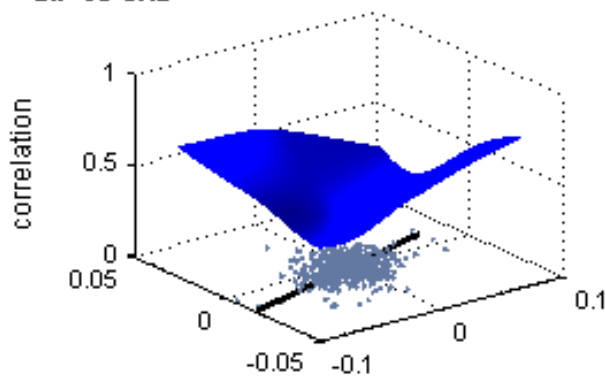
The NIS showing conditional correlations between returns on global equity markets and returns on commodity currency deposits are very different in shape. The bottom left panel in figure 5.4 shows that deposits in NZD exhibit increasing correlation in response to negative stock market shocks. Conditional correlation is not only positive on average, but it changes unfavorably in times of large downward movements in equity markets. Although a bit less pronounced, the same can be said for correlation surfaces between equities and currency risk premia on AUD and on CAD investments. The correlation dynamics between commodity currency investments and world equity markets could thus be seen as the mirror image of the correlation pattern observed for CHF deposits and equities shown in figure 5.3.

USD perspective

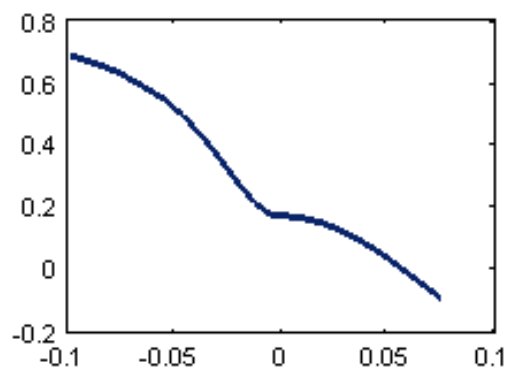
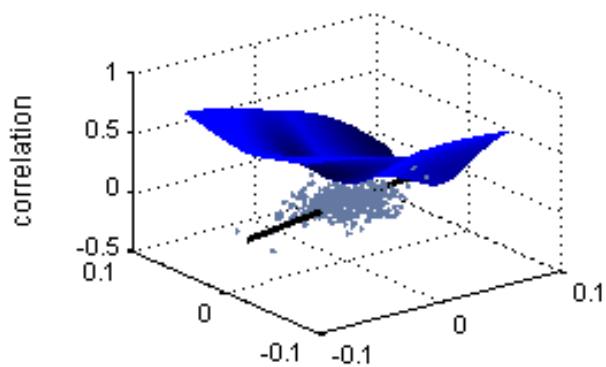
UIP vs AUD



UIP vs CAD



UIP vs NZD



UIP shock

stock market shock

stock market shock

Figure 5.4: Correlation surfaces for returns on a commodity currency and returns on equities (USD)

5.6 Exceedance Correlation Analysis

MV-GARCH analysis provides a good notion for correlation dynamics and results in illustrative NIS. Unfortunately, NIS do not directly reveal whether asymmetric effects bear any statistical relevance. Exceedance correlation measures the correlation in the tails of a multivariate distribution and provides an alternative framework for the analysis of correlation asymmetries. It notably offers a simple testing procedure.

Ang and Chen (2002) define exceedance correlation as the correlation between two standardized variables, \hat{x} and \hat{y} , where both of these deviate from their mean by a certain threshold level. Calculation is straightforward. First, observations are sorted into subsets depending on how much they deviate from their mean. For that purpose, threshold levels, usually expressed in terms of standard deviations, are defined. Second, exceedance correlations are obtained by calculating correlations within these subsets. Technically speaking, we can say:

$$\begin{aligned}\hat{\rho}^+(\vartheta) &= \text{corr}(\hat{x}, \hat{y} \mid \hat{x} > \vartheta, \hat{y} > \vartheta) \\ \hat{\rho}^-(\vartheta) &= \text{corr}(\hat{x}, \hat{y} \mid \hat{x} < -\vartheta, \hat{y} < -\vartheta)\end{aligned}\tag{5.8}$$

where $\hat{\rho}^+$ ($\hat{\rho}^-$) denotes the correlation when both variables register an upward (downward) increase of at least ϑ standard deviations. Observations are standardized, which simplifies notation in that time series means and variances can be dropped from the right hand side of equation 5.8. As emphasized by Longin and Solnik (2001) and Forbes and Rigobon (2002), conditioning correlation on whether returns increase by at least ϑ standard deviations results in a conditioning bias. Longin and Solnik show that a bivariate normal distribution with constant correlation implies a tent-shaped exceedance correlation pattern. This means that exceedance correlations, calculated along the lines outlined above, decrease with larger ϑ even though the data stem from a bivariate normal distribution with constant correlation by definition. A simple comparison of exceedance correlations at different threshold levels, ϑ , might thus lead to the erroneous conclusion that correlations decrease as markets become more volatile. Longin and Solnik (2001) advocate comparing empirical exceedance correlations with correlations implied by a bivariate normal distribution. Ang and Chen propose test statistics which permit quantifying the degree of deviation between exceedance correlations implied by the data and exceedance correlations implied by a bivariate normal or any other bivariate distribution. If the discrepancy is too large, the data are inappropriately described by the chosen distribution. By applying Ang and Chen's

test to two subsets, once conditioning on upside moves $(\hat{x}, \hat{y} \mid \hat{x} > 0, \hat{y} > 0)$ and once on downside moves $(\hat{x}, \hat{y} \mid \hat{x} < 0, \hat{y} < 0)$, one can evaluate whether there indeed exist asymmetric correlation effects. For equity markets, it is found that exceedance correlations on the downside deviate considerably more from a bivariate normal than exceedance correlations on the upside. Ang and Chen's (2002) test procedure requires information on theoretical exceedance correlations of bivariate distributions, which can only be obtained by diving into extreme value theory. Besides the fact that closed-form calculations of exceedance correlations are rather cumbersome, there remains the difficulty of choosing an appropriate distributional form. Therefore, we follow Hong et al. (2003), who suggest an elegant alternative for testing asymmetric correlations which allows circumventing both obstacles.

Hong et al's (2003) test is based on the idea that under symmetry exceedance correlations on the upside should not be too different from exceedance correlations on the downside. In terms of equation 5.8, the H_0 -hypothesis demands that

$$H_0 : \quad \hat{\rho}^+(\vartheta) = \hat{\rho}^(-\vartheta) \quad \text{for all} \quad \vartheta > 0 \quad (5.9)$$

In other words, the null hypothesis states that tail correlations depend on the absolute distance measure, $|\vartheta|$, but not on sign. Under symmetry, all elements of the following vector must therefore lie somewhere close to zero:

$$\hat{\rho}^+ - \hat{\rho}^- = [\hat{\rho}^+(\vartheta_1) - \hat{\rho}^(-\vartheta_1), \dots, \hat{\rho}^+(\vartheta_m) - \hat{\rho}^(-\vartheta_m)]' \quad (5.10)$$

where m denotes the number of exceedance levels. Introducing regularity conditions, Hong et al. (2003) show that the vector $\hat{\rho}^+ - \hat{\rho}^-$ is asymptotically normal distributed with a mean of zero and a positive definite variance-covariance matrix Ω . This allows postulating a simple test statistic for the null hypothesis of symmetry, viz:

$$J_\rho = t(\hat{\rho}^+ - \hat{\rho}^-)' \hat{\Omega}^{-1} (\hat{\rho}^+ - \hat{\rho}^-) \quad (5.11)$$

where t denotes the number of observations. As t approaches infinity, J_ρ converges to a χ -square distribution with m degrees of freedom.

5.6.1 Results

In this section, we calculate exceedance correlations between returns on carry trade investments and returns on the world equity portfolio. Our calculation is based on four exceedance levels with $\vartheta = [0, 0.33, 0.66, 1]$. In contrast to Hong et al. (2003), who include four cut-offs by setting ϑ equal to $[0, 0.5, 1, 1.5]$, we choose a tighter step size of only 0.33 standard deviations. The optimal number of exceedance levels and optimal step sizes crucially depend on the size of the sample. The reason is that the number of observations decreases as one moves towards the outer tails of a distribution. Choosing too many exceedance levels or a step size which is too wide might therefore lead to inaccurate correlation estimates due to lack of observations in outer buckets. On the other hand, we might lose valuable information on asymmetry for extreme values if the number of exceedance levels is insufficient or if the step size is too narrow. While Hong et al.'s data set includes 1825 weekly observations, our sample has merely 508 values. That justifies our tighter step size.

Table 5.4 displays asymmetric effects in correlations between returns on the world equity portfolio and profits from a carry trade strategy where investors buy commodity currency deposits by taking a loan on the CHF money market. The second column provides χ -square statistics, whereas the third column shows corresponding p-values. P-values reveal that only one symmetry hypothesis is rejected at the 10% significance level, viz. for correlations between returns on equities and returns on the CAD/CHF carry strategy. For that case, correlations are significantly larger in stock market downturns as opposed to stock market upturns. Although we cannot reject the null of symmetry for other strategies, it is interesting that almost all entries of the $\hat{\rho}^+ - \hat{\rho}^-$ -vector bear a negative sign. An exception is the CAD/CHF example for movements exceeding 0.66 standard deviations where $\hat{\rho}^+ - \hat{\rho}^-$ is slightly positive. Apart from that, we observe that downside correlations are larger than corresponding upside correlations for all strategies and at all exceedance levels. In other words, correlations between carry trade investments and equity market returns are larger during joint market downturns as opposed to joint market upturns. Note as well, that differences in exceedance correlations are substantial in magnitude. For the $\hat{\rho}_4^+ - \hat{\rho}_4^-$ -entry in the CAD/CHF example, the correlation differential amounts to -0.5328. This is large if one considers that correlation is bound to values between -1 and +1. Similar conclusions can be drawn from tables 5.6 and 5.9 in the appendix, which present results from the viewpoint of an EUR and GBP investor, respectively.

	J_p	p-value	$\hat{\rho}_1^+ - \hat{\rho}_1^-$	$\hat{\rho}_2^+ - \hat{\rho}_2^-$	$\hat{\rho}_3^+ - \hat{\rho}_3^-$	$\hat{\rho}_4^+ - \hat{\rho}_4^-$
AUD/CHF	1.2	0.87	-0.08	-0.14	-0.12	-0.12
CAD/CHF	9.5	0.05	-0.25	-0.10	0.01	-0.53
NZD/CHF	1.6	0.81	-0.20	-0.15	-0.20	-0.09

Table 5.4: Exceedance correlations between returns on carries and returns on equities (USD)

Note that from the perspective of an EUR investor, Hong's test statistics indicate significant asymmetries for CAD/CHF as well as for NZD/CHF carry trade investments. Another interesting observation emerges from these tables, namely that the $\hat{\rho}^+ - \hat{\rho}^-$ -vector shows particularly large differences for the fourth exceedance level, i.e. when movements exceed one standard deviation. It seems that asymmetries widen as we move towards more extreme values. That could intuitively be explained by the safe haven characteristics of the CHF, which only unveils its true value in case of severe market downturns.

5.7 Conclusion

We show that carry traders are exposed to unfavorable correlation with global stock markets. That holds for unconditional and even more for time-varying correlation. A MV-GARCH analysis reveals that conditional correlation between profits from a carry trade strategy and returns on global equities changes unfavorably in response to negative stock market shocks. In fact, we obtain a considerable rise in correlation during times of stock market crises for all carry strategies analyzed. That holds irrespective of whether the viewpoint of an USD, EUR or GBP investor is taken. Asymmetry in correlation does also emerge from an analysis based on exceedance correlation. Exceedance correlation is defined as the correlation in the outer tails of a bivariate distribution. It is found that correlations are usually larger during joint downward moves as opposed to joint upward moves. For certain strategies such as the CAD/CHF in terms of EUR, these correlation asymmetries are of statistical significance. Correlation shifts are quite large so that they are not only of a statistical but also of economic relevance. Not taking account of time-variation in second moments might therefore lead to severe portfolio misallocation in terms of an ill-founded overweight in high-yield currencies and carry trade positions. Investors not aware of conditional correlation dynamics are thus likely to face an unexpected diversification meltdown in times of crises when diversification is most wanted.

We show that classical carry trades boil down to a double speculation against

UIP. A decomposition of carry trades into UIP components reveals that high interest rate currencies such as the AUD, CAD or NZD are exposed to considerable contagion. Put differently, the correlation between these currencies and global equity markets is positive on average and increases in response to negative shocks to stock markets. An opposite correlation pattern is observed for long positions in CHF money deposits, which are negatively correlated with equity markets on average. For CHF investments, correlation becomes even more negative in the aftermath of stock market downturns. This indicates that the CHF meets its expectation as a safe haven currency and acquires strength in times of financial crises. Carry investors often incur debt in CHF, which is why they are negatively affected by safe haven attributes of the latter.

Our analyses suggest that expected excess returns from UIP speculation are accompanied by systematic risks in terms of an unfavorable correlation exposure to global equity markets. On the basis of these findings, we conjecture that a conditional CAPM relating excess returns to time-varying correlation with equity markets might go a long way towards explaining the forward rate anomaly. This should at least hold for the antipodal currency pairs investigated in this chapter, but that investigation is left for future research.

5.A Appendix

5.A.1 Viewpoint of an EUR Investor

EUR	AUD/CHF	CAD/CHF	NZD/CHF
mean	2.03%	2.36%	3.00%
stddev	11.97%	10.71%	12.37%
t-stat	0.17	0.22	0.24
skew	-0.53	-0.50	-0.41
kurt	5.40	3.99	3.96
JB-test	143.73	41.33	33.07
cor equity	0.52	0.62	0.46

Table 5.5: Summary statistics on carry trade returns (EUR)

	J_p	p-value	$\hat{\rho}_1^+ - \hat{\rho}_1^-$	$\hat{\rho}_2^+ - \hat{\rho}_2^-$	$\hat{\rho}_3^+ - \hat{\rho}_3^-$	$\hat{\rho}_4^+ - \hat{\rho}_4^-$
AUD/CHF	4.8	0.31	0.02	0.04	-0.05	-0.28
CAD/CHF	8.8	0.07	-0.18	-0.05	-0.24	-0.52
NZD/CHF	8.1	0.09	-0.12	0.01	-0.20	-0.34

Table 5.6: Exceedance correlations between returns on carries and returns on equities (EUR)

MSCI world - Carry AUD/CHF				MSCI world - Carry CAD/CHF				MSCI world - Carry NZD/CHF			
params	stddev	t-stats		params	stddev	t-stats		params	stddev	t-stats	
c(11)	0.0045	0.0099	0.45	0.0024	0.0025	0.98		0.0022	0.0020	1.08	
c(21)	0.0088	0.0401	0.22	0.0108	0.0015	7.38		0.0122	0.0027	4.49	
c(22)	0.0000	0.0172	0.00	0.0001	0.0013	0.08		-0.0001	0.0355	0.00	
a(11)	0.2439	2.2715	0.11	-0.0033	0.0189	-0.18		0.1240	0.0851	1.46	
a(12)	0.2551	1.9213	0.13	-0.0053	0.0228	-0.23		0.1875	0.1104	1.70	
a(21)	-0.1764	3.3941	-0.05	0.1721	0.0749	2.30		0.1122	0.2549	0.44	
a(22)	0.0194	4.2583	0.00	-0.0233	0.0493	-0.47		-0.0401	0.4102	-0.10	
b(11)	0.9845	0.5714	1.72	1.0183	0.0338	30.16		0.9996	0.0263	38.01	
b(12)	0.0192	0.8537	0.02	0.1740	0.1203	1.45		0.0928	0.0512	1.81	
b(21)	-0.1870	0.8859	-0.21	-0.1317	0.1188	-1.11		-0.1401	0.1231	-1.14	
b(22)	0.7034	2.1410	0.33	0.4548	0.2717	1.67		0.5321	0.2180	2.44	
g(11)	0.2341	1.0461	0.22	0.2497	0.0581	4.30		0.1981	0.1484	1.33	
g(12)	0.0519	1.7864	0.03	0.1747	0.0510	3.43		-0.0413	0.1803	-0.23	
g(21)	0.2184	1.6097	0.14	0.0072	0.0272	0.26		0.1452	0.2760	0.53	
g(22)	0.2859	2.3649	0.12	-0.1700	0.0907	-1.87		0.3757	0.2294	1.64	

Table 5.7: Results of a GARCH(1,1,1) estimation for three bivariate systems, each based on returns from a carry trade and returns on global equity markets (EUR)

EUR perspective

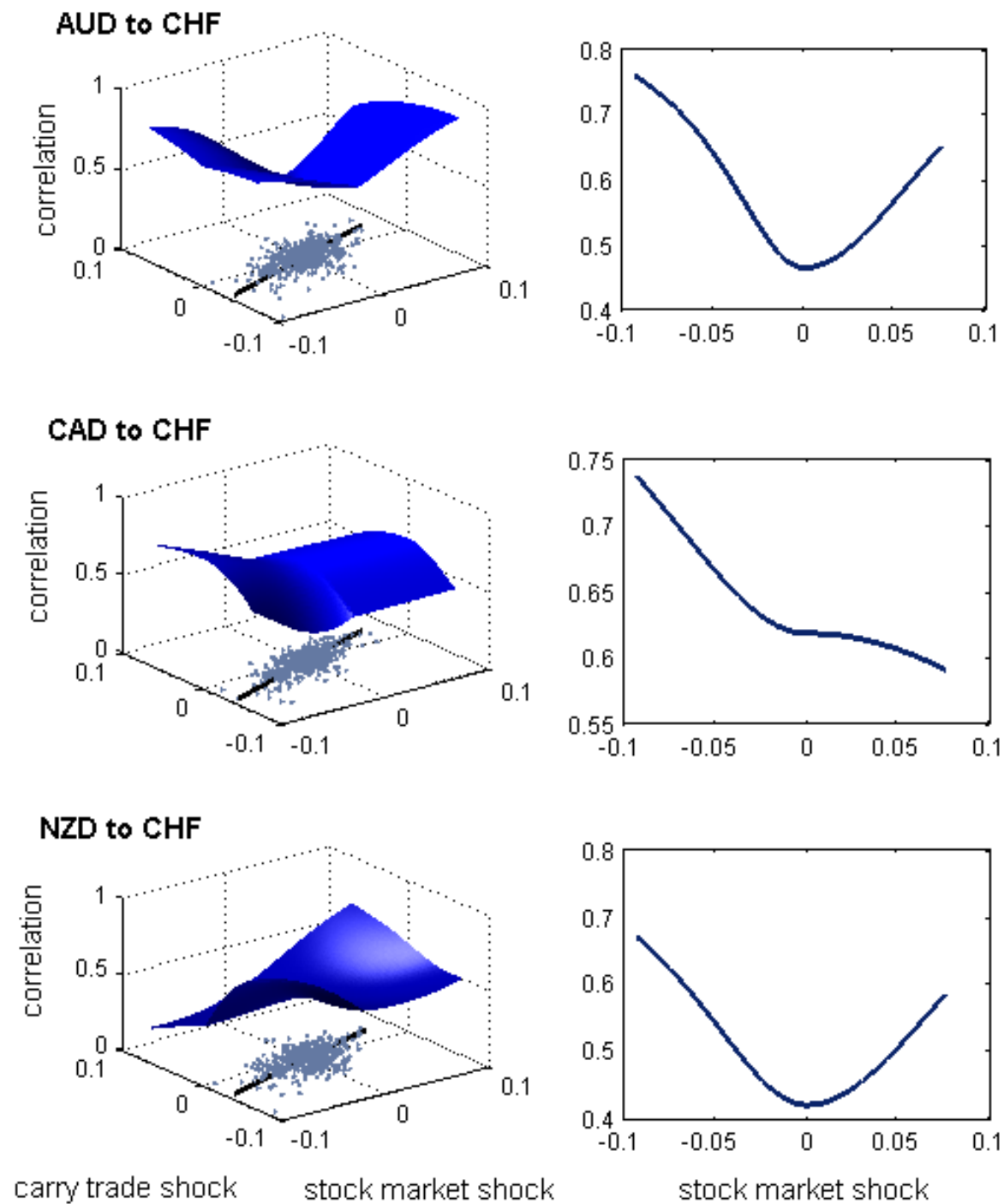


Figure 5.5: Correlation surfaces for returns from a carry trade and returns on equities (EUR)

5.A.2 Viewpoint of a GBP Investor

GBP	AUD/CHF	CAD/CHF	NZD/CHF
mean	0.02%	2.07%	2.71%
stddev	11.97%	10.72%	12.36%
t-stat	0.00	0.19	0.22
skew	-0.56	-0.53	-0.44
kurt	5.42	4.02	3.99
JB-test	147.89	44.76	35.88
cor equity	0.40	0.48	0.34

Table 5.8: Summary statistics on carry trade returns (GBP)

	J_p	p-value	$\hat{\rho}_1^+ - \hat{\rho}_1^-$	$\hat{\rho}_2^+ - \hat{\rho}_2^-$	$\hat{\rho}_3^+ - \hat{\rho}_3^-$	$\hat{\rho}_4^+ - \hat{\rho}_4^-$
AUD/CHF	4.6	0.34	-0.02	-0.09	-0.26	-0.32
CAD/CHF	3.6	0.46	-0.23	-0.14	-0.18	-0.20
NZD/CHF	6.1	0.19	-0.12	-0.11	-0.32	-0.29

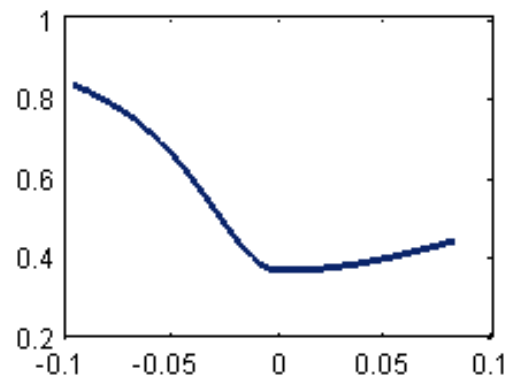
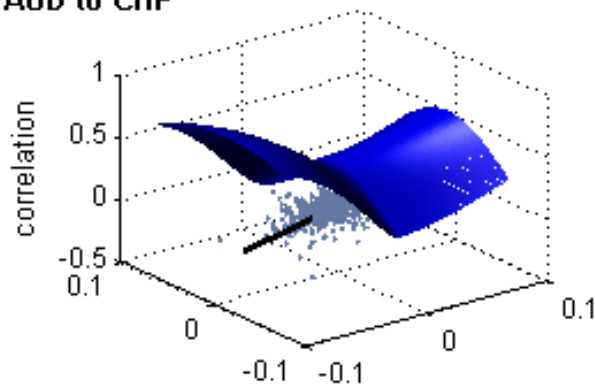
Table 5.9: Exceedance correlations between returns on carries and returns on equities (GBP)

MSCI world - Carry AUD/CHF				MSCI world - Carry CAD/CHF				MSCI world - Carry NZD/CHF			
	params	stddev	t-stats		params	stddev	t-stats		params	stddev	t-stats
c(11)	-0.0001	0.0061	-0.02		0.0043	0.0012	3.58		0.0021	0.0023	0.94
c(21)	-0.0005	0.0283	-0.02		0.0035	0.0011	3.18		0.0124	0.0024	5.19
c(22)	0.0127	0.0030	4.23		0.0000	0.0000	0.00		0.0001	0.0060	0.01
a(11)	0.1372	0.0871	1.58		0.1751	0.0960	1.82		0.1234	0.0712	1.73
a(12)	0.1052	0.1358	0.77		0.0721	0.0516	1.40		0.1862	0.1165	1.60
a(21)	-0.2225	0.0955	-2.33		-0.2386	0.0822	-2.90		0.1180	0.1534	0.77
a(22)	0.1371	0.0762	1.80		-0.0056	0.0321	-0.17		-0.0300	0.4049	-0.07
b(11)	0.9811	0.0183	53.61		0.9387	0.0197	47.65		1.0000	0.0244	40.95
b(12)	0.1601	0.1022	1.57		-0.0280	0.0096	-2.92		0.0977	0.0527	1.85
b(21)	-0.1439	0.0845	-1.70		-0.0346	0.0284	-1.22		-0.1422	0.1294	-1.10
b(22)	0.3669	0.3641	1.01		0.9682	0.0234	41.38		0.5122	0.2176	2.35
g(11)	0.3849	0.0910	4.23		0.3888	0.0679	5.73		0.2015	0.1071	1.88
g(12)	0.2392	0.0857	2.79		0.1694	0.0405	4.18		-0.0346	0.1161	-0.30
g(21)	0.0133	0.0736	0.18		-0.0363	0.0420	-0.86		0.1343	0.1674	0.80
g(22)	0.1686	0.1569	1.07		-0.0064	0.0488	-0.13		0.3634	0.1671	2.18

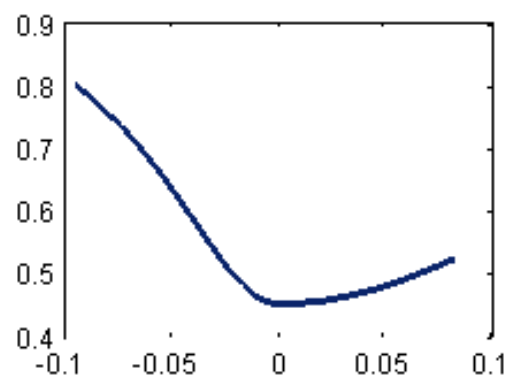
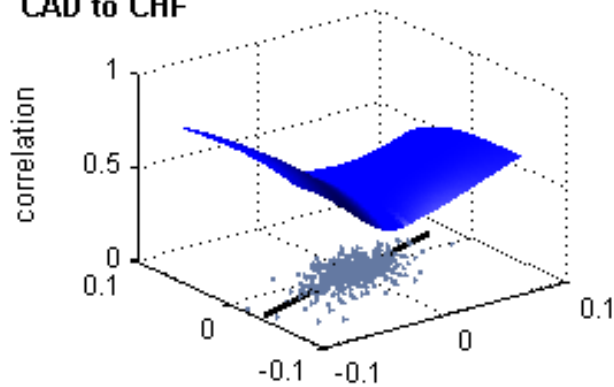
Table 5.10: Results of a GARCH(1,1,1) estimation for three bivariate systems, each based on returns from a carry trade and returns on global equity markets (GBP)

GBP perspective

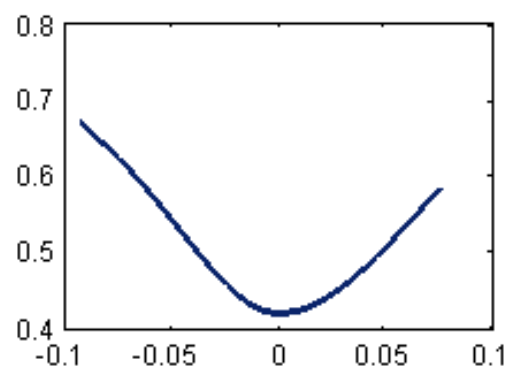
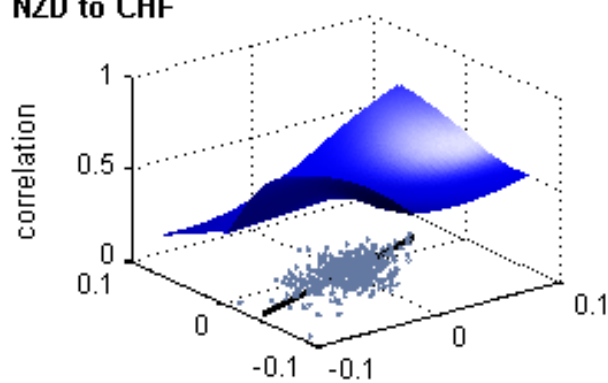
AUD to CHF



CAD to CHF



NZD to CHF



carry trade shock

stock market shock

stock market shock

Figure 5.6: Correlation surfaces for returns from a carry trade and returns on equities (GBP)

Chapter 6

Currency Risk Premia and Ultimate Consumption

We argue that a consumption-based pricing model (C-CAPM) explains about two-thirds of the variation in deviation from uncovered interest rate parity (UIP) across a large cross-section of currencies. These promising results are obtained if deviation from UIP is related to Parker and Julliard's (2005) ultimate consumption instead of contemporaneous consumption. Ultimate consumption is measured as the consumption growth over the period of the return and many subsequent periods. It is a forward-looking risk measure and captures that currencies react well in advance to movements in contemporaneous consumption. A second innovation concerns the data set, which is based on carry trade and "reverse" carry trade payoffs. Since carry trades boil down to a double speculation against UIP, currency risk premia emerge more distinctively in our data set compared to previous work relying on deviation from UIP directly.

6.1 Introduction

It is empirically well-established that uncovered interest rate parity (UIP) fails. UIP predicts an appreciation of low interest rate currencies and a depreciation of high interest rate currencies where currency movements exactly countervail nominal interest rate differentials. However, empirical evidence suggests that UIP provides a poor prediction for future currency movements. Various studies even find that UIP points to the wrong direction. Fama (1984) and McCallum (1994) show that low interest rate currencies are more likely to depreciate than to appreciate as UIP would suggest. By consequence, speculation against UIP rewards investors with a double gain on average, viz. stemming from interest rate differentials and from currency movements in their favor. The goal of this chapter is to shed light on the drivers responsible for departure from UIP. We try to relate the puzzling phenomenon to the consumption-based capital asset pricing model (C-CAPM) and to recent extensions thereof.

Failure of UIP does not constitute a puzzle per se. After all, persistent under- or outperformance might accrue as compensation for exposing investors to systematic risk. A conundrum arises, however, due to the fact that traditional asset pricing settings such as the capital asset pricing model (CAPM) or the C-CAPM fail to account for cross-sectional variation in currency risk premia.¹ Part of the research community thus resorts to theories based on irrationality in order to explain the puzzle. That strand assumes that UIP fails due to a systematic mismatch between investors' expectations about future spot exchange rates and actual realizations thereof. We acknowledge that irrationality might bear explanatory power for certain currencies during periods of change or turbulence because agents require time to understand the impact of a change in economic policy or the consequences of an external shock. During such transitional phases, the formation of exchange rate expectations is complicated, and episodes might occur during which agents get forecasts systematically wrong. We do not believe that the irrationality literature provides useful insights for long-run deviations from UIP. After all, Abraham Lincoln's quotation still proves true:

*You can fool all the people some of the time,
and some of the people all the time,
but you cannot fool all the people all the time.*

¹The currency risk premium corresponds to the expected return from speculating against UIP. See section 2.4 for a more detailed definition.

Put differently, we think that the representative investor does not make systematically biased predictions in the long run. Since we focus on long-run phenomena, rationality is assumed throughout this chapter. We try to find more evidence for the risk premia strand of literature by relating deviation from UIP to covariance exposure with consumption growth. Compared to previous investigations pricing deviations from UIP within the C-CAPM setting, we are able to explain much more of the cross-sectional variation in currency risk premia. Our models are not rejected, and we generally obtain reasonable estimates for the coefficient of relative risk aversion. The improved performance is the result of two innovations. The first concerns the model's specification, notably the choice of a forward-looking risk factor, whereas the second is related to the measurement of currency risk premia.

We modify the pricing kernel of the C-CAPM by substituting contemporaneous consumption for ultimate consumption. The resulting model relates current returns to the covariance between current returns and consumption growth over the period of the return and many subsequent periods. Ultimate consumption is a forward-looking risk measure and takes account of the fact that exchange rates precede future GDP growth. In fact, section 6.4 shows that the CHF/AUD exchange rate moves almost in parallel with the OECD leading indicator. Since the latter is thought to predict GDP in six to nine months, exchange rates must react well in advance to shifts in contemporaneous consumption. This corresponds to economic intuition according to which market prices move in anticipation of future business cycle conditions. Various commentators claim, for instance, that the CHF tends to move against the cycle. If investors believe that the CHF acquires strength in periods of economic downturn, the franc should already appreciate somewhat in advance to slowdowns, viz. as soon as agents get wind of trouble ahead. That in contrast to consumption, which adjusts more slowly to bearish sentiment. Consumption sluggishness might stem from durable consumption components, consumption habits or costs related to adjusting consumption plans. By the time consumption finally adapts, market prices already incorporate all relevant information.

The second innovation concerns a modification of the data set. We base analysis on carry trade payoffs and not on deviation from UIP as previous studies usually do. A carry trade corresponds to a double speculation against UIP where investors take a long position in high interest rate currencies and a short position in low interest rate currencies. This dual exposure leaves us with much larger spreads. Besides amplifying currency risk premia, we are left with a larger data set. To

understand that, note that carry strategies can be designed between any two currency markets. Since our data set contains money market deposits in seven different currencies, we are able to construct 21 different carry trade strategies by combining each market with every other. Finally, the construction of carries allows us to conveniently incorporate conditional information inherent in interest rate differentials. Section 6.3 presents the applied data set in more detail.

6.2 Related Literature

Consumption-based asset pricing models (C-CAPM) postulate that assets exhibiting positively correlated payoffs with consumption growth should yield a return above the risk-free rate. The reason is that such assets expose investors to a procyclical payoff pattern, which leads to larger fluctuation in agents' consumption flow. The standard C-CAPM in its unconditional form with time-separable utility typically fails to price currency risk premia. One reason is that variation in consumption growth is far smaller than variation in departure from UIP. The interest rate puzzle resembles the equity premium puzzle in that respect. The latter says that return differentials between bond and equity markets cannot be explained by differences in the covariance with consumption growth unless one assumes an implausibly large coefficient of relative risk aversion (see Mehra and Prescott, 1985). In addition, currency pricing models must account for large variations in currency risk premia. Fama (1984) notes that the forward rate anomaly, according to which high-yield currencies tend to appreciate, whereas low-yield currencies tend to depreciate, implies that time-variation in currency risk premia is larger than time-variation in expected depreciation. We subsequently summarize the literature on currency risk premia in consumption-based settings with particular emphasis on how the risk aversion and the time-variation complexity are tackled.

Mark (1985) relates currency risk premia to the covariance with contemporaneous non-durable plus services consumption growth. He assumes that utility is time-separable. Analysis is conducted from the perspective of a USD investor. To account for time-variation in currency risk premia, moment conditions are scaled with two different sets of instruments. The first encompasses past consumption growth ratios and realized profits from foreign exchange speculation and the second past consumption growth in combination with forward premia. The model's overidentifying restrictions are rejected, and an implausibly large coefficient of relative risk aversion is obtained. Hodrick (1989) also assumes time-separability

in utility. He includes more currencies than Mark and conducts analyses from the perspective of an USD and GBP investor. Overidentifying restrictions are not rejected, but an implausibly large value for the coefficient of relative risk aversion (60.9) is reported for the USD estimation. The coefficient drops to only 2.15 if estimation is conducted from the perspective of a GBP investor. Another study based on time-separability by Modjtahedi (1991) leads to a decisive rejection of overidentifying restrictions. The coefficient of relative risk aversion turns out to be larger than what economic intuition would suggest.² The lowest risk aversion with a value slightly above 13 is obtained for the specification using forward premia as instruments and non-durable as opposed to non-durable plus services consumption as the risk factor.

Mehra and Prescott's (1985) paper on the equity premium puzzle provoked a plethora of articles with the aim to reconcile variation in consumption growth with variation in risk premia. While most contributions focus on pricing equities and bonds, studies applying extended C-CAPM specifications to the pricing of currency markets are relatively rare. Backus, Gregory and Telmer's (1993) contribution investigating currency risk premia under habit persistence is particularly noteworthy. In contrast to the standard C-CAPM, they postulate non-separability, which means that utility depends on current and on past consumption. The inclusion of habits seems promising from an economic standpoint. After all, agents are likely to get used to consumption levels so that their welfare not only depends on current but also on current relative to past consumption levels. Nevertheless, Backus et al. reject overidentifying restrictions, and they obtain a risk aversion coefficient which is just as large as in preceding studies assuming time-separability. Sarkissian (2003) receives more promising results by introducing heterogeneity across nations. Heterogeneity arises due to market incompleteness so that consumption cannot be hedged entirely. As a consequence, the Euler equation is not only driven by intertemporal marginal rates of substitution but also by an idiosyncratic risk component. The latter is related to the cross-sectional variance in consumption growth rates and is called consumption dispersion.³ Technically speaking, consumption dispersion increases the utility function's sensitivity with respect to consumption growth shocks, which leads to

²Mehra and Prescott (1985) cite various studies providing economically plausible estimates for the coefficient of relative risk aversion. They conclude that risk aversion is unlikely to be larger than ten. In fact, ten can be seen as an upper bound. Most studies report values between zero and four.

³For further explanations on how to incorporate heterogeneity, see Constantinides and Duffie (1996).

a considerable reduction in the coefficient of relative risk aversion. Sarkissian reports a coefficient of almost 119 for the standard C-CAPM. The coefficient drops to values between 2.75 and 23.33 if consumption dispersion is taken into consideration. A similar improvement is reported for the R-squared which increases from 2% for the standard C-CAPM to approximately 20% for the augmented model. Lustig and Verdelhan (2005) construct eight portfolios in ascending interest rate level order where the first portfolio contains deposits in the lowest-yielding currencies, the second portfolio contains deposits in the second lowest-yielding currencies and so on. In each portfolio, average deviation from UIP is calculated. Portfolios are frequently rebalanced to account for changing rankings in interest rate levels. Lustig and Verdelhan's sorting amounts to conditioning information on interest rate differentials, which are known to predict returns from currency speculation. In fact, it is well-established that high interest rate currencies tend to outperform low interest rate currencies on average (see, for instance, Chinn, 2006). Lustig and Verdelhan estimate various C-CAPM specifications using the GMM methodology, and find that consumption growth can account for a surprisingly large fraction of the cross-sectional variation in currency risk premia. They report R-squares of up to 80% when estimations are based on annual data from 1953 to 2002. On a quarterly basis and for the period from 1971 to 2002, R-squares drop considerably. More recently, Lustig and Verdelhan (2007) base analysis on portfolios constructed along the lines explained in Lustig and Verdelhan (2005). They try to capture currency risk premia using Yogo's (2006) durable consumption growth model, which postulates that intraperiod utility is a non-separable function of durable and nondurable consumption flows. It is found that the model can account for almost 87% of the total variation in expected portfolio returns. Lustig and Verdelhan (2007) meet with severe criticism from Burnside (2007), who argues that Yogo's model could barely explain any of the cross-sectional variation in deviation from UIP if the Fama-MacBeth two-step estimation procedure were correctly applied.⁴

⁴More specifically, Burnside criticizes that Lustig and Verdelhan do not correct standard errors for using estimated inputs in their second-pass regression. He, moreover, objects that the second-pass regression includes a constant that differs significantly from zero. That should not be the case if the model could account for the cross-section in expected returns. See Fama and MacBeth (1973) for a description of the Fama-MacBeth estimation procedure and Shanken (1992) for correcting standard errors in the second-pass regression.

6.3 Data

Our analysis is based on 1-month Euromarket deposits in seven currencies, viz. the Australian dollar (AUD), the British pound (GBP), the Canadian dollar (CAD), the Euro or the German mark prior to January 1999 (EUR), the New Zealand dollar (NZD), the Swiss franc (CHF) and the US dollar (USD). For all these markets, we could obtain data from January 1987 to December 2006, which leaves us with 240 monthly observations. The OECD leading indicator for the US is obtained from the OECD Main Economic Indicators data base. Changes in the indicator are calculated as %-movements over a 6-months window, which is what the OECD proposes in order to predict turning points in GDP growth rates. Data on non-durables and on services are published on a monthly basis by the Bureau of Economic Analysis. Non-durables and services are aggregated and the combined series is deflated using the seasonally adjusted consumer price index (CPI) published by the Bureau of Labor Statistics. The risk factor in the standard C-CAPM corresponds to the logarithmic consumption growth rate over the month of the return. Ultimate consumption, which we advocate using as the risk factor instead, is calculated as the logarithmic consumption growth rate over the month of the return and 11 subsequent months. We have chosen an annual time span because we assume that market prices forerun business-cycle movements by 6 to 12 months. That assumption is nourished by the observation that currency prices move slightly in advance of the OECD leading indicator (see figure 6.3), where the latter is thought to predict business-cycles by 6 to 9 months.⁵ The leading indicator and ultimate consumption are both calculated on a rolling window basis over several months, while the model is estimated on a monthly interval. For that reason, we need to account for overlapping data by adjusting estimation outputs for potential autocorrelation and heteroskedasticity in residuals. That is done by applying the Newey-West correction. All our time series are tested for stationarity using the Augmented Dickey-Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test.⁶ Both tests indicate that non-stationarity constitutes neither a problem for carry trade yields nor for contemporaneous consumption growth. However, the ADF cannot reject the null hypothesis of an unit root for the ultimate consumption time series. That does not come as a surprise because it is well known that the ADF test possesses only modest power when time series

⁵See OECD (2008)

⁶See Dickey and Fuller (1979) or Said and Dickey (1984) for a description of the Dickey-Fuller and the augmented Dickey-Fuller test, respectively. The KPSS test was introduced by Kwiatkowski et al. (1992).

exhibit autocorrelation. Since ultimate consumption is calculated on an overlapping window basis, it exhibits strong autocorrelation by construction. The KPSS test, based on the null hypothesis of stationarity, cannot be rejected. In view of these divergent results and in consideration of the power deficiencies of the ADF test, we subsequently assume that all our time series are stationary.

6.3.1 Measuring Currency Risk Premia

An important innovation of this chapter is that we construct carry trades and so-called “reverse” carry trades, where the currency risk premium is defined as the yield provided by these strategies. That is in contrast to previous work which typically analyzes the currency risk premium on the basis of deviation from UIP.

Our data set is constructed by forming all possible combinations of currency pairs. That leaves us with $n!/((n-k)!k!)$ combinations where n denotes the total number of elements, and k denotes the size of the group. In our case, n corresponds to the number of currencies and is equal to seven, whereas k is equal to two, which gives us a total of 21 currency pairs. These are then arbitrarily divided into two groups, one containing 11 and the other 10 currency combinations. It is assumed that the first portfolio is managed by a traditional carry trader who runs 11 carry trade strategies, viz. one on each pair. The rational investor takes a long position in the high-yield currency and a short position in the low-yield currency. The second basket is managed by a seemingly irrational trader who follows ten “reverse” carry strategies, again one for each pair. The seemingly irrational trader is taking a long position in low-yield markets by shorting high-yield currencies. Figure 6.1 displays how currency combinations are obtained, and how they are sorted into baskets.

The following example shows how carry trade yields are calculated. We assume a rational carry trader speculating on AUD versus CAD interest rate differentials where $i_{t,t+1}^{aud} > i_{t,t+1}^{cad}$ at time t . Yields are obtained as follows:

$$y_{t,t+1} = i_{t,t+1}^{aud} - i_{t,t+1}^{usd} + s_{t+1}^{usd/aud} - s_t^{usd/aud} - (i_{t,t+1}^{cad} - i_{t,t+1}^{usd} + s_{t+1}^{usd/cad} - s_t^{usd/cad}) \quad (6.1)$$

where $i_{t,t+1}^{aud}$ denotes the nominal interest rate on AUD Euromarket deposits between t and $t + 1$. $i_{t,t+1}^{usd}$ and $i_{t,t+1}^{cad}$ correspond to Euromarket rates for USD and CAD deposits, respectively. $s_t^{usd/aud}$ is the spot exchange rate between the USD and the AUD at time t and $s_t^{usd/cad}$ the exchange rate between the USD

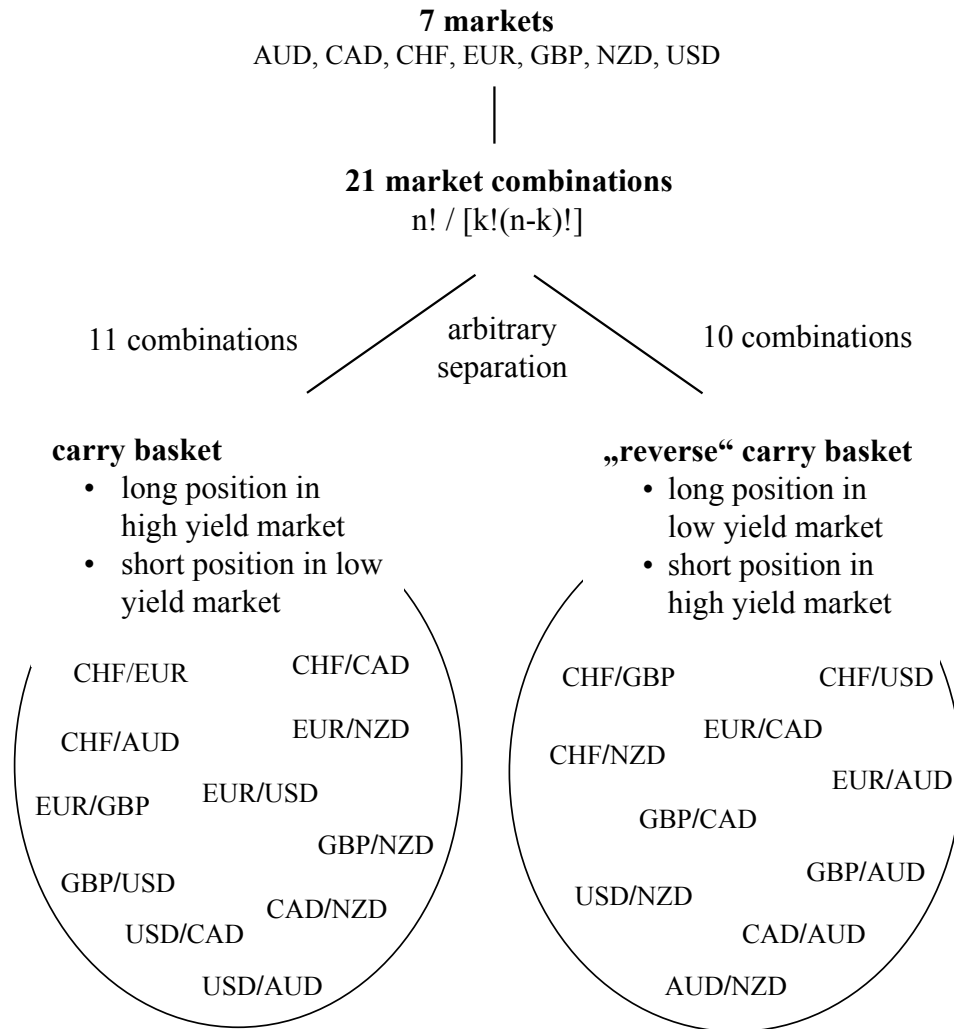


Figure 6.1: Scheme for building carry trade and “reverse” carry trade baskets

and the CAD. $y_{t,t+1}$ represents the yield from the carry trade investment between t and $t + 1$. Exchange rates are denominated in logarithmic form and all yields are expressed in terms of the USD. A carry trade investment thus amounts to a double speculation against UIP where USD investors take a long position on the AUD money market and a short position on the CAD money market. “Reverse” or

seemingly irrational carry traders, by contrast, take a long position on the CAD money market and a short position on the AUD money market. “Reverse” carry trades amount thus to the mirror strategy of traditional trades. Basing analysis on carries and “reverse” carries requires us to perform some calculations, but that is worth the trouble because carry formation entails several advantages:

1. Carry strategies boil down to a double speculation against UIP. After all, investors short low-yield currencies and invest the proceeds in high-yield currencies. By focusing on carry trades instead of deviation from UIP, we obtain a much larger currency risk premium. The distinction between carry and “reverse” carry speculation leads to a further amplification of risk premia.
2. Studies based on deviation from UIP usually suffer from data shortage. The problem is that deviations can only be calculated if deposits exhibit comparable maturities and comparable default spreads across currencies. UIP calculations depend, moreover, on freely floating exchange rates. One cannot obtain a large cross-section of reasonable length under these restrictions. The construction of carry trade combinations offers an elegant solution because analysis can be based on currency combinations. Starting from only seven well-developed markets with long data histories, we obtain a rich cross-section of 21 carry trade strategies.
3. We form carry and “reverse” carry strategies based on nominal interest rate differentials at time t . The latter are widely known to forecast deviation from UIP (see, for instance, Fama 1984). Sorting on interest rate differentials is therefore a way of conditioning information.

6.4 Preliminary Analysis

The C-CAPM relates risk premia to the covariance with consumption by postulating that an asset’s return is a positive function of its covariance with consumption growth. Figure 6.2 gives a first notion of the relationship between currency risk premia and consumption growth rates. It shows a scatter plot with average deviation from UIP on the vertical axis and with the correlation between deviation from UIP and non-durable plus services consumption on the horizontal axis. Due to slow consumption adjustments, correlations are not based on contemporaneous but on a long-term consumption growth measure. The USD is used as numeraire currency, which is why it is situated at the origin of the coordinates. According to theory, all money market deposits should be located on an upward-sloping line with a gradient of 45° . Although the graph does not exactly map

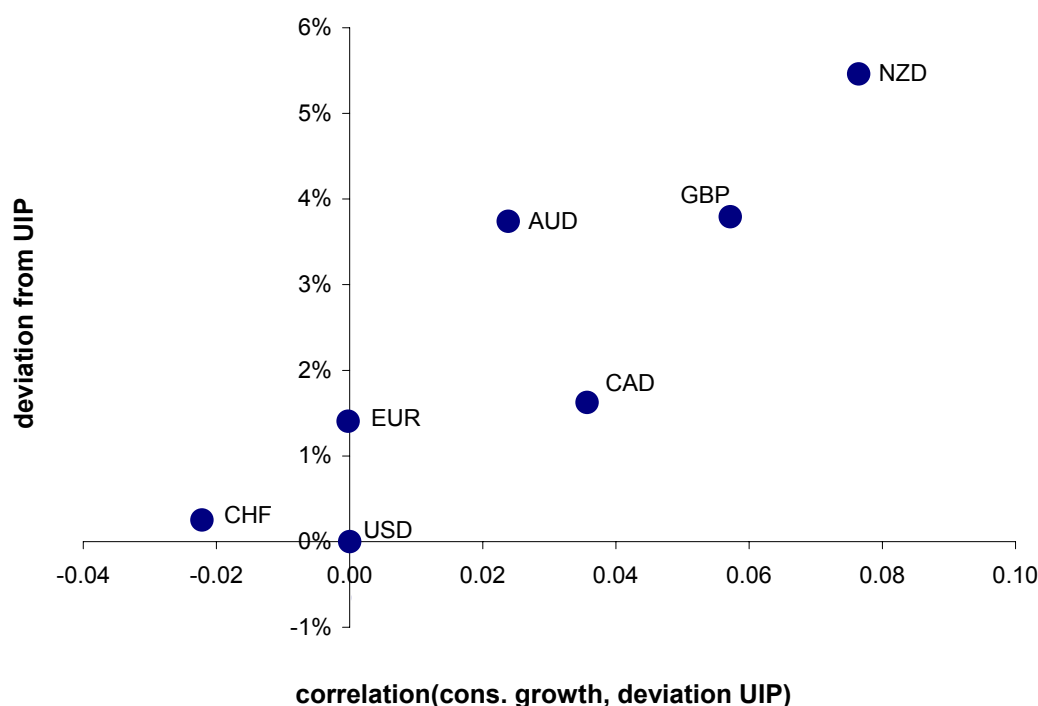


Figure 6.2: Relationship between deviation from UIP and consumption growth

what theory predicts, we can clearly see an upward sloping scatter cloud. Among the deposits investigated, the NZD brought the highest excess return with an outperformance of more than 5% p.a. over a comparable deposit in USD, but NZD deposit also exhibit the highest correlation with US nondurable plus services consumption growth. In other words, investments in NZD expose investors to highly pro-cyclical payoff patterns. Deposits in CHF are located at the other pole and only show a slight overperformance compared to Eurocurrency deposits in USD. It seems as if CHF investors receive compensation for their deposit's poor performance in terms of a negative covariance with respect to US consumption growth. Deposits in most other currencies lie somewhere in an upward sloping oval to the south-west of the NZD and to the north-east of the CHF investment.

6.4.1 Summary Statistics

The upper panel of table 6.1 shows distributional statistics for the carry trade basket and its constituents, whereas the lower panel summarizes statistics for the “reverse” carry trade basket. The second column shows that all carry trade strategies generated positive returns between January 1987 and December 2006

carry	mean	stddev	skew	kurt	corr
CHF/EUR	2.50	3.82	-0.08	3.20	-0.06
CHF/CAD	5.37	11.91	-0.09	3.10	0.06
CHF/AUD	5.16	13.62	-0.36	3.73	0.05
EUR/GBP	2.45	7.38	-0.54	4.77	0.04
EUR/USD	4.53	10.30	-0.44	3.65	0.11
EUR/NZD	4.15	11.58	-0.40	5.25	0.10
GBP/USD	3.50	9.92	-0.54	5.13	-0.02
GBP/NZD	2.41	11.60	-0.74	5.35	-0.02
USD/CAD	3.31	5.54	-0.37	3.40	0.10
USD/AUD	6.98	9.55	-0.48	3.51	0.04
CAD/NZD	4.28	9.57	-0.10	3.57	-0.04
average	4.06	9.53	-0.38	4.06	0.04

“reverse” carry	mean	stddev	skew	kurt	corr
CHF/GBP	-4.19	8.10	0.40	5.43	-0.10
CHF/USD	-2.37	11.14	0.31	2.92	0.01
CHF/NZD	-6.03	12.36	0.19	4.15	-0.11
EUR/CAD	-4.83	11.03	-0.25	3.32	-0.03
EUR/AUD	-5.03	12.74	-0.15	3.62	-0.05
GBP/CAD	-4.39	10.70	0.12	3.95	0.05
GBP/AUD	-3.68	11.97	0.06	3.69	-0.06
USD/NZD	-5.64	10.10	0.09	4.02	-0.03
CAD/AUD	-2.48	8.73	-0.01	2.96	0.07
AUD/NZD	-3.98	8.21	0.37	6.71	-0.01
average	-4.26	10.51	0.11	4.08	-0.03

Table 6.1: Summary statistics on carry trade baskets and their constituents

on average. The mean return for the carry trade basket was slightly more than 4%. The corresponding return for a trader with a stake in the “reverse” carry trade basket was -4.26 % with all basket constituents lying in the minus region. The carry trade strategy has thus been working reliably across a wide range of currency pairs in the long run. That is not true for short term investment horizons. In fact, annualized standard deviations are much larger than annualized mean returns which implies that short term oriented traders run a large risk of ending up with a loss.

Skewness bears a negative sign for all carry trade strategies and a positive sign

for most “reverse” carry investments. Put differently, carry trade profits exhibit asymmetry with distributional tails ranging further into the loss than into the profit region.⁷ Moreover, carry trade profits exhibit fatter tails than under a normal distribution. That can be seen from the values for kurtosis shown in column five, which are usually larger than three. The last column shows that carry trades tend to be positively correlated with ultimate consumption growth, whereas “reverse” carries tend to be negatively correlated. That corresponds to what we would expect and is an indication that currency risk pricing within a consumption-based framework might meet with success.

6.4.2 CHF/AUD Exchange Rate as Leading Indicator

Bank strategists advocate paying attention to the CHF/AUD exchange rate as a gauge for future business-cycle conditions.⁸ The economic rationale underlying such predictions is that exports of commodities account for a relatively large fraction of the Australian GDP. This dependency makes the AUD prone to fluctuations in commodity prices, which respond in a very sensitive manner to business-cycle conditions. As a matter of fact, Chen and Rogoff (2002) show that commodity prices in USD terms have a strong and stable impact on the real exchange rate of Australia. On the other hand, the CHF is commonly thought to appreciate in times of economic or political turbulence. Investors might seek protection in CHF assets if they perceive that a downturn in global business conditions is on the verge. In short, the AUD and the CHF are two opposing poles, whereas the former loses in value prior to an economic downturn, the latter typically gains during such episodes. Figure 6.3 illustrates that the 6-months’ logarithmic change in the CHF/AUD exchange rate moves almost in parallel with the OECD leading indicator. Since we limit analysis to the viewpoint of an USD investor in this chapter, the leading indicator for the US is used for comparison. The picture would not change by much if the leading indicator for the OECD zone were chosen instead. CHF/AUD exchange rates even slightly forerun changes in the leading indicator. That is because the exchange rate is a pure market measure, whereas the OECD leading indicator contains market as well as survey data such as consumer confidence or durable goods orders. In contrast to market information, which is readily available at any time, survey data require time to accumulate. This explains the OECD leading indicator’s lag.

We interpret figure 6.3 as evidence that exchange rates react immediately to

⁷That observation brought us to more closely analyze the relationship between deviation from UIP and skewness in chapter 7, where currency risk premia are priced within an extended

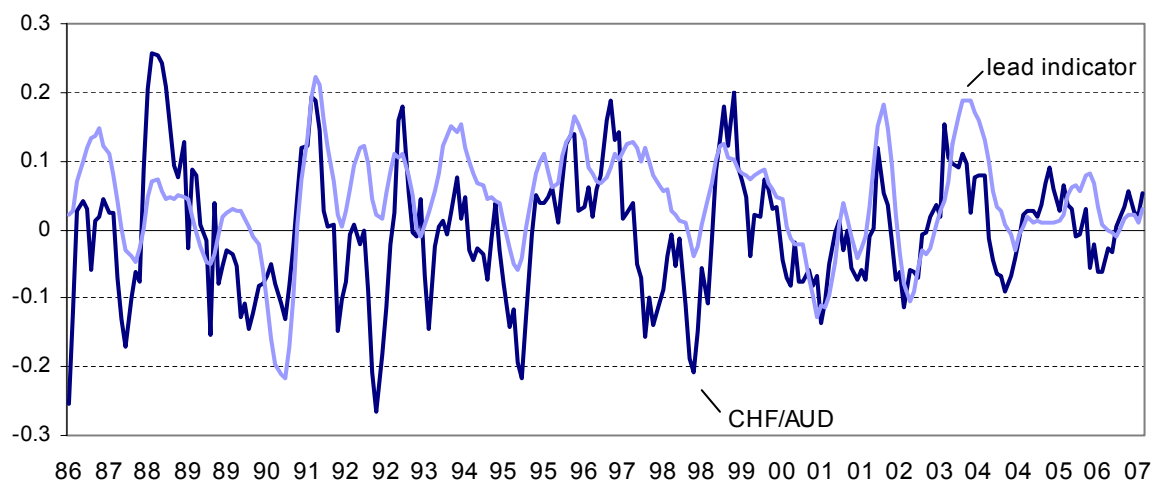


Figure 6.3: AUD/CHF exchange rate and OECD leading indicator

new information about future business-cycle conditions. Assume, for instance, that the market believes in safe haven properties of the CHF and accordingly expects an appreciation in times of economic slowdown. One should then already expect a slight appreciation as soon as the first forecast indicator signals trouble ahead. Put differently, markets react in response to expectations about future states of the world and not in response to movements in current states. In light of these findings, we modify the C-CAPM by substituting contemporaneous consumption by Julliard and Parker's ultimate consumption, which is a forward-looking consumption growth measure. As shown in the results section, this modification leads to a considerable improvement of the C-CAPM's goodness-of-fit measured in terms of R-squares and J-statistics.

6.5 Intertemporal Asset Pricing

Virtually all asset pricing theories operate on the central assumption of arbitrage-free markets. No arbitrage implies the existence of a strictly positive discount factor, m , which consistently prices all traded payoffs and returns.⁹ The following formula can therefore be seen as a general pricing law driving all intertemporal pricing models:

CAPM setting.

⁸The CHF/NZD and the CHF/CAD lead to similar results.

⁹See Cochrane (2001) for a formal proof.

$$p_t = E_t[m_{t+1}x_{t+1}] \quad (6.2)$$

where p denotes an asset's price and x its stochastic payoff at time $t + 1$. m is a strictly positive variable, known as the stochastic discount factor (SDF) or as the pricing kernel.¹⁰ Hence, in an arbitrage-free market prices are obtained by discounting future payoffs, where both the SDF and the payoff are unknown at time t . Equation 6.2 holds for all assets including risk-less zero bonds with a final payoff equal to one:

$$p_{\text{bond},t} = E_t[m_{t+1}1_{t+1}] \quad (6.3)$$

It follows that the gross risk-free rate of return, denoted as R_{rf} , corresponds to

$$R_{rf;t,t+1} = \frac{1}{p_{\text{bond},t}} = \frac{1}{E_t m_{t+1}} \quad (6.4)$$

That insight allows us to express equation 6.2 as follows:

$$p_t = \frac{E_t x_{t+1}}{R_{rf;t,t+1}} + \text{cov}_t[m_{t+1}, x_{t+1}] \quad (6.5)$$

Equation 6.5 requires all assets to pay an expected return equal to the risk-free rate plus a covariance term. The latter is known as the risk premium and is an increasing function of the conditional covariance between the SDF and the contingent claim x_{t+1} . So far, the risk premium is a rather abstract concept, related to the covariance between payoffs and an undefined pricing kernel. We now bring in some structure by relating kernels to consumption growth.

6.5.1 Consumption-Based First Order Condition

Consider a two-period setting, where agents must decide on how much to consume and how much to save for future consumption. Decisions have to be made in a stochastic environment with uncertain income flows and uncertain future states of the world. After having decided upon consumption and investment, agents face a second decision set, viz. how to invest their savings. They can choose from a vast number of investment vehicles, which differ with respect to systematic

¹⁰Both terms are synonymously used hereafter.

risk and expected return characteristics. We now present the joint consumption-investment problem of an agent maximizing a time-additive intertemporal utility function. Two-period time-separable utility is defined as follows:

$$U(c_t, c_{t+1}) = U(c_t) + \beta E_t[U(c_{t+1})] \quad (6.6)$$

where c denotes consumption, and β is the time discount factor. U represents utility and is a concavely increasing function in both arguments c_t and c_{t+1} . Hence, equation 6.6 captures the principles of insatiableness and decreasing marginal utility. Agents' initial endowment, w_t , is either consumed at date t or invested in a set of n financial assets with prices given by the vector $p_t = [p_{1,t}, p_{2,t}, \dots, p_{n,t}]'$. If labor income is ignored, the investor's budget constraint at date t is given by:

$$w_t = c_t + \sum_i^n \xi_i p_{i,t} \quad (6.7)$$

where ξ_i denotes the quantity of asset i bought at time t . We now define a vector of stochastic asset payoffs at time $t + 1$ which we write as

$$x_{t+1} = [x_{1,t+1}, x_{2,t+1}, \dots, x_{n,t+1}]' \quad (6.8)$$

This leads to the second-period budget constraint:

$$0 = c_{t+1} - \sum_i^n \xi_i x_{i,t+1} \quad (6.9)$$

Substituting the two constraints into the objective function 6.6 leaves us with the following optimization problem:

$$\max_{\xi} U(c) = U\left(w_t - \sum_i^n \xi_i p_{i,t}\right) + \beta E_t\left[U\left(\sum_i^n \xi_i x_{i,t+1}\right)\right] \quad (6.10)$$

If the first order condition is set to zero and if we reshuffle, we finally obtain the optimal consumption-investment decision:

$$p_{i,t} U'(c_t) = E_t[\beta U'(c_{t+1}) x_{i,t+1}] \quad (6.11)$$

Equation 6.11 says that the marginal utility loss of an investment today is equal to the expected marginal utility gain of the investment tomorrow discounted by the time preference rate β . Solving for $p_{i,t}$ gives:

$$p_{i,t} = E_t \beta \left[\frac{U'(c_{t+1})}{U'(c_t)} x_{t+1} \right] \quad (6.12)$$

The model relates asset prices to the marginal rate of substitution between future and current consumption. The pricing kernel or SDF, m_{t+1} , is given by:

$$m_{t+1} = \beta \frac{U'(c_{t+1})}{U'(c_t)} \quad (6.13)$$

In consumption-based asset pricing, the discount factor is an increasing function of the marginal utility of future consumption. The latter is relatively large in times of low c_{t+1} , i.e. during bad states of the world. If agents expect bad states ahead, they are apparently more willing to save. That leads to an increase in prices at time t and to smaller discounts on future payoffs.

6.5.2 Introducing Power Utility

The previous analysis is based on an implicit utility function. We subsequently assume that $U(c)$ is governed by power utility:

$$U(c) = \frac{c^{1-\rho} - 1}{1-\rho} \quad (6.14)$$

where ρ represents the coefficient of relative risk aversion. If we compute the pricing kernel defined in equation 6.13 under power utility, the following explicit expression is obtained:

$$m_{t+1} = \beta \left(\frac{c_t}{c_{t+1}} \right)^\rho \quad (6.15)$$

The SDF is now a decreasing function of consumption growth. If we express equation 6.5 by plugging consumption growth into the covariance term, we obtain:

$$p_{i,t} = \frac{E_t x_{t+1}}{R_{rf;t,t+1}} + \beta \text{cov}_t \left[\left(\frac{c_t}{c_{t+1}} \right)^\rho, x_{t+1} \right] \quad (6.16)$$

The covariance term is positive if asset i performs well in times of low consumption growth. Such assets yield relatively large returns in bad states of the

world when payoffs are most needed. That is a highly appreciated characteristic for which investors pay a premium. Such assets thus trade at a higher price than assets with the same expected return but with a procyclical payoff stance. Variances are irrelevant because investors do not care about movements in individual securities. What matters is systematic, non-diversifiable risk with consumption growth. Equation 6.16 shows that assets exhibiting a positive covariance term even underperform the risk-free rate. Insurance is an extreme example because it pays off when agents are hit by catastrophes and desperately need financial support (see Cochrane, 2001). Therefore, investors accept a negative expected return when closing an insurance contract.

6.6 Estimation Procedure

The pricing kernel imposes the following payoff restriction (see equation 6.2):

$$p_t = E_t[m_{t+1}(b)x_{t+1}] \quad (6.17)$$

In our case, x_{t+1} corresponds to real payoffs from carry trade and “reverse” carry trade strategies. Since a carry trade involves a long as well as a short position, it amounts to a zero investment. Put differently, with the exception of transaction costs and margin accounts, carries do not involve any upfront payment, which implies that $p_t = 0$. We assume that the SDF is a linear function of logarithmic consumption growth,¹¹ which leads to the following expression:

$$m_{t+1} = b_0 + b_1 \left(\ln \frac{c_{t+1}}{c_t} - E_t \left(\ln \frac{c_{t+1}}{c_t} \right) \right) \quad (6.18)$$

Similarly to the pricing of excess returns, we need to restrict the mean of the SDF to some convenient value when pricing zero-fund investments. This choice is arbitrary and has no effect on test statistics. b_0 is hence set to one. If equation 6.18 is then plugged into equation 6.17, we receive:

$$0 = E_t \left[\left(1 + b_1 \left(\ln \frac{c_{t+1}}{c_t} - E_t \left(\ln \frac{c_{t+1}}{c_t} \right) \right) \right) x_{t+1} \right] \quad (6.19)$$

In an exactly identified system, Hansen and Singleton’s (1982) General Method of Moments (GMM) allows estimating b_1 by setting the sample average in equation 6.19 to zero. In overidentified systems, the number of moments is larger than

¹¹This assumption is usually made in empirical work.

the number of free parameters, so that moments cannot hold precisely. The GMM estimator then tries to fit equation 6.19 as close as possible. The econometrician has to specify a weighting scheme which tells the estimator if a certain moment bears more or less importance. It is usually recommended to use a two-stage procedure to obtain a so-called optimal weighting matrix. First, all moment restrictions are assigned equal weights. This first round optimization results in a variance-covariance matrix of moments whose inverse serves again as weighting scheme for a second round optimization. We report results based on such optimal weights. In addition, we run estimations using equal weights and Hansen-Jagannathan's matrix of second-moments (see Hansen and Jagannathan, 1997). Whereas optimal weights lead to efficient estimates, equal and Hansen-Jagannathan weights are statistically inefficient. In return, they allow comparing J -values across different SDF specifications. The J -value is a χ^2 -distributed test statistic which can be interpreted as a distance or a goodness-of-fit measure. It is defined as follows:

$$J = t(\bar{g}'S^{-1}\bar{g}) \quad (6.20)$$

where the column vector \bar{g} represents average pricing errors, and S^{-1} is the error variance-covariance matrix. If the model specification provides a good fit, average errors are small compared to their variance-covariance matrix, which results in a small J -value.¹²

6.6.1 Conditional Asset Pricing

Agents' willingness to substitute present for future consumption increases when they are pessimistic about future states of the economy and vice versa when they are optimistic. Consequently, we expect the pricing kernel to increase in periods of bearish forecasts and to decrease in periods of bullish forecasts. That effect can be captured by augmenting kernel specifications with instrumental variables providing information about the future state of the economy. Instruments must be chosen according to economic theory. We use credit default spreads and a measure for exchange rate volatility.

More technically speaking, movements in the degree of optimism translate into a time-varying parameter $b_{1,t}$ in equation 6.19. This in turn leads to time-variation in currency risk premia, which is an indispensable prerequisite for successful currency risk modeling (see Fama, 1984). We therefore postulate that changes in $b_{1,t}$

¹²See section 7.6 for a more detailed review of the GMM estimation procedure and for a description of the advantages and disadvantages of using different weights.

depend linearly on an instrumental variable vector denoted by z_t :

$$b_{1,t} = \gamma_1 + \gamma_2 z_{t,df} + \gamma_3 z_{t,vol} \quad (6.21)$$

where γ_1 , γ_2 and γ_3 represent parameters. $z_{t,df}$ denotes the credit default spread and $z_{t,vol}$ exchange rate volatility. If we plug equation 6.21 into equation 6.19 and if we do a bit of reshuffling, we obtain:

$$0 = E_t \left[(1 + \gamma_1 f_{t,t+1} + \gamma_2 z_{t,df} f_{t,t+1} + \gamma_3 z_{t,vol} f_{t,t+1}) x_{t+1} \right] \quad (6.22)$$

where f represents the risk factor which corresponds to $\ln\left(\frac{c_{t+1}}{c_t} - E_t \frac{c_{t+1}}{c_t}\right)$. The time-varying coefficient representation with only one risk factor can thus be transformed into a model with fixed coefficients and three risk factors. The first factor denotes consumption growth as defined in the standard C-CAPM. The second and the third factor are obtained by multiplying consumption growth with instruments. For reasons explained hereafter, we believe that credit default spreads and exchange rate volatility might have an influence on factor premia.

6.6.1.1 Credit Default Spread

The credit default spread is measured as the difference in yields between a portfolio of US corporate bonds with a BBB rating and almost risk-less Treasury Bills. Since we adjust for term structure effects by choosing equal maturities, the yield difference reflects pure default premia. The rationale for using credit default spreads as instruments emanates from the assumption that default spreads rise as the economic outlook darkens. During periods of hardship, the representative investor thus demands a higher factor premium, $b_{1,t}$. The assumption that credit default spreads forecast business-cycle conditions is empirically corroborated by Stock and Watson (1990), who run a “horse race” between potential forecast variables. Credit default spreads are found to lead to better business-cycle predictions than most other instruments.

6.6.1.2 Exchange Rate Volatility

We run univariate GARCH(1,1) estimations for each of our carry trade series, which leaves us with 21 time series for the conditional volatility. The latter are then aggregated by taking the cross-sectional average at each point in time. That gives us a measure of aggregate UIP volatility, which we use as instrument. Aggregate volatility based on a GARCH specification might be of importance for two

reasons. First, it is a measure for expected turbulence in financial markets in general. Since agents' wealth is driven by financial markets, and since wealth has an impact on consumption, we would expect a positive correlation between expected volatility in financial markets and expected volatility in consumption growth. We conjecture that investors demand a higher factor premium, $b_{1,t}$, as they expect rising turbulence in consumption growth. Second, aggregate exchange rate volatility is a direct measure for risks associated with speculation against UIP. We assume that the factor premium increases as these risks increase.

6.7 Results

Table 6.2 shows that contemporaneous consumption growth cannot explain cross-sectional variation in currency risk premia. Although the J-statistic does not reject the model, we obtain a R-squared of only 2% and an adjusted R-squared of -1% for the estimation based on equal weights. These diverging results are probably due to a large error variance-covariance matrix, S , which reduces the power of the J-test (see equation 6.20). Coefficients b_1 are negative, irrespective of the weighting scheme used, which implies that pricing kernels decrease during periods of optimism when agents expect strong consumption growth. That is what theory predicts. However, we cannot reject the null hypothesis for b_1 when performing estimations with equal or with Hansen-Jagannathan weights. Estimates of b_1 lie in a range between -59.9 for equal weights and -146.9 for optimal weights. That is far too large to represent relative risk aversion, which it should in a setting like ours based on time-separable preferences and power utility. According to Mehra and Prescott (1985), it is highly unlikely that b_1 is larger than ten. They provide a broad overview of studies reporting economically plausible estimates for the coefficient of relative risk aversion. Most of the work cited assumes that estimates are somewhere between zero and four. At the heart of the problem is contemporaneous consumption, which apparently is not variable enough to explain variation in deviation from UIP.

Figure 6.4 illustrates the poor performance of the contemporaneous consumption growth model by plotting actual deviation from UIP on the horizontal axis versus model implied predictions on the vertical axis. If the model provided a perfect description, we would expect dots to form an upward-pointing line with a slope of 45 degree. By contrast, we obtain a scatter cloud which is not even upward looking. In other words, there does not exist any relationship between predictions and actual realizations.

Standard C-CAPM			
weights	optimal	equal	HJ
b(1)	-146.92	-59.94	-66.66
stddev	60.31	93.81	63.83
t-stat	-2.44	-0.64	-1.04
p-value	0.02	0.52	0.30
chi-square	26.28	27.32	27.22
chi p-value	0.16	0.13	0.13
R^2		0.02	
R^2_{adj}		-0.01	

Table 6.2: Results for the contemporaneous C-CAPM

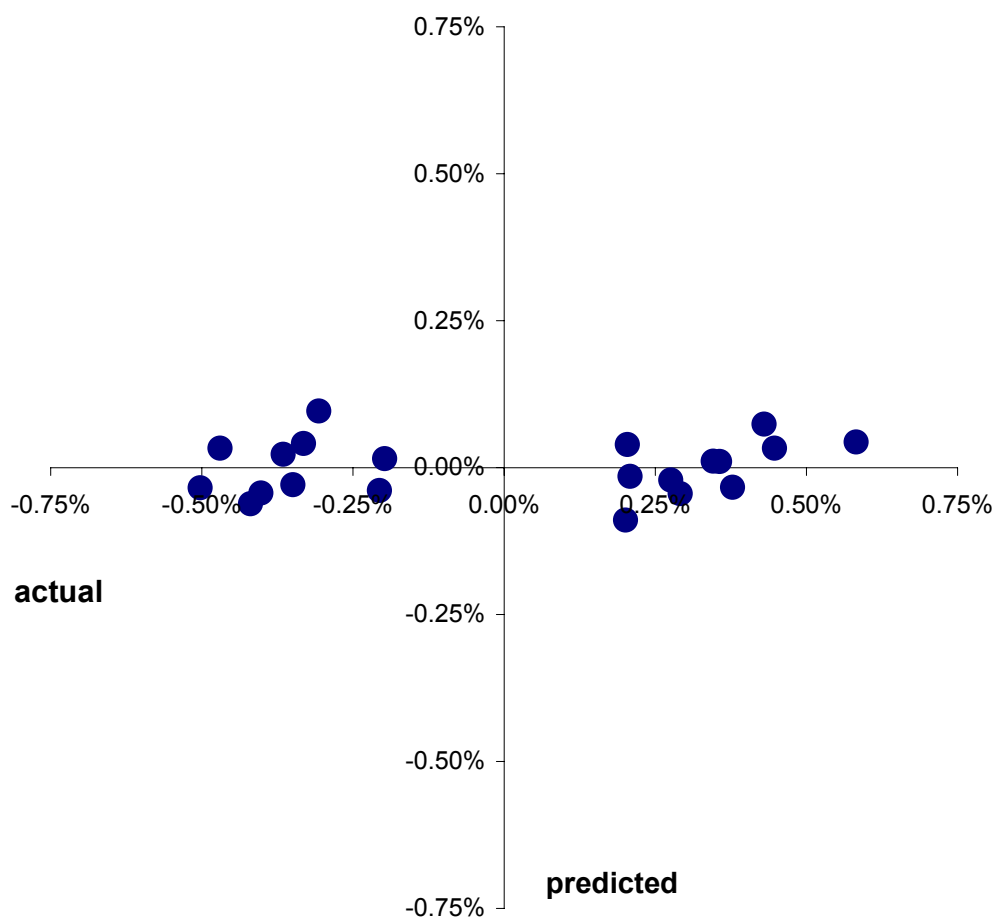


Figure 6.4: Model predictions of the C-CAPM with contemporaneous consumption as the risk factor (vertical axis) versus actual realizations (horizontal axis)

6.7.1 C-CAPM with Ultimate Consumption

Consumption growth reacts with a time lag to movements in asset prices. Assume, for instance, that the world is hit by a negative asset price shock leading to a loss in wealth. Consequently, agents will try to cut consumption expenditures. Adjustments occur, however, only gradually due to menu costs, consumption habits and durable consumption components. Parker and Julliard (2005) therefore argue that contemporaneous consumption cannot explain asset price movements. Instead, they propose to measure risk by the covariance between returns and ultimate consumption, where ultimate consumption is defined as consumption growth over the period of the return and many subsequent periods. Causality might also work the other way round, viz. from expected business cycle conditions to asset prices. Due to market efficiency, most prices respond momentarily to changing environments, i.e. as soon as agents receive reliable signals on the future path of the economy. Section 6.4.2 shows that currency prices even tend to forecast the OECD leading indicator, which reinforces the efficient market hypothesis.

Irrespective of whether causality goes from asset prices and wealth to consumption or from expected business cycle conditions to asset prices, contemporaneous consumption is doomed to fail. A forward-looking risk measure is needed and Parker and Julliard propose ultimate consumption. Another promising approach is to incorporate instruments when running estimations because these serve to capture expected business cycle conditions. The derivation of the pricing kernel governed by ultimate consumption is explained in the appendix. Table 6.3 shows that results for the ultimate C-CAPM improve considerably compared to

C-CAPM with ultimate consumption			
weights	optimal	equal	HJ
b(1)	-88.86	-116.48	-13.41
stddev	29.82	70.50	27.25
t-stat	-2.98	-1.65	-0.49
p-value	0.00	0.10	0.62
chi-square	18.17	14.67	27.19
chi p-value	0.58	0.80	0.13
R^2		0.39	
R^2_{adj}		0.37	

Table 6.3: Results for the C-CAPM with ultimate consumption

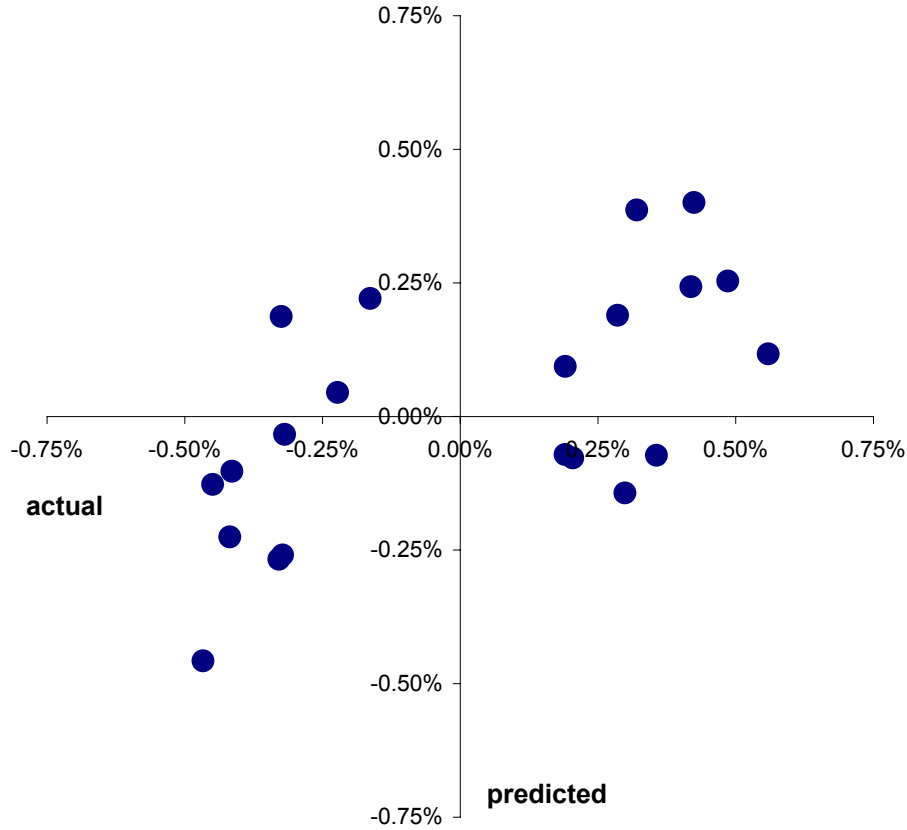


Figure 6.5: Model predictions of the C-CAPM with ultimate consumption as the risk factor (vertical axis) versus actual realizations (horizontal axis)

estimations based on contemporaneous consumption. The new model explains approximately 39% of the total variation in currency risk premia if estimation is based on equal weights (adjusted R-squared: 37%). We do not reject overidentifying restrictions, irrespective of whether estimation is based on optimal, equal or Hansen-Jagannathan weights. The coefficient, b_1 , bears the correct sign and is statistically significant for the optimal weighting scheme. The model's improved performance is also visible in figure 6.5 whose scatter cloud is now clearly upward-pointing.

6.7.2 C-CAPM with Ultimate Consumption and Instruments

In this section, equation 6.22 is estimated with ultimate consumption as the risk factor and with credit default spreads and exchange rate volatilities as instruments. The fit of the model improves considerably and we obtain an adjusted R-squared of 66% (unadjusted R-squared: 67%). That is much more than what we receive for the unconditional specification (37%) or the standard C-CAPM

(-1%).¹³

optimal weights	γ_1	γ_2	γ_3
coeff	-75.38	-5945.60	82.09
stddev	32.92	6206.46	55.59
t-stat	-2.29	-0.96	1.48
p-value	0.02	0.34	0.14
chi-square	16.92		
chi p-value	0.53		

equal weights	γ_1	γ_2	γ_3
coeff	-112.02	-3482.96	174.59
stddev	92.16	9513.07	176.95
t-stat	-1.22	-0.37	0.99
p-value	0.23	0.71	0.32
chi-square	12.33		
chi p-value	0.83		
R^2	0.67		
R^2_{adj}	0.66		

HJ-weights	γ_1	γ_2	γ_3
coeff	-36.34	-8347.23	100.16
stddev	40.41	7227.63	67.26
t-stat	-0.90	-1.15	1.49
p-value	0.37	0.25	0.14
chi-square	16.89		
chi p-value	0.53		

Table 6.4: Results for the conditional C-CAPM with ultimate consumption as the risk factor and with exchange rate volatilities (γ_2) and credit default spreads (γ_3) as instruments

¹³Comparison needs to be based on the adjusted R-squared, which takes into consideration that the instrumental variable approach uses more explaining factors.

Table 6.4 shows that J-statistics are not rejected, irrespective of the weighting scheme applied. J-values improve considerably compared to the unconditional specification, notably for the Hansen-Jagannathan estimation, and the market factor, γ_1 , always bears the correct sign. The model's improved performance is also evident from the scatter cloud in figure 6.6, which displays that model predictions are now much closer to actual realizations compared to the corresponding figures shown previously.

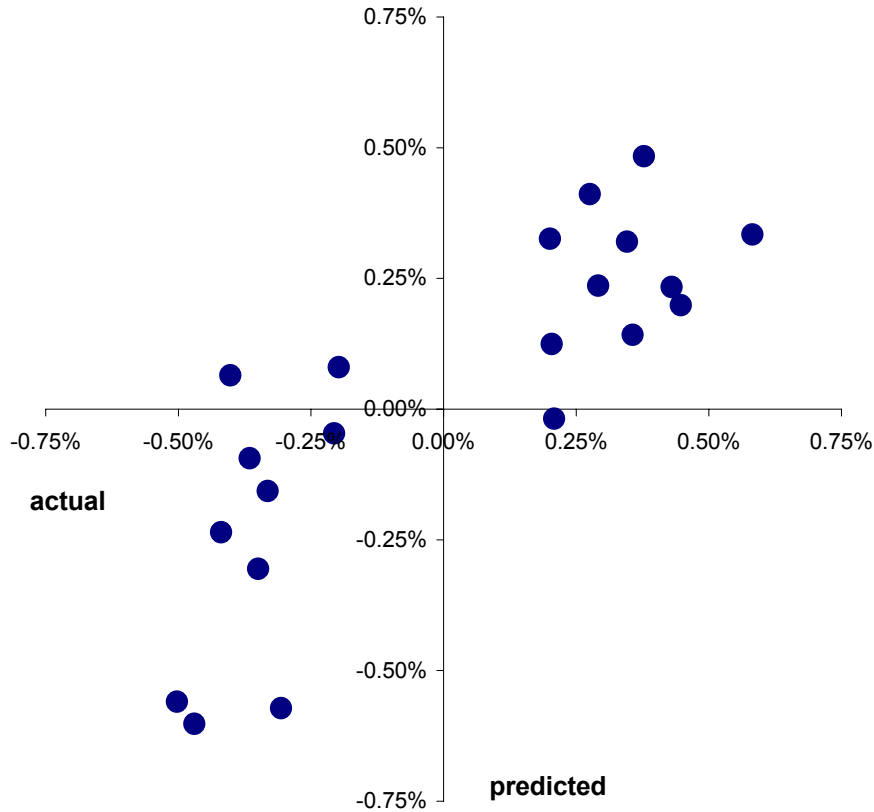


Figure 6.6: Model predictions of the conditional C-CAPM with ultimate consumption as the risk factor (vertical axis) versus actual realizations (horizontal axis)

6.8 Conclusion

This chapter analyzes whether consumption-based asset pricing models (C-CAPM) can account for the cross-sectional variation in carry trade payoffs. Carry trades amount to a strategy based on a double speculation against uncovered interest rate parity (UIP) where investors borrow in low-yield currencies to invest in high-yield currencies. Whereas most previous studies failed to relate deviation from UIP to consumption growth, our refined model can explain approximately

two-thirds of the total variation in carry trade payoffs. The main insight is that contemporaneous consumption growth cannot explain deviation from UIP because currency prices move in anticipation of future business-cycle conditions. As a matter of fact, we provide evidence that certain currency pairs provide a reasonable prediction for future consumption growth by forerunning the latter by 9 to 12 months. This observation leads us to modify the standard pricing kernel. We notably advocate substituting contemporaneous consumption for Parker and Julliard's (2005) ultimate consumption where the latter is measured as consumption growth over the period of the return and many subsequent periods. The empirical success of our model is attributed to the fact that ultimate consumption is a forward-looking consumption growth measure. A further improvement of the model's fit is obtained by scaling ultimate consumption with credit default spreads and a measure for exchange rate volatility. This substantiates evidence that it is important to incorporate forward-looking information when pricing currency risk premia.

6.A Appendix

6.A.1 Derivation of the Ultimate C-CAPM

Consider the Euler equation for excess returns between t and $t + 1$:

$$E_t \left(\beta \frac{u'(c_{t+1})}{u'(c_t)} x_{t,t+1} \right) = 0 \quad (6.23)$$

where $x_{t,t+1}$ denotes excess returns between t and $t + 1$. Multiplying both sides by $u'(c_t)$ and dividing by β gives

$$E_t(u'(c_{t+1})x_{t,t+1}) = 0 \quad (6.24)$$

Equation 6.24 provides an interesting insight, namely that the expected future increase in marginal utilities must be the same across all assets. If we assume, for a moment, that we are in $t + 1$, and that we want to price a gross risk free rate of return paying off in $t + 1 + S$, we can write:

$$u'(c_{t+1}) = E_{t+1}(\beta u'(c_{t+1+S}) R_{t+1,t+1+S}^{rf}) \quad (6.25)$$

Expected marginal utility at $t + 1 + S$ obtained from $R_{t+1,t+1+S}^{rf}$ and discounted by the time preference rate β must be equal to marginal utility today. Replacing $u'(c_{t+1})$ in equation 6.24 with the expression on the right hand side of equation 6.25 and dividing by $\beta u'(c_t)$ yields:

$$E_t(m_{t+1}^S x_{t,t+1}) = 0 \quad (6.26)$$

where $m_{t+1}^S = R_{t+1,t+1+S}^{rf} u'(c_{t+1+S}) / u'(c_t)$, and where S denotes the duration over which the consumption response is analyzed. If we use the definition for the covariance, equation 6.26 can be written in terms of expected excess returns:

$$E(x_{t,t+1}) = - \frac{\text{Cov}(m_{t+1}^S, x_{t,t+1})}{E(m_{t+1}^S)} \quad (6.27)$$

An asset's excess return between t and $t + 1$ is driven by its covariance with the ultimate consumption kernel, which is defined as the change in marginal utilities between t and $t + 1 + S$ times the gross risk-free rate from $t + 1$ to $t + 1 + S$. For ease of comparison with other factor models, Parker and Julliard propose to analyze a linear transformation of equation 6.26, which is given below:

$$E_t \left[\left(R_{t+1,t+1+S}^{rf} - b_1(S) R_{t+1,t+1+S}^{rf} \ln \left(\frac{c_{t+1+S}}{c_t} \right) \right) x_{t,t+1} \right] = 0 \quad (6.28)$$

They also emphasize that expected returns are primarily driven by ultimate consumption growth as opposed to risk-free rates. That is why they run additional estimations keeping $R_{t+1,t+1+S}^{rf}$ constant. Following their approach, we perform our estimations by minimizing the moment restriction given below:

$$E_t \left[\left(b_0 - b_1(S) \ln \left(\frac{c_{t+1+S}}{c_t} - E_t \frac{c_{t+1+S}}{c_t} \right) \right) x_{t,t+1} \right] = 0 \quad (6.29)$$

Chapter 7

Currency Risk Premia and Coskewness

This chapter shows that investors speculating against uncovered interest rate parity must take negative skewness on board. UIP speculators thus face a distribution with an elongated tail to the left, reaching well into the loss region. We test an extended CAPM taking account of coskewness, which can explain a large fraction of the cross-sectional variation in currency risk premia. Coskewness is defined as a function of the covariance between deviation from UIP and squared equity market returns. It is found that the model performs better than the standard CAPM or a Fama-French extension thereof. Investors speculating against UIP apparently get exposed to potentially large losses.

7.1 Introduction

It is well-established that the forward rate provides a poor prediction for future spot exchange rates. Unfortunately, there does not yet exist a consensus about the forces causing such decoupling. Multiple solutions have been suggested, ranging from market irrationality to currency risk premia explanations. This chapter sheds light on the relationship between the forward rate bias and systematic coskewness and thus belongs to the risk premia literature. Our findings are of relevance for investors with a stake in foreign currencies and, in particular, for those deliberately speculating against uncovered interest rate parity (UIP). It is shown that investors speculating against UIP can only do so by taking negative coskewness on board. In fact, a CAPM-like framework taking account of coskewness can account for a surprisingly large fraction of the cross-sectional variation in deviation from UIP.

Fama (1984) argues that the forward rate is a poor predictor for future spot exchange rates. It even appears as if forwards point in the wrong direction. Put differently, if forward markets expect an appreciation, a depreciation is more likely to occur and vice versa if the forward signals a depreciation. Various studies draw similar conclusions, among others Frankel and Froot (1989) and McCallum (1994). To understand the anomaly, it might be useful to consider Frankel (1992), who demonstrates that the forward rate bias can be decomposed into deviation from uncovered interest rate parity (UIP) and deviation from covered interest rate parity (CIP). CIP holds at all times by virtue of arbitrage, which is why the forward rate bias corresponds in size to deviation from UIP. We therefore use both expressions synonymously hereafter. The phenomenon of forward rates being converse predictors has hence a counterpart in UIP language, viz. one observes that currencies with high nominal interest rates tend to appreciate. That leaves investors with a double gain, namely on the interest as well as on the currency side. On the other hand, currencies bearing low interest rates are more likely to depreciate so that low-yield investors tend to experience a double loss. UIP would, by contrast, demand a depreciation of high-yield currencies and an appreciation of low-yield currencies where exchange rate movements should precisely offset interest rate differentials.

We examine systematic risks in an extended capital asset pricing framework (CAPM) where analysis is based on the implicit assumption that agents' intertemporal marginal rate of substitution is driven by global equity returns. Numerous studies have applied a CAPM or a CAPM-like framework to the analysis of currency risk premia, usually with sobering results. It is generally found that the

CAPM has no or very limited explanatory power and reported R-squares are in general well below 5%. We demonstrate that explanatory power can be enhanced by introducing two modifications: The first concerns the model's structure and the second the data set applied. Instead of following earlier studies, which either focus on the standard or the Fama-French three-factor CAPM, we propose a two-factor specification. Our modified model is geared towards capturing systematic covariance as well as systematic coskewness with stock market returns. For that purpose, we extend the standard CAPM by a second factor, viz. quadratic market returns. This so-called quadratic kernel has been successfully applied to the pricing of equities, but not yet to the pricing of currency risk premia. The second modification concerns the data set and has recently been proposed by Lustig and Verdelhan (2005). Instead of analyzing UIP vis-à-vis individual currencies, Lustig and Verdelhan form eight foreign money market portfolios and calculate aggregate portfolio returns as simple averages. Currencies are sorted into portfolios on the basis of interest rate levels. The lowest-yielding currencies are assigned to portfolio one, the second lowest-yielding currencies are assigned to portfolio two and so on. In comparison to earlier studies, Lustig and Verdelhan capture a much larger fraction of cross-sectional variation in currency risk premia, notably within a consumption-based asset pricing framework. Due to the many advantages portfolio construction brings along, we follow Lustig and Verdelhan's approach.

7.2 Related Literature

Mark (1988) estimates currency risk premia within a conditional CAPM setting. He chooses an autoregressive conditional heteroskedasticity specification (ARCH) for the beta parameter in order to capture time-variation in risk exposure. The ARCH parametrization restricts market returns to evolve in an autoregressive manner. Using Hansen and Singleton's (1982) general methods of moments estimator (GMM), significant ARCH- and AR-parameters are obtained, and the model's overidentifying restrictions cannot be rejected. Mark interprets these results, probably falsely, as providing evidence that currency risk premia arise due to systematic risk in terms of covariance exposure to equity markets. Unfortunately, he does not provide any goodness-of-fit measure so that we cannot evaluate the model's explanatory power. Engel (1996) criticizes, that Mark's specification does not really capture whether currency risk premia can be explained by systematic covariance risk. Mark's model setting is rather geared towards answering whether

beta follows an ARCH process, and whether the market return is driven by an autoregressive component. Engel assumes that the model's explanatory power is poor. McCurdy and Morgan (1991) estimate a similar specification. The main difference is that their beta is modeled as a multivariate GARCH process, whereas Mark uses an univariate ARCH specification. In contrast to Mark, who runs simultaneous estimations, McCurdy and Morgan estimate the model currency by currency. Despite significant beta coefficients for all currencies, the model can only account for a small fraction of the total variance in foreign excess returns. For Japanese yen (JPY) investments, for instance, the R-squared is merely 3.9% and vis-à-vis other currencies it is even lower. They, moreover, find evidence for predictable currency risk components not captured by their specification. McCurdy and Morgan (1992) specify expected market excess returns as a function of the difference between US interest rates and a simple average of foreign interest rates. Similarly to their preceding study, they find that beta risk has significant explanatory power but, nevertheless, their R-squared remains disappointingly low. Bansal and Dahlquist (2000) use excess returns on US aggregate equity market portfolios as explaining factor to test 28 currency risk premia. Like in most other studies, analysis is limited to the viewpoint of an USD investor. In comparison to the before mentioned investigations, Bansal and Dahlquist do neither specify a process for excess market returns nor do they impose restrictions on the beta parameter. Instead, they estimate a plain vanilla unconditional CAPM on the basis of ex-post data using Fama and MacBeth's (1973) estimation methodology. The novel contribution of their work is the large data set which covers currency risk premia from 28 developed and emerging market economies. They report an impressively large t-ratio for beta. Interpretation is, however, difficult due to the fact that the two-step Fama-MacBeth procedure suffers from an error-in-variables problem.¹ Similarly to the studies before, Bansal and Dahlquist report an R-squared in the vicinity of zero. Lustig and Verdelhan (2005) are more successful and show that the CAPM and a Fama-French version thereof can explain up to 36% of the variation in foreign excess returns. That is much more than what earlier studies obtained. They attribute their success to the construction of portfolios which are sorted on the basis of interest rate levels. The first portfolio is constructed as a simple average of currency risk premia from markets with the lowest interest rate level, the second portfolio is calculated on the basis of data from markets with the second lowest interest rate level and so on. Portfolios are rebalanced period after period and markets change portfolio category frequently. Making use of their

¹See Shanken (1992) for insufficiencies related to the Fama-MacBeth procedure and possible corrections.

findings, we also assign currencies to portfolios conditional on nominal interest rate levels. The following section presents our data set and explains in detail how portfolios are constructed.

7.3 Data

Our analysis is based on weekly returns from June 23rd, 1978, to December 29th, 2006, which leaves us with a total of 1489 observations. Weekly data are chosen because we assume that skewness effects could level off at longer frequencies. A daily or hourly frequency might lead to even more distinctive results. That would, however, complicate timing calibration considerably because we are dealing with data from different markets trading in different time zones.

Datastream's total return index for global equities is used to calculate returns on the world market portfolio. Excess returns are obtained by subtracting 1-week Euromarket interest rates from global equity returns. Euromarket interest rates are obtained from the Financial Times, and the exchange rate data series is from Reuters. Both these sources are accessible via Datastream. Based on stocks listed on the NYSE, the AMEX and the NASDAQ, French (2008) publishes value-weighted return data on portfolios of small minus big (SMB) and value minus growth (HML) companies on his website.² Deviation from UIP is calculated as follows:

$$\Delta UIP_{t,t+1} = r_{t,t+1}^f - r_{t,t+1} + \ln(s_{t+1}/s_t) \quad (7.1)$$

where $\Delta UIP_{t,t+1}$ represents deviation from UIP between t and $t + 1$. $r_{t,t+1}^f$ is the foreign 1-week Euromarket rate, $r_{t,t+1}$ the corresponding domestic rate and s_t (s_{t+1}) the spot exchange rate at time t ($t + 1$).

Returns on foreign money market deposits are sorted into eight baskets on the basis of interest rate levels. More specifically, returns on money market deposits at time $t + 1$ from markets with the lowest interest rate levels at time t are assigned to portfolio “xxs”, time- $t + 1$ returns from markets with the second lowest interest rate levels at time t are sorted into portfolio “xs” and so on. This leaves us with eight portfolios going from “xxs” to “xl”. Portfolio constituents change periodically due to permanent rebalancing as a consequence of changing interest rate rankings. Return aggregation within portfolios is performed by calculating

²See Fama and French (1993) for a description of SMB and HML portfolios. French's data library is published on <http://mba.tuck.dartmouth.edu/pages/faculty/ken.french>

an equally weighted arithmetic average of $\Delta UIP_{t,t+1}$ in discrete terms. Portfolio construction serves several purposes. First and foremost, it captures pricing information inherent to interest rate levels. In fact, numerous studies have shown that interest rate levels at time t are useful predictors for deviation from UIP at time $t + 1$ (see, for instance, Fama 1984 or McCallum 1994). Our way of constructing portfolios is closely related to an instrumental variable approach conditional on interest rate differentials. In addition, return aggregation within portfolios softens the effect of outliers and other data irregularities. That enables us to focus on the core of the matter, viz. deviation from UIP due to systematic risks as opposed to idiosyncratic shocks. Another advantage is that portfolio formation allows us to handle a large cross-section of markets without leading to trouble for estimation. Traditional studies based on individual currencies instead of portfolios would experience an explosion of variance-covariance relationships if they tried to handle an equally large system of assets. The large number of moment restrictions would render estimation impossible. Finally, the availability of time series data on exchange and interest rates differs across countries. For many emerging market countries we have not been able to recover short-term interest rate and exchange rate data for the 1970s or 1980s. The reason is that some of the countries considered had a fixed exchange rate regime or capital controls in earlier times. In other countries, there did not yet exist a comparable short-term credit market. Moreover, time series for countries belonging to the Euro area need to be curtailed to the period prior to the introduction of the single currency market. If, by contrast, estimations were conducted on individual currency markets, such data shortages would force us to either shorten the length of all time series or to reduce the number of markets considered. Portfolio formation circumvents difficulties related to data shortage while allowing us to incorporate a large panel of observations. Our portfolios are based on data from 27 markets, both from industrialized as well as emerging market countries. The selection of countries and periods is mainly based on the availability of 1-week Euromarket or comparable interest rates. The following markets and periods are included: Australia [11.04.97 - 29.12.06], Argentina [02.05.97 - 29.12.06], Belgium [23.06.78 - 01.01.99], Canada [23.06.78 - 29.12.06], Denmark [21.06.85 - 29.12.06], Euro zone [01.01.99 - 29.12.06], Finland [20.01.95 - 29.12.06], France [23.06.78 - 01.01.99], Germany [23.06.78 - 01.01.99], Hong Kong [13.03.87 - 29.12.06], Hungary [15.09.95 - 29.12.06], Italy [23.06.78 - 01.01.99], Japan [11.08.78 - 29.12.06], Malaysia [20.08.93 - 29.12.06], Netherlands [23.06.78 - 01.01.99], New Zealand [11.04.97 - 29.12.06], Norway [11.04.97 - 29.12.06], Poland [11.06.93 - 29.12.06],

Singapore [09.01.87 - 29.12.06], Spain [27.12.91 - 29.12.06], Sweden [11.12.92 - 29.12.06], Switzerland [23.06.78 - 29.12.06], Taiwan [21.01.00-29.12.06], Thailand [14.01.05 - 29.12.06], Turkey [09.08.02 - 29.12.06], USA [23.06.78 - 29.12.06], UK [23.06.78 - 29.12.06]. Due to the fact that we are unable to recover data from all 27 markets for the entire observation period, the number of deposits considered changes as time passes. This should not constitute a problem for the empirical analysis.

7.4 Preliminary Analysis

The upper left panel of figure 7.1 displays average deviation from UIP in percentage p.a. for eight foreign money market portfolios. The first portfolio on the left, entitled “xxs”, is based on 1-week Euromarket deposits in those foreign currencies where interest rate levels are at the lowest. The figure shows that an USD investor would have suffered an average underperformance of more than 4% p.a. in comparison to a domestic investment by holding the “xxs” basket over the period from June 1978 to December 2006. The “xl” basket on the very right shows that money market deposits in high interest rate markets overperformed by almost 5.7% compared to USD deposits. An almost monotonic upward trend can be observed when moving from low- to high-yield portfolios. Hence, figure 7.1 provides an illustrative presentation of the well-known UIP puzzle saying that high-yield currencies tend to appreciate, and that low-yield currencies tend to depreciate. If, on the other hand, UIP held permanently, one would not observe return differentials between low-yield, high-yield and domestic deposits. In such a world, all bars in figure 7.1 would disappear. Note that the UIP puzzle emerges also if the perspective of an EUR or GBP investor is taken. This can be seen from figures 7.3 and 7.5 shown in the appendix to this chapter.

The UIP puzzle is empirically well-established, and there exists an extensive body of literature aiming at its solution. It is therefore surprising that, to the best of our knowledge, nobody has yet tried to relate the phenomenon to third and fourth moments in return distributions. As a matter of fact, low- and high-yield deposits seem to exhibit distinctively different skewness and kurtosis features. The lower left panel of figure 7.1 clearly shows that low-yield portfolios tend to be positively skewed while high-yield portfolios exhibit negative skewness. For portfolios in the middle, we obtain a skewness value of approximately zero, which indicates that return distributions are fairly symmetric. In short, we can say that skewness decreases more or less continuously as one moves from “xxs” to “xl”

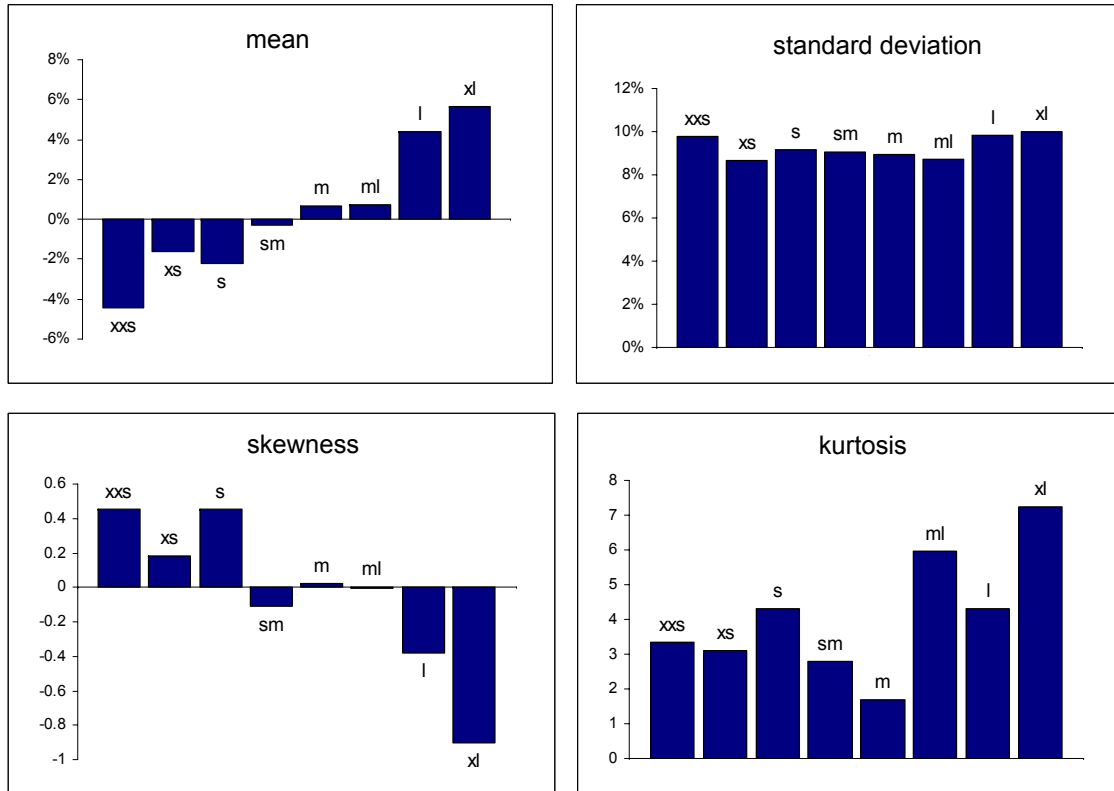
USD perspective

Figure 7.1: Moments of the return distribution from speculation against UIP in USD per annum. The eight portfolios shown are sorted on the basis of interest rate levels at time $t-1$ and range from “xxs” to “xl”. The “xxs” portfolio adds up returns of deposits within the lowest interest rate level basket, whereas the “xl” portfolio adds up returns of deposits in the highest interest rate level basket.

portfolios. The skewness phenomenon is not limited to returns in USD terms and is also evident on the lower left panel of figure 7.3 and figure 7.5 from the perspective of an EUR and a GBP investor, respectively (see appendix). Risk-averse investors dislike negative skewness because it exposes their wealth to large potential losses. The upward slope in mean returns shown on the upper left panel is maybe simply a compensation for the downward slope in skewness. That is the hypothesis we are going to test in subsequent sections.

The fourth moment, kurtosis, might also be of relevance. A large kurtosis signals fat tails, which means that returns fluctuate widely around means. Intuition suggests that agents do not appreciate large values for kurtosis since it exposes their wealth to extreme outcomes. We observe an increase in kurtosis as we move from low to high-yield deposits, irrespective of which investor’s viewpoint is taken. That finding is graphically illustrated on the lower right panel of figures 7.1, 7.3

and 7.5. For the EUR investor, for instance, we obtain a kurtosis of slightly more than 15 for the “xl” portfolio compared to only 4 for the “xxs” investor. A kurtosis of 15 seems extremely large if one considers that a normal distribution has a kurtosis of 3. A similar pattern emerges from the viewpoint of an USD and GBP investor. We refrain from including kurtosis in our pricing framework. The reason is that we believe that a cubic kernel specification, necessary to capture cokurtosis, could induce multicollinearity in explaining variables. The empirical analysis is thus restricted to systematic covariance and systematic coskewness risks. In the next section, we present a Fama-French CAPM extension, and we explain in more detail how coskewness and cokurtosis enter pricing kernels.

7.5 Skewness Preference and other CAPM Extensions

In virtually all asset pricing models, a risk premium arises due to correlation between payoffs and movements in model-specific risk factors. The CAPM requires assets exhibiting positive correlation with equity markets to pay a return in excess of the risk-free rate. This outperformance can be interpreted as a compensation for adding variance or fluctuation to the wealth portfolio of the representative investor. The CAPM, which was introduced independently by Sharpe (1964) and Lintner (1965), is based on Markowitz’s (1952) landmark article on portfolio selection. Soon after its introduction, the CAPM met with strong criticism, both on empirical and theoretical grounds. Friend and Blume (1970) and Fama and MacBeth (1973) report, for instance, that the intercept in the CAPM expression differs significantly from zero, which it should not according to theory. In addition, the CAPM has come under attack by research showing that company characteristics such as size and book-to-market or price-to-earnings ratios bear explanatory power for the cross-section of equity returns even after accounting for covariance exposure with equity markets. In an influential article, Fama and French (1992) show that as soon as one controls for size, defined as the stock price times the number of shares outstanding, the CAPM’s β does not matter any more. The direction of the size effect is such that small firms outperform large firms on average. Fama and French identify another pricing factor which seems to bear importance, viz. book-to-market equity (BE/ME). Growth stocks characterized by a low BE/ME ratio seem to yield lower returns than value stocks with a relatively large BE/ME. In response to their evidence, Fama and French (1993) propose the use of a three-factor model where they advocate extending the standard CAPM by so-called SMB- and HML-factors. Whereas the SMB-

factor measures the return differential between small and large company stocks, the HML-factor captures the return differential between value and growth stocks. The three-factor model performs surprisingly well in equity pricing exercises but it lacks theoretical underpinning. In other words, there does not exist a convincing story which could explain systematic outperformance of small and value stocks. Under market rationality, one would assume that risk premia are eventually driven by macroeconomic risk factors. The question, therefore, is what underlying macroeconomic force causes size and HML effects.

Kraus and Litzenberger (1976) propose another interesting CAPM extension. Empirically, their model is just as successful as the Fama-French three factor framework, and it comes with the advantage of being based on theoretically sound assumptions. Kraus and Litzenberger argue that Markowitz tells only part of the story because he assumes that portfolio optimization is a function of means and variances only. They suggest incorporating a second risk factor accounting for skewness. Skewness is a symmetry measure, which reveals whether a distribution is more biased to the right than to the left or vice versa. Under negative skewness, the probability of outperforming the mean is higher than the probability of ending up below. This implies that the median lies above the distribution's average. However, negative skewness signifies also that there is considerable downside risk exposing investors to potentially large losses. Under positive skewness, investors are more likely to make a large gain as opposed to a large loss. The bulk of the distribution is to the left, indicating that the median return is lower than the mean. According to Arditti and Levy (1972), representative agents characterized by non-increasing absolute risk aversion exhibit a preference for positive skewness. Kraus and Litzenberger show that systematic skewness can be captured by a two-factor specification where the risk premium does not only depend on the covariance with market returns but also on the covariance with squared market returns. In its unconditional form, the coskewness CAPM is defined as follows:

$$r_{i,t,t+1}^e = \lambda_0 + \lambda_1 \beta_i + \lambda_2 \gamma_i + \epsilon_{i,t,t+1} \quad (7.2)$$

where $r_{i,t,t+1}^e$ is the excess return on asset i between time t and $t + 1$, λ_1 is the market price for covariance risk, and λ_2 is the market price for coskewness risk. $\epsilon_{i,t,t+1}$ denotes the error term. Parameters β_i and γ_i measure asset i 's risk exposure and can be written as follows:

$$\beta_i = \frac{\sum_{j=1}^T (r_{i,t,t+1}^e - \bar{r}_i^e)(r_{m,t,t+1}^e - \bar{r}_m^e)}{\sum_{j=1}^T (r_{m,t,t+1}^e - \bar{r}_m^e)^2} \quad (7.3)$$

$$\gamma_i = \frac{\sum_{j=1}^T (r_{i,t,t+1}^e - \bar{r}_i^e)(r_{m,t,t+1}^e - \bar{r}_m^e)^2}{\sum_{j=1}^T (r_{m,t,t+1}^e - \bar{r}_m^e)^3} \quad (7.4)$$

where $r_{m,t,t+1}^e$ is the market excess return between time t and $t + 1$, and T denotes the number of time series observations. \bar{r}_m^e and \bar{r}_i^e represent mean market excess returns and mean excess returns on asset i , respectively. β_i increases with the asset's market exposure and corresponds precisely to the definition of the β in the standard CAPM. γ_i is a measure for systematic coskewness which can be shown to depend on the covariance between excess returns on asset i and squared market excess returns. Positive covariance with squared market excess returns means that an asset has a tendency to payoff in turbulent environments, i.e. when markets fluctuate wildly. That seems desirable since, intuitively, that should lead to a reduction in the wealth portfolio's skewness. As a consequence, one can expect that investors demand a lower or even a negative risk premium for assets exhibiting positive coskewness risk. Kraus and Litzenberger apply the coskewness CAPM to an analysis of returns on equity portfolios traded on the New York Stock Exchange (NYSE). In contrast to similar studies based on the standard CAPM, they do not reject the null hypothesis for the intercept term λ_0 . Furthermore, they obtain a significant risk premium for parameter values λ_1 and λ_2 . This leads them to the conclusion that the empirical failure of the single factor CAPM is due to model misspecification in terms of neglect of a systematic coskewness term.

Kraus and Litzenberger base estimations on the Fama-MacBeth estimation procedure (see Fama and MacBeth, 1973). In short, Fama and MacBeth propose to estimate β and γ for each asset individually, using time series data alone. Thereafter, the results for the estimates β and γ are used as regressors in a cross-sectional estimation with average excess returns as dependent variables. This leads to risk premia estimates for λ_0 , λ_1 and λ_2 . Although simple and intuitive, the Fama-MacBeth procedure has an important drawback, viz. the cross-sectional regression suffers from an errors-in-variable problem. The reason is that the second round estimation is itself based on estimates, namely on β and on γ .³ The transformation of the CAPM specification into a stochastic discount factor (SDF) representation offers an elegant way to circumvent errors-in-variables and difficulties related to its correction. Dittmar (2002) shows that the coskewness CAPM can be transformed by assuming that the SDF is a linear function of market and

³See Shanken (1992) for a description of the insufficiencies of the Fama-MacBeth procedure and for a possible correction of the errors-in-variable problem.

squared market excess returns:

$$m_{t,t+1} = a_0 + a_1 r_{m,t,t+1}^e + a_2 r_{m,t,t+1}^{e,2} \quad (7.5)$$

where $m_{t,t+1}$ is the stochastic discount factor or pricing kernel between time t and $t+1$, $r_{m,t,t+1}^e$ is the market excess return over the same period and a_0 , a_1 and a_2 are parameters. The pricing kernel represents the marginal rate of substitution of a representative investor between time t and $t+1$, which the coskewness CAPM assumes to be a function of market and squared market returns.

In a world without arbitrage, the SDF is strictly positive and prices all traded payoffs.⁴ This implies that the following equation must hold for all excess returns:

$$0 = E_t[m_{t,t+1} r_{i,t,t+1}^e] \quad (7.6)$$

Plugging equation 7.5 into equation 7.6 and expressing the result in terms of expectations and covariances, yields:

$$E(r_{i,t,t+1}^e) = \theta_1 \text{cov}(r_{i,t,t+1}^e, r_{m,t,t+1}^e) + \theta_2 \text{cov}(r_{i,t,t+1}^e, r_{m,t,t+1}^{e,2}) \quad (7.7)$$

where θ_1 and θ_2 are functions of the parameters a_0 , a_1 and a_2 and of the expected value for the pricing kernel, $E_t(m_{t,t+1})$. The quadratic pricing kernel relates expected excess returns linearly to a covariance term with market as well as with squared market returns. Note the similarity between equation 7.7 and equation 7.2 in Kraus and Litzenberger's CAPM specification. The latter is also a linear expression in covariances between returns on asset i and returns on the market portfolio and between returns on asset i and returns on the squared market portfolio.

Harvey and Siddique (2000) estimate a coskewness CAPM and obtain promising results when pricing equities. Their paper differs from Kraus and Litzenberger's in that they analyze conditional coskewness, which means that they account for time-variation in coskewness exposure. Their results show that coskewness bears considerable explanatory power for the cross-section of equity returns, even after accounting for size and book-to-market factors. Interestingly, coskewness seems to be related to size, book-to-market and momentum factors. Small firm portfolios, for instance, exhibit negative coskewness on average, whereas

⁴For a formal proof, see Cochrane (2001), chapter 4.

large firm portfolios tend to be positively skewed. Hence, the coskewness premium might take us a step closer to the solution of the size conundrum. Another interesting extension is proposed by Dittmar (2002), who advocates using a cubic SDF specification. The cubic kernel does not only account for systematic covariance and coskewness but also for systematic cokurtosis with market excess returns. Dittmar shows that incorporating a squared as well as a cubic term results in a much better fit of portfolio returns in comparison to the standard CAPM. Dittmar performs estimation by applying Hansen and Singleton's (1982) general methods of moments (GMM) procedure. Similarly to Harvey and Siddique, he estimates a conditional model and scales moments with various instruments.

7.6 Estimation Procedure

In light of the promising results reported by Kraus and Litzenberger (1976), Harvey and Siddique (2000) and Dittmar (2002), who all successfully apply the coskewness CAPM to the pricing of equity portfolios, we assume that the model also improves our understanding of currency risk premia. After all, under no-arbitrage, risk factors capturing risk premia in equity markets should also explain risk premia in other markets. Put differently, no-arbitrage guarantees that the SDF prices all traded assets and returns including excess returns on money market deposits denominated in foreign currency. For foreign money market investments, equation 7.6 can be written as follows:

$$0 = E_t \left[m_{t,t+1} \left(r_{t,t+1}^f \frac{s_{t+1}}{s_t} - r_{t,t+1} \right) \right] \quad (7.8)$$

where $r_{t,t+1}^f$ denotes the nominal interest rate on the foreign money market deposit between t and $t+1$, $r_{t,t+1}$ is the interest rate on the corresponding domestic deposit and s is the spot exchange rate. The expression within the round brackets corresponds to deviation from UIP, which could alternatively be expressed in terms of the forward rate bias. In that case, it would be a function of forward and spot exchange rates. To simplify notation, we henceforth use the symbol ΔUPI_{t+1} to denote deviation from UIP. We can now replace $m_{t,t+1}$ with a pricing kernel representation of our choice. In the empirical part, we compare estimations from four different kernel specifications. We first postulate that $m_{t,t+1} = a_0 + a_1 r_{m,t,t+1}^e$, which leads to the standard CAPM. We also plug in $m_{t,t+1} = (a_0 + a_1 r_{m,t,t+1}^e + a_2 r_{SMB,t,t+1}^e)$, where $r_{SMB,t,t+1}^e$ captures the Fama-French size effect. We estimate another two-factor specification taking account of the value effect by setting $m_{t,t+1}$

to $(a_0 + a_1 r_{m,t,t+1}^e + a_2 HML, t, t+1^e)$. Results from these models are compared to those obtained for the coskewness CAPM whose pricing kernel is defined in equation 7.5. In theory, one should choose the kernel specification providing the best description of the intertemporal rate of marginal utility of the representative agent. Unfortunately, marginal utilities cannot be measured directly, and a proxy needs to be specified. The CAPM assumes that marginal utilities are driven by returns on equity markets alone. That is a simplification because utility does also depend on other asset classes such as real estate or human capital. Difficulties related to the measurement of these latter asset classes force us, however, for reasons of practicality, to define the market portfolio solely in terms of global equity market returns.

We apply Hansen and Singleton's (1982) general method of moments (GMM) to estimate linear factor models in SDF representation. The SDF specification is not affected by the errors-in-variable problem encountered by Kraus and Litzenberger (1976), who applied the Fama-MacBeth procedure. Moreover, the SDF-framework allows incorporating conditional information by scaling moments with instruments. We now briefly explain GMM estimation by taking the coskewness kernel as an example. If the quadratic SDF defined in equation 7.5 is plugged into equation 7.8, we obtain:

$$0 = E_t[(a_0 + a_1 r_{m,t,t+1}^e + a_2 r_{m,t,t+1}^{e,2})(\Delta UPI_{t,t+1})] \quad (7.9)$$

In its exactly identified form, GMM chooses parameters a_0 , a_1 and a_2 such that equation 7.9 aggregates to zero. One usually needs to handle more moments than parameters, which means that one faces an overidentified system. We manoeuvre eight restrictions, one for every foreign money market portfolio, but we can only choose three parameter values. In such settings, it is obviously impossible to satisfy all moment restrictions and GMM can only try to make moments fit as close as possible. The econometrician can influence optimization by telling the estimator if a certain moment restriction should bear more or less importance. For a better understanding of optimization dynamics, it might be useful to apply a mathematical representation. GMM minimizes the following expression by running a simplex search method:⁵

$$\min_a (g_T(a)' W^{-1} g_T(a)) \quad (7.10)$$

⁵Matlab's optimization function `fminsearch` is used. See the documentation of the Optimization Toolbox and the references therein for a description of the `fminsearch` optimization procedure.

where $g_T(a)$ represents the vector of moment conditions with each entry corresponding to a moment restriction as defined on the right hand side of equation 7.9. GMM estimates parameters a by minimizing sample averages of g_T . W serves as weighting scheme, assigning more or less importance to certain moments. For reasons explained hereafter, we perform all estimations with three different weighting matrices, viz. with the asymptotically efficient weighting matrix, with a matrix assigning equal weights to all moments and with Hansen and Jagannathan's (1997) matrix of second-moments.

Once a is estimated, we can evaluate the fit of the model by running a J-test. If optimal weights are used, the J-value is basically obtained by multiplying expression 7.10 by the number of time series observations:

$$J = T \min_a (g_T(a)' S_0^{-1} g_T(a)) \quad (7.11)$$

where S_0 denotes the optimal weighting matrix explained subsequently. Since g_T can be interpreted as a vector of errors, the J-value corresponds to a distance measure whose value decreases as the model's fit improves. The J-value follows a χ^2 distribution. The J-test is slightly more involved if equal or Hansen-Jagannathan weights are used. For that case, see Cochrane (2001), who provides a good description of the test under general weights.⁶ The next section explains the estimation procedure for all three weighting schemes and balances the pros and cons of using one or another.

7.6.1 “Optimal” versus Prespecified Weights

In overidentified systems, GMM estimation is usually based on a two-step procedure. In the first round, expression 7.10 is minimized by assigning equal weights to all moments. W thus corresponds to the identity matrix. The first-round optimization generates errors, g_T , whose variance-covariance matrix, S_0 , serves again as weighting scheme in a second round optimization. Analogously to generalized least squares (GLS), the two-step procedure puts more weight on statistically relevant moments. Due to its efficient processing of information, it is sometimes referred to as being optimal, but that is only meant in a strictly statistical sense. In fact, there sometimes exists good reason for choosing a different weighting scheme because statistical relevant moments not always correspond to economic relevant moments. Another drawback of the optimal procedure is that it does not allow comparing test statistics across different model specifications. The reason is

⁶See Cochrane (2001), chapter 11

that different models lead to different errors and therefore different second round weighting matrices, S_0 , which renders comparability of J -values across models impossible. To understand that, note that the J -value defined in equation 7.11 decreases for one of two reasons: First, due to a better fit of the model and consequently lower values for g_T and second, simply as a consequence of a larger error variance-covariance matrix, S_0 . When running a “horse race” between different models, one is only interested in goodness-of-fit measures, which show up in g_T , but the J -statistic does not reveal whether it decreases as a consequence of g_T or S_0 . It might happen that a certain model specification leads to a boost in S_0 and consequently to a lower J -value without reducing errors, g_T . Fortunately, we can apply alternative weighting schemes, which allow comparing J -values across different models. These alternatives have in common that they are based on a one-step procedure. As a consequence, the W -matrix remains constant as one switches from one model to another. An obvious alternative is the use of the identity matrix, which assigns equal weights to all moments. This procedure corresponds to an OLS cross-sectional regression of mean deviation from UIP on covariances. A second alternative is Hansen and Jagannathan’s (1997) second-moment matrix, which is defined as follows:

$$W = E(\Delta UIP \cdot \Delta UIP')^{-1} \quad (7.12)$$

Hansen and Jagannathan motivate their choice by showing that the second-moment matrix can be interpreted as an interesting distance measure between the space of the true SDF and the SDF used.

7.7 Results

This section presents results for the standard one-factor CAPM, Fama-French extensions thereof as well as for the coskewness CAPM. All estimations are based on optimal, equal and Hansen-Jagannathan weights. We take account of heteroskedasticity and autocorrelation by applying the Newey-West estimator (see Newey and West, 1987), where the optimal lag length of the error variance-covariance matrix is governed by the Bartlett kernel. Newey-West ensures heteroscedasticity and autocorrelation consistent estimates and test statistics. In contrast to most other studies, we do not restrict analysis to the perspective of an USD investor but additionally report results from the viewpoint of an EUR and a GBP investor. Since our response variable, deviation from UIP, is an excess return, a

normalization for the kernel parameter a_0 needs to be chosen.⁷ We set $a_0 = 1$ and run estimations for a_1 in the CAPM setting and for a_1 and a_2 in the Fama-French and the coskewness framework.

7.7.1 Standard versus Coskewness CAPM

Table 7.1 shows the estimation output for the standard CAPM from the perspective of an USD investor. The standard model is strongly rejected, irrespective of the weighting scheme used. This can be seen from the p-values for the χ -square distributed J -statistics, which are all close to zero. The CAPM apparently provides a poor explanation for the forward rate anomaly. The R-squared statistic, shown for the equally weighted scheme, shows that the standard CAPM captures less than 1% of the total variation in deviation from UIP. Although the model is clearly rejected, parameters bear correct signs: All a_1 -estimates are negative. This means that portfolios with a more positive covariance with equity market returns pay a positive excess return on average and vice versa for portfolios exhibiting a negative covariance exposure to stock markets. Parameter estimates are not significant, with t-values gravitating between -0.31 (equal weights) and -1.19 (optimal weights). The model's failure shows up illustratively on the left hand panel of figure 7.2, depicting model predictions from the equally weighted scheme against deviation from UIP. If the model provided a perfect description, all dots would form a line with a slope of 45 degree. By contrast, the scatter cloud lies horizontally here, which indicates that there does not exist any relationship between actual returns and model predictions. Our results corroborate Bansal and Dahlquist (2000), who find that the CAPM cannot explain deviation from UIP.

The explanatory power of the model improves substantially if we add squared market returns to the pricing kernel. That can be seen from table 7.2 which presents results for the coskewness CAPM from the viewpoint of an USD investor. Irrespective of the weighting scheme used, the augmented model is not rejected. When optimization is based on optimal or equal weights, we receive χ -square values that are much lower than what the 5% significance level would imply. We do neither reject the model for the Hansen-Jagannathan scheme although there the p-values are closer to rejection. In short, we can say that the J -value, which amounts to a difference measure between actual returns and model predictions, is fairly low. That is remarkable because the output signals that the skewness factor is significantly larger than zero. More specifically, the null hypo-

⁷Cochrane, p. 256 (2001) notes that some arbitrary parameter identification is required in systems including excess returns only.

Standard CAPM			
weights	optimal	equal	HJ
a_1	-5.58	-1.51	-3.51
stddev	4.70	4.83	4.75
t-stat	-1.19	-0.31	-0.74
p-value	0.24	0.75	0.46
chi-square	32.26	44.41	43.81
chi p-value	0.00	0.00	0.00
R^2		0.01	
adj. R^2		-0.15	

Table 7.1: Results for the standard CAPM in USD

thesis for the coskewness premium, a_2 , is rejected at the 5% significance level for the optimal and equal weighting scheme and at the 10% significance level for the Hansen-Jagannathan estimate. The significance of t - as well as J -statistics provides evidence that the low J -value is not simply the consequence of an increase in noise and thus an increase in the weighting matrix S_0 or W (see equation 7.11). If that were the case, we would expect insignificant coefficient estimates, with t -statistics driven down by large error terms. Significance in both statistics thus indicates that the J -value mainly reflects the model's goodness-of-fit. The signs of the parameters a_1 and a_2 are as expected. Foreign money market investments

Coskewness CAPM						
	optimal weights		equal weights		HJ-weights	
	a_1	a_2	a_1	a_2	a_1	a_2
params	-16.88	2697.64	-8.67	1928.28	-7.90	1320.16
stddev	9.44	869.81	8.76	873.66	7.22	722.89
t-stat	-1.79	3.10	-0.99	2.21	-1.09	1.83
p-value	0.07	0.00	0.32	0.03	0.27	0.07
chi-square	4.39		8.28		12.42	
chi p-value	0.62		0.22		0.05	
R^2			0.57			
adj. R^2			0.40			

Table 7.2: Results for the coskewness CAPM in USD

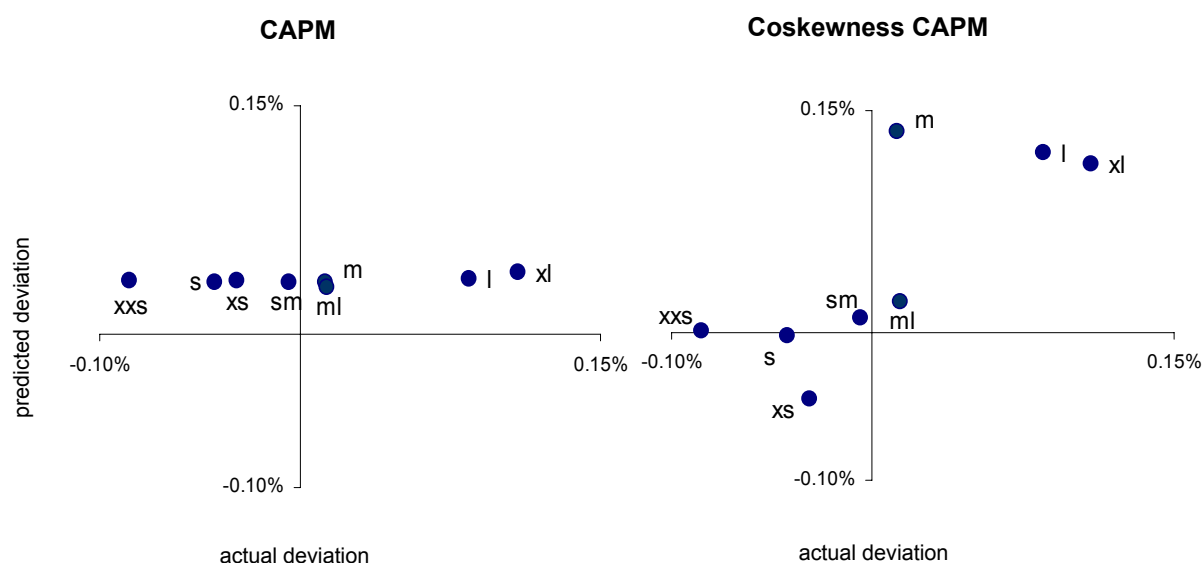


Figure 7.2: Predicted versus actual deviation from UIP in USD for the CAPM (left) and the coskewness CAPM (right)

exhibiting positive correlation with equity markets should yield a positive risk premium on average, which implies a negative sign for a_1 . On the other hand, investments exhibiting positive coskewness should trade at a discount, leading to a positive sign for a_2 . To understand the coskewness factor, note that assets characterized by positive coskewness tend to perform well in turbulent market periods. Since that is a desirable attribute, investors are willing to hold such assets despite their relative underperformance. Moving from the standard to the coskewness specification improves explanatory power considerably. The R-squared of the standard CAPM is close to zero, whereas we now obtain a R-squared of 57% for the equally-weighted scheme. For enhanced comparability with the standard CAPM, which is a one-factor specification, we additionally report adjusted R-squares. The latter penalize for increasing the number of explanatory variables. Whereas the adjusted R-squared turns out to be slightly negative for the standard model (-15%), the corresponding measure amounts to 40% for the coskewness CAPM. The improvement in performance does also emerge on the right hand side of figure 7.2, which now depicts an upward pointing scatter cloud.

Compared to the sobering results from previous investigations applying the CAPM to the pricing of currency risk,⁸ the coskewness extension leads to a considerable gain in explanatory power. That holds at least for returns denominated in USD. To test the robustness of the model, we subsequently run the same analysis from the viewpoint of an EUR and from the viewpoint of a GBP investor. The results for the standard specification are reported in tables 7.5 and 7.7 shown in the appendix to this chapter. The R-squared is zero from the perspective of an EUR investor, which indicates that the one-factor CAPM does not explain anything. Explanatory power is slightly better from the viewpoint of an GBP investor where the R-squared amounts to 5%. Given the small fraction in total variation explained, it is not surprising that J-tests reject the standard CAPM, irrespective of the weighting scheme used or of the currency perspective taken. In all estimations, parameters turn out to be insignificant. For the GBP investor, the market risk premium is positive, which runs against theory because it would imply that agents appreciate positive covariance with equity market returns.

The coskewness specification leads to a considerable improvement of the model's explanatory power. That is notably true if returns are denominated in GBP. From the GBP perspective, we obtain an R-squared of 82% and a distance measure which is considerably lower than what would be implied by the 5% confidence level. Note as well that the coskewness premium, a_2 , is positive and significant, irrespective of the weighting scheme used, and that the covariance premium, a_1 , now bears the correct sign. From the perspective of an EUR investor, the results are somewhat less impressive although still considerably better than those from the one-factor specification. The coskewness coefficients bear the correct sign and are highly significant. That cannot be said for the covariance coefficient, which turns out to be positive, albeit insignificantly so. The coskewness CAPM in EUR terms explains approximately one third of the total variation, independent of the weighting matrix used. The adjusted R-squared is relatively low (11%) although still much higher than in the standard CAPM (-17%). The model is rejected at the 5% significance level under optimal and Hansen-Jagannathan weights but is not rejected under equal weights.

7.7.2 Fama-French HML- and SMB-Factors

Besides testing whether deviation from UIP can be explained by systematic covariance and systematic coskewness, we examine here the explanatory power of

⁸See, for example, McCurdy and Morgan (1991) or Bansal and Dahlquist (2000).

the Fama-French SMB- and HML-factors (see Fama and French (1992)). Numerous studies find that these factors can successfully price equities. SMB- and HML-returns are thought to capture unknown macroeconomic risks. If deviation from UIP is subject to the same risk drivers, the Fama-French factors should also explain variation in currency risk premia.

Table 7.3 presents results for a CAPM-like specification with two factors. The first parameter, a_1 , captures the risk premium for covariance exposure to equity markets and corresponds to β in the standard CAPM. The second parameter, a_2 , measures the premium for exposure to the HML-factor which is constructed along the lines of Fama and French (1993). Analogously, table 7.4 shows results from a two-factor estimation based on market and SMB-portfolio returns. For better comparability with the results of the coskewness CAPM, and due to the fact that the cross-section of our asset pool comprises eight portfolios only, analysis is restricted to a two-factor specification. That in contrast to Fama and French (1993), who propose the use of a three-factor model including market, HML- as well as SMB-portfolio returns. Returns on HML- and SMB-portfolios are published on the website of Kenneth French but unfortunately only for the US.⁹ For this reason, we limit here analysis to the perspective of an USD investor.

The model based on equity market and HML-portfolio returns generates an adjusted R-squared of 19% (see table 7.3). Although this is better than what we obtain in the standard CAPM (See table 7.1), explanatory power is still considerably lower than in the coskewness specification where the corresponding measure

⁹see <http://mba.tuck.dartmouth.edu/pages/faculty/ken.french>

HML-CAPM						
	optimal weights		equal weights		HJ-weights	
	a_1	a_2	a_1	a_2	a_1	a_2
params	-4.14	0.61	-0.80	1.05	-2.89	0.65
stddev	5.78	0.29	7.33	0.41	5.91	0.30
t-stat	-0.72	2.10	-0.11	2.54	-0.49	2.16
p-value	0.47	0.04	0.91	0.01	0.62	0.03
chi-square	18.64		14.00		21.43	
chi p-value	0.00		0.03		0.00	
R^2			0.42			
adj. R^2			0.19			

Table 7.3: Results for the HML-CAPM in USD

SMB-CAPM						
	optimal weights		equal weights		HJ-weights	
	a_1	a_2	a_1	a_2	a_1	a_2
params	-8.06	-1.07	-2.48	-1.59	-5.05	-1.00
stddev	7.11	0.49	9.66	0.71	7.07	0.47
t-stat	-1.13	-2.19	-0.26	-2.23	-0.71	-2.13
p-value	0.26	0.03	0.80	0.03	0.47	0.03
chi-square test	8.08		5.92		10.93	
chi p-value	0.23		0.43		0.09	
R^2			0.46			
adj. R^2			0.24			

Table 7.4: Results for the SMB-CAPM in USD

amounts to 40% (see table 7.2). The J -statistic, moreover, leads to a rejection of the HML-extension, irrespective of the weighting scheme used. The estimates bear the correct signs, and the risk premium for the exposure to the HML-factor, a_2 , is significantly different from zero. If the standard CAPM is extended by the SMB-factor instead, we obtain slightly better results. The SMB-model, shown in table 7.4, is not rejected, and the adjusted R-squared is higher than in the HML-specification. Despite these improvements, we still do not reach the R-squared reported for the coskewness specification.

7.7.3 Introducing Instruments

In a world without arbitrage, the expected product between pricing kernels and deviation from UIP is zero (see equation 7.8). The GMM estimator chooses parameters such that equation 7.9 fits as close as possible. Thereby, it is assumed that the product of discount factors times excess returns is independently and identically distributed (iid) - only under that assumption, can one run estimations by simply minimizing sample averages. The iid-assumption is a good approximation for returns from our portfolios. After all, we control for interest rate differentials as predictors for deviation from UIP. That is done by forming portfolios on the basis of interest rate levels which amounts to an indirect way of conditioning information. In excess of using interest rates, it is extremely difficult to exploit information sets in order to predict deviation from UIP. Instead of forecasting returns, it might be more promising to focus on the prediction of pricing kernels. The

latter capture marginal rates of intertemporal substitution and are, intuitively, more likely to exhibit predictable patterns. Predictability implies that expectations in equation 7.8 change according to agent's information set. Consequently, it is incorrect to base minimization on simple averages and one needs to account for conditional information instead. That is usually done by scaling returns by instruments. Instruments are variables bearing explanatory power for the prediction of the joint distribution of returns times pricing kernels. In a GMM framework, conditional information can be easily incorporated by multiplying both sides of equation 7.8 by an instrument vector z_t .

We separately apply the TED- and the term-spread as instrumental variables. Both are thought to bear information on future business-cycle conditions, which should in theory lead to a more accurate measure for agents' intertemporal rate of marginal substitution. In fact, Stock and Watson (1990) run a "horse race" between potential forecast variables and find that the TED- and the term-spread lead to better business-cycle predictions than most other instruments. Our estimation results do, however, not improve when instruments are included. For this reason, we do neither present nor comment estimations incorporating conditional information.

7.8 Conclusion

An analysis of the return distribution of foreign money market deposits reveals a negative relationship between skewness and performance, where performance is measured in terms of deviation from UIP. We find that low-yield deposits are more positively skewed than comparable investments denominated in high-yield currencies on average. This observation motivates us to examine the deviation from UIP within the framework of the coskewness CAPM. We therefore extend the pricing kernel of the standard CAPM by a second pricing factor accounting for squared market returns. The augmented framework enables us to capture exposure to systematic covariance as well as to systematic coskewness with equity markets. According to preference theory, investors worry about both these exposures which is why the quadratic specification provides a more accurate description of preferences. Besides having strong theoretical underpinnings, the coskewness CAPM performs surprisingly well empirically.

Recent evidence for the model's superior performance can be found in Harvey and Siddique (2000) and in Dittmar (2002). Both papers examine whether the coskewness specification can explain cross-sectional variation in equity returns.

To the best of our knowledge, we are the first to apply the model to the pricing of currency risk. We find that the coskewness CAPM explains a large fraction of the total cross-sectional variation in currency risk, and that the model performs considerably better than the standard CAPM or a Fama-French extension thereof. In fact, the J-test strongly rejects the standard specification but not its coskewness counterpart. The latter explains up to 57% of the total variation in currency risk premia from the perspective of an USD investor.

Our analysis is based on portfolios of currencies as proposed by Lustig and Verdelhan (2005). They advocate conditioning information by assigning money deposits to eight portfolios. The sorting is based on interest rate levels where the first portfolio contains deposits from the lowest-yielding currencies, the second from the second-lowest and so on. Basing analyses on portfolios instead of individual deposits serves several purposes. It allows using information implied by interest rate differentials. Portfolio construction, moreover, results in smoother time series since it moderates the impact of outliers. That leaves us with purer data reflecting deviation from UIP due to structural causes as opposed to idiosyncratic shocks.

To stress the robustness of the model, estimations are performed from the perspective of three different reference currencies, viz. the USD, the EUR and the GBP. GMM optimization is based on optimal as well as equal and Hansen-Jagannathan weights. Irrespective of the reference currency or the weighting scheme used, all estimations provide qualitatively similar results. We conclude that the coskewness specification accounts for a surprisingly large fraction of the total variation in currency risk premia, and that it performs considerably better than the standard CAPM.

7.A Appendix

7.A.1 Viewpoint of an EUR Investor

Standard CAPM			
	optimal weights	equal weights	HJ-weights
a_1	-2.03	-2.56	-2.33
stddev	2.26	2.29	2.27
t-stat	-0.90	-1.12	-1.03
p-value	0.37	0.26	0.30
chi-square test	36.13	45.92	45.98
chi critical (5%)	14.07	14.07	14.07
chi p-value	0.00	0.00	0.00
R^2		0.00	
adj. R^2		-0.17	

Table 7.5: Results for the standard CAPM in EUR

Coskewness CAPM						
	optimal weights		equal weights		HJ-weights	
	a_1	a_2	a_1	a_2	a_1	a_2
params	2.11	1346.60	3.54	1695.51	1.00	964.98
stddev	4.41	502.74	5.17	640.78	3.70	454.36
t-stat	0.48	2.68	0.68	2.65	0.27	2.12
p-value	0.63	0.01	0.49	0.01	0.79	0.03
chi-square test	12.71		10.02		18.15	
chi critical (5%)	12.59		12.59		12.59	
chi p-value	0.05		0.12		0.01	
R^2			0.36			
adj. R^2			0.11			

Table 7.6: Results for the coskewness CAPM in EUR

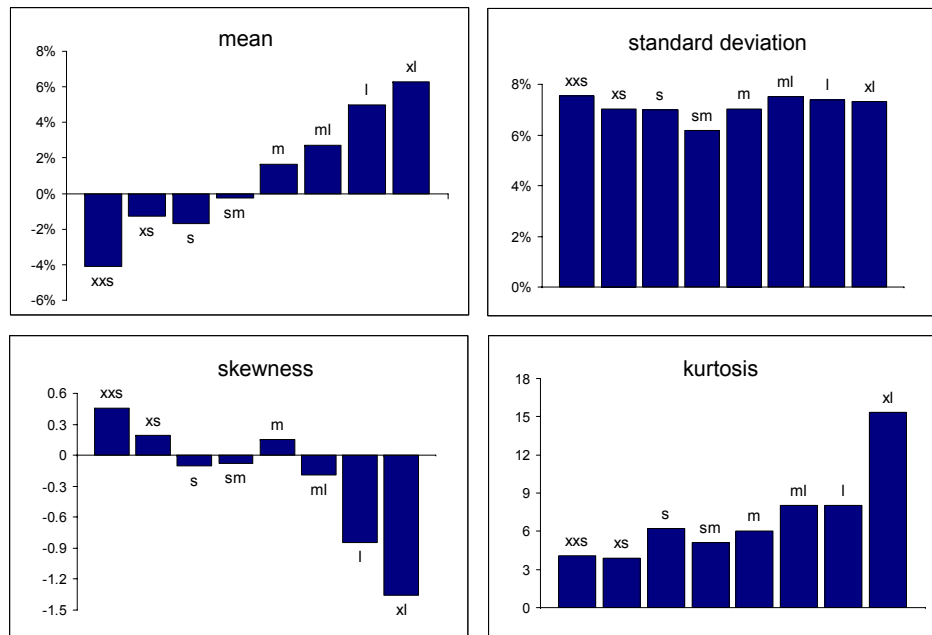
EUR perspective

Figure 7.3: Moments of the return distribution from the perspective of an EUR investor. See figure 7.1 for a more detailed description.

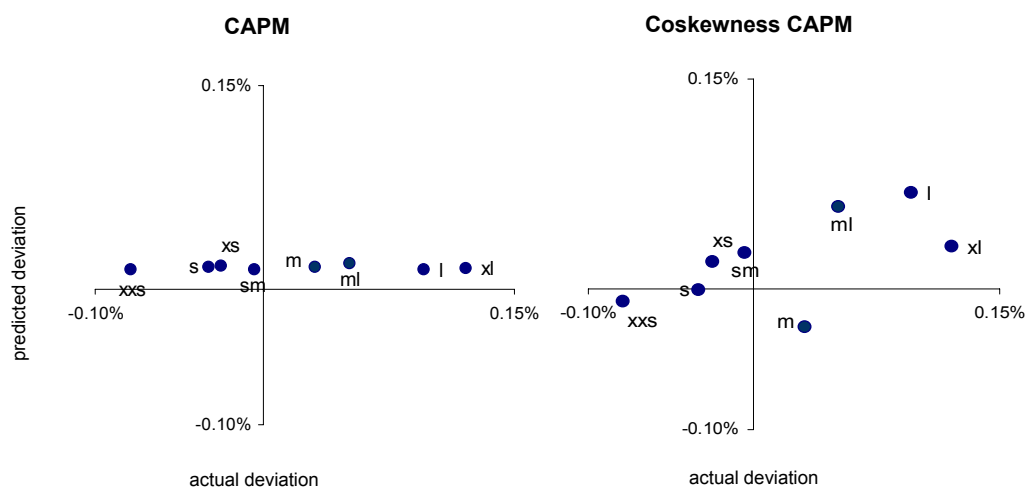


Figure 7.4: Predicted versus actual deviation from UIP in EUR for the CAPM (left) and the coskewness CAPM (right)

7.A.2 Viewpoint of a GBP Investor

Standard CAPM			
in GBP	optimal weights	equal weights	HJ-weights
a_1	3.97	5.26	3.85
stddev	2.94	3.13	2.99
t-stat	1.35	1.68	1.29
p-value	0.18	0.09	0.20
chi-square test	21.30	25.13	25.34
chi critical (5%)	12.59	12.59	12.59
chi p-value	0.00	0.00	0.00
R^2		0.05	
adj. R^2		-0.11	

Table 7.7: Results for the standard CAPM in GBP

Coskewness CAPM						
in GBP	optimal weights		equal weights		HJ-weights	
	a_1	a_2	a_1	a_2	a_1	a_2
params	-1.89	978.04	-4.25	1245.35	-3.08	1019.38
stddev	6.32	469.63	8.85	610.60	7.13	495.20
t-stat	-0.30	2.08	-0.48	2.04	-0.43	2.06
p-value	0.76	0.04	0.63	0.04	0.67	0.04
chi-square test	7.97		6.51		7.41	
chi critical (5%)	11.07		11.07		11.07	
chi p-value	0.16		0.26		0.19	
R^2			0.82			
adj. R^2			0.75			

Table 7.8: Results for the coskewness CAPM in GBP

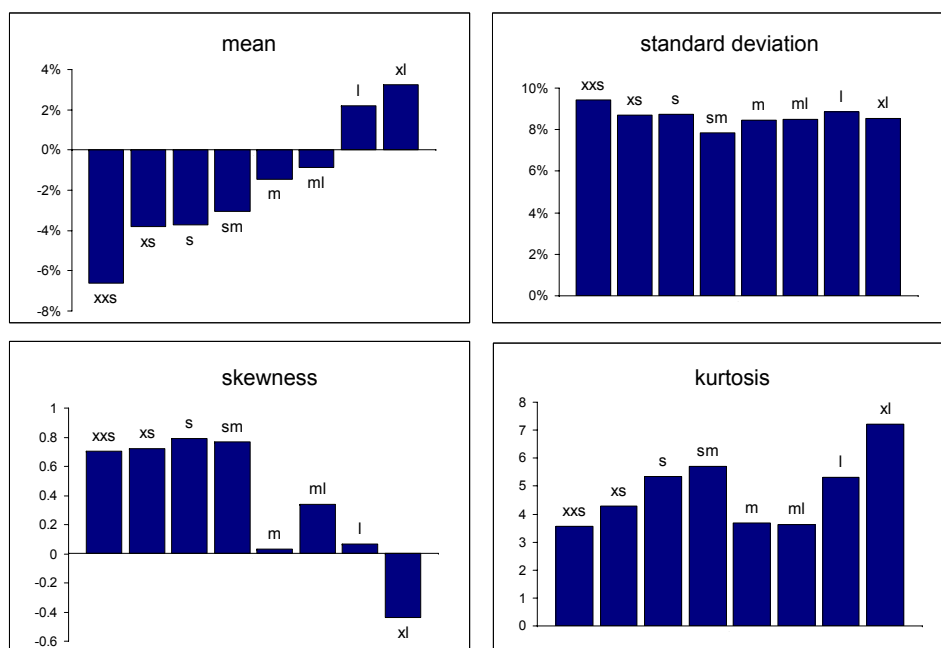
GBP perspective

Figure 7.5: Moments of the return distribution from the perspective of a GBP investor. See figure 7.1 for a more detailed description.

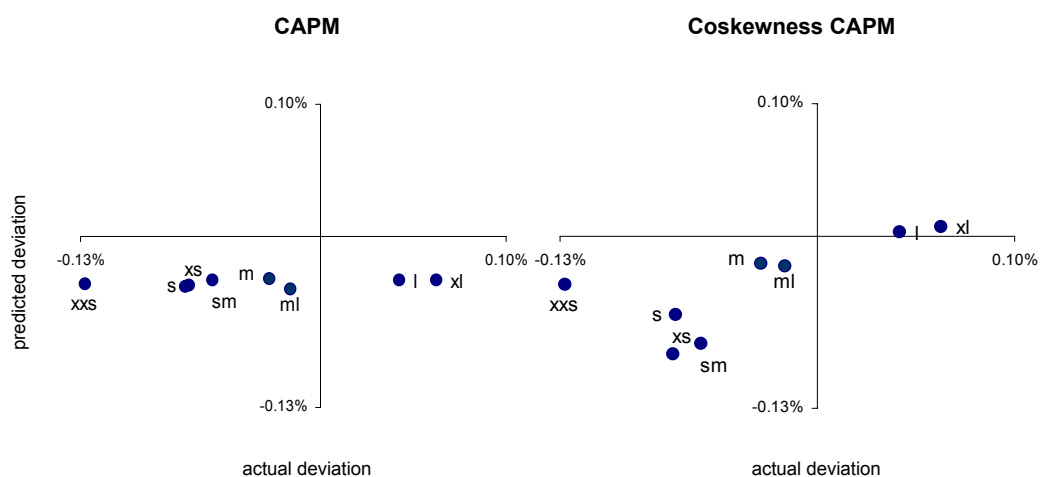


Figure 7.6: Predicted versus actual deviation from UIP in GBP for the CAPM (left) and the coskewness CAPM (right)

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Curriculum Vitae

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Education

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1998 – 2003	University of St. Gallen, Studies in Economics, Licentiate
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Recent Work Experience

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2006 – 2008	Zürcher Kantonalbank, Economic Research
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