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Implied Volatility Term Structure and Exchange Rate Predictability

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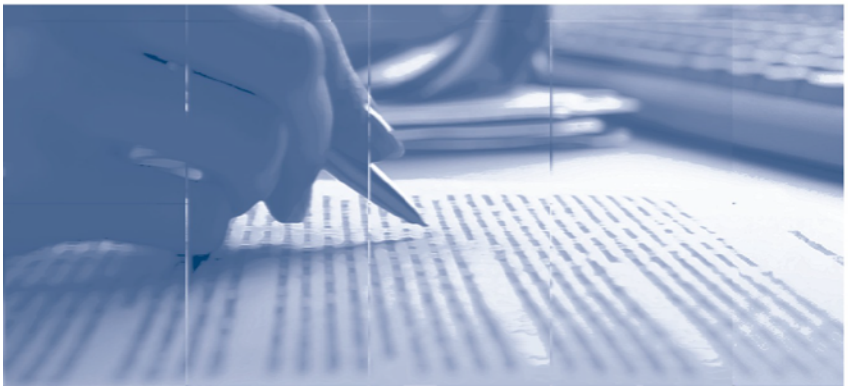

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Non-technical Summary

The prediction of future exchange rate returns has been on the attention of the academic literature for a long time. Many models based on implied volatility have arisen to try to capture the future path of the exchange rate, especially those focused on Volatility Risk Premium (VRP) ï the difference between the implied volatility and the realized volatility of the series.

This paper focuses on the predictive ability of the implied volatility term structure (IVTS) of several currency pairs against the US dollar on the future returns of those currencies. The IVTS is calculated considering 10 different maturities for the exchange rate options, ranging from one week to ten years. We use currencies from 10 developed countries and 8 emerging markets, and the results change significantly depending on the market.

The time series analysis, which focuses on the predictive ability of the IVTS on the 3- and 6-month future returns for all the 18 currencies, shows the difference in the results between developed economies and emerging markets. For developed economies, a high slope leads to low future returns, while for emerging markets the result is the opposite. The logic behind these results seems to be the high importance of the risk premium term in emerging markets when compared to developed economies. In emerging markets, high IVTS means high risk premium, which leads currencies to depreciate immediately and recover in the future, in line with the literature findings. For developed economies, as the risk premium term is not so important, a high slope means that current physical volatility is lower than the future expected one, which leads to lower future returns.

This paper also performs cross-section analysis, building currency portfolios based on the slope of the IVTS. For emerging markets, we buy 20% of the currencies with higher slope and sell 20% of them with lower slope. For developed economies, we buy 25% of the currencies with lower slope and sell 25% of them with higher slope. In this way, we build portfolios based on a new investment strategy and compare the performance to benchmark strategies from the literature. The results appear to be competitive.

We show that the correlation between these portfolios are high among the benchmark strategies and relatively low between the proposed strategy and the benchmark ones. This shows that the characteristics of the slope portfolios make them a good candidate for entering in mean-variance currency portfolios.

We also analyze our portfolios from the perspective of portfolio optimization, using efficient frontiers built with the portfolios we propose and the portfolios based on the common strategies proposed in the literature. The results indicate that the proposed strategy portfolio has a high weight on both the minimum variance portfolio and the higher risk portfolios, showing that the strategy is useful from the portfolio optimization perspective.

Sum§rio N«o t®cnico

A previs«o dos retornos de moedas tem chamado ¨ aten-«o da literatura acad°mica h§ muito tempo. Muitos modelos baseados na volatilidade impl²cita surgiram para tentar capturar a trajet· ria futura da taxa de c©mbio, especialmente aqueles focados no Pr°mio de Risco de Volatilidade (VRP) - a diferen-a entre a volatilidade impl²cita e a volatilidade realizada.

Este artigo tem como foco a capacidade preditiva da estrutura a termo da volatilidade impl²cita (ETVI) sobre os retornos de moedas. A ETVI ® calculada considerando 10 diferentes vencimentos para as op-»es de taxa de c©mbio contra o d· lar americano, variando de uma semana a dez anos. Calcula-se a inclina-«o dessa curva de volatilidade impl²citas em fun-«o do prazo de vencimento das op-»es, para cada moeda. Utilizam-se dois grupos de moedas: um composto por 10 de pa²ses desenvolvidos e outro por 8 de pa²ses emergentes. Curiosamente os resultados mudam significativamente dependendo do grupo de moedas. A an§lise ®feita com duas estrat®gias: s®rie temporal e corte seccional.

A an§lise em s®rie temporal foca na capacidade preditiva da ETVI nos retornos de 3 e de 6 meses para cada um das 18 moedas. Para as economias desenvolvidas, uma alta inclina-«o leva a baixos retornos futuros, enquanto para os pa²ses emergentes o resultado ®o oposto. A l· gica por tr§s desses resultados parece ser a alta import©ncia do pr°mio de risco de volatilidade nos pa²ses emergentes quando comparado ¨s economias desenvolvidas. Para os emergentes, a ETVI elevada significa pr°mio de risco mais alto, o que faz com que as moedas se desvalorizem imediatamente e se recuperem no futuro. J§ para economias desenvolvidas, como pr°mio de risco n«o ®t«o importante, uma alta inclina-«o significa que a volatilidade f²sica atual ®menor do que a esperada no futuro, o que leva a menores retornos futuros.

Este artigo tamb®m realiza um estudo de corte seccional, construindo carteiras *long-short* de moedas com base na inclina-«o da ETVI. Para os pa²ses emergentes, compramos 20% das moedas com maior inclina-«o e vendemos 20% delas com menor inclina-«o. Para as economias desenvolvidas, compramos 25% das moedas com menor inclina-«o e vendemos 25% delas com maior inclina-«o. Dessa forma, constru²mos portf· lios com base em uma nova estrat®gia de investimento e comparamos o desempenho com as estrat®gias de refer°ncia da literatura. Os portf· lios baseados na ETVI s«o bastante competitivos quando comparados com os portf· lios de refer°ncia, especialmente quando consideramos os retornos de varia-«o cambial.

Al®m disso, a correla-«o entre as estrat®gias baseadas na ETVI e as de refer°ncia ® relativamente baixa. Em um exerc²cio de otimiza-«o de portf· lio, constroem-se fronteiras eficientes com as carteiras de moedas, a-»es e t²tulos. Os resultados indicam que as estrat®gias de ETVI propostas t°m um peso alto tanto na carteira de vari©ncia m²nima quanto nas carteiras de maior risco, mostrando que a estrat®gia ®¼til a partir da perspectiva de otimiza-«o de portf· lio.

Implied Volatility Term Structure and Exchange Rate Predictability*

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Abstract

This paper provides empirical evidence of the predictive power of the currency implied volatility term structure (IVTS) on exchange rate behavior from both cross-section and time-series perspectives. Intriguingly, the direction of the prediction is not the same for developed and emerging markets. For developed markets, a high slope means low future returns, while for emerging markets this means high future returns. In order to analyze predictability from a cross-section perspective, we build portfolios based on the slope of the term structure, and thus present a new currency trading strategy. For developed (emerging) currencies, we buy (sell) the two currencies with the lowest slopes and sell (buy) those two with the highest slopes. The proposed strategy performs better than common currency strategies - carry trade, risk reversal and volatility risk premium - based on the Sharpe ratio, considering only currency returns, which supports the exchange rate predictability of the IVTS from a cross-section perspective.

Keywords: exchange rate predictability, implied volatility, risk premium

JEL Classification: G17, G15, G12, G11

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1. Introduction

The prediction of exchange rates can significantly help policy makers, firms involved in international trade, as well investment managers. However, forecasting exchange rate fluctuations has been challenging finance practitioners and academics for a long time (see, for instance, Meese and Rogoff, 1983 and Cheung et all, 2005). In this paper, we analyze the predictive ability of currency implied volatility term structure (IVTS) over currency returns. Specifically, we analyze the predictive ability of currency IVTS using both a time-series and cross-section perspective. Our results are different for developed (G-10) and emerging market currencies. For developed countries, a steep term structure means negative future returns, and currencies with high slopes underperform those with low slopes. For emerging currencies, the results are inverted, i.e., the steeper is the slope, the higher will be future returns.

The term structure of option-implied volatilities has been studied since the 1980s based on the works of Poterba and Summers (1986) and Stein (1989). The focus of earlier studies was on the relationship between short- and long-term volatilities for equity markets. Stein (1989) and Diz and Finucane (1993) analyzed the possible overreaction of long-term volatilities due to short-term volatility shocks. Heynen et al. (1994) fitted several models for the term structure of volatilities, including mean-reversion and e-GARCH. Xu and Taylor (1995) and Krylova et al. (2005) focused on currency options and tried to model the term structure. These authors also analyzed the cross-dynamics of volatility term structure between different currencies.

More recent papers have attempted to predict the future shape of the volatility surface, i.e., both the moneyness shape and term structure. This is the case of Chalamandaris and Tsekrekos (2010, 2011) and Guo et al. (2014) for currency options. From the perspective of practitioners, several papers have analyzed the VIX[1] and VIX future term structures, trying to infer future movements in the spot VIX and physical volatility (Buetow and Hendenrson, 2016; Luo and Zhang, 2012) and in the spot equity index (Fassas, 2012).

[1] VIX is the CBOE Volatility Index. It is a measure of the U.S. stock market implied volatility, calculated and published by the Chicago Board Options Exchange.

The paper of Della Corte et al. (2017) is closely related to ours. The authors also form portfolios based on the term structure of implied volatility. Their empirical evidence ï which uses emerging and developed currencies - is consistent with our emerging market sample results, i.e., a steep term structure leads to higher future returns. However, for developed countries, our results and theirs contrast. Several methodological differences could explain discrepancies in the results. First, we explicitly separate emerging and developed countries, while they combine them. Second, their sample starts eight years before ours, when implied option data was available almost exclusively for developed countries. Since Della Corte et al. (2017) include new currencies as data become available, their sample may have a composition bias. Third, they use a model-free implied volatility, while we account for differences on the left and rights tails, i.e., calls and puts. By splitting model-free implied volatility into the middle, left and right of the distribution, we are able to gather insights regarding the slope predictability. In fact, our results uncover different predictive abilities of the left and right tails. Fourth, we use the entire set of option maturities, including long-term maturities of 5 and 10 years, while Della Corte et al. (2017) only use options up to 2 years. Finally, our focus is on the predictive ability over exchange rates, while they focus on total returns.

Our paper is also related to the volatility risk premium (VRP)[2] literature in the sense that the slope of the term structure can be viewed as a risk premium, or the additional risk premium required for extending the maturity. For the equity market, Bollerslev et al. (2009) and Bollerslev et al. (2014) find evidence that a high (low) variance risk premium can predict high (low) future equity index returns, i.e., there is a positive/direct relationship between VRP and future returns. For commodity market, Ornelas and Mauad (2017) present an analysis of the predictive ability of commodity-related VRPs on future returns of several assets, such as commodity indexes, exchange rates and equity indexes, as well as sovereign and corporate bonds. Their results support a positive relationship.

There is also evidence of predictability for exchange rates, but the direction of the predictability is not a consensus: while Ornelas (2017) also finds a positive relationship as in equity markets, Londono and Zhou (2017) find the opposite: a high (low) variance

[2] We define volatility risk premium as the difference of an implied (or risk-neutral) and a realized (or physical) volatility. It is worth noting that many papers define volatility risk premium as realized minus implied.

risk premium can predict low (high) future equity index returns. Still regarding the currency market, Della Corte et al. (2016) support the results of Londono and Zhou (2017), but from a cross-section perspective. One of the differences that can explain different predictability results for currency VRP is the maturity of the options. While Londono and Zhou (2017) and Della Corte et al. (2016) use long-term options (six months and one year, respectively), Ornelas (2017) uses short-term options (one week and one month). This also motivates this study of the implied volatility term structure.

We build the implied volatility term structure using three types of implied volatilities: ATM (at-the-money) implied volatility, and 10-delta implied volatilities for the left and right tails[3]. For each type, we use options with ten different maturity periods, ranging from one week to ten years. We calculate for each day the slope of the IVTS for these three implied volatility types and for each of the 18 currencies in our sample (10 developed and 8 emerging countries). The predictability of these slopes is assessed from both the time-series and cross-section standpoints.

From a time-series perspective, our overall results suggest that a steep implied volatility slope means low future returns (negative/inverse relationship) for developed markets, and high future returns (positive relationship) for emerging markets. However, statistical significance is strong only for developed markets, especially for the right tail slope, where 8 out of 10 currencies have statistically negative coefficients. For emerging markets, coefficients are mostly positive, but only in the left tail case we have somewhat strong statistical significance.

In order to analyze results from a cross-section perspective, we build portfolios based on the slope of the term structure, and thus we present a new currency strategy. Our portfolios have two currencies with a long position and two with a short position. Given results of the time-series analysis, we perform separate analysis for developed and emerging currencies. For developed currencies, we buy the two currencies with the lowest slopes an sell the two with the highest slopes. For emerging market currencies, we buy the two currencies with the highest slopes an sell the two with the lowest slopes. The proposed strategy performs better than common currency strategies - carry trade, risk

[3] We consider returns of the exchange rate expressed as the amount of US dollars per unit of the other currency (indirect quote). In this way, the left tail means negative returns of the currency, i.e., currency devaluation. Conversely, the right tail means currency appreciation.

reversal and the VRP - based on the Sharpe ratio, considering currency returns, supporting the exchange rate predictability of the IVTS from a cross-section perspective. When we add interest rate returns and consider total return, carry trade and risk reversal strategies of emerging markets beat our strategy, but only for emerging markets, due to the high cross-section dispersion of interest rates. From a diversified investor perspective, we show that our strategies are useful in terms of risk, return and diversification within a portfolio optimization framework.

The different results for developed and emerging countries are somewhat puzzling. One possible interpretation is the following. The implied volatility slope reflects two different components ï risk premium and expected future physical volatility ï and these components induce opposite future returns. The risk premium component has a positive relationship with future returns, consistent with the model of Bollerslev et al. (2009). However, the expected physical volatility movement has an inverse relationship. It is well documented that physical volatility is mean-reverting. Thus, if the term structure of physical volatility is inverted, this means short-term volatility is higher than long-term or equilibrium volatility. We then expect a downward movement in physical short-term volatility, which is usually accompanied by rising asset prices.

It is likely that the IVTS of emerging markets is more influenced by the risk premium than future physical volatility behavior. For developed countries, risk premium should be smaller, so future physical volatility behavior should dominate the slope of the IVTS. This would explain why developed country slopes have a negative relationship with future returns and emerging market slopes have a positive relationship. Appendix I shows two theoretical models that formalize the intuition of these economic interpretations. The first model describes the dynamics considering only physical volatility, where the theoretical results fit empirical evidence from developed countries. The second model expands the first model by adding a market price of risk, so that we have separate dynamics for physical and risk-neutral probabilities. We argue that this model fits the empirical evidence on emerging market currencies if the market price of risk is large, and developed countries if it is low. Nevertheless, we cannot empirically validate this differentiation, as we cannot disentangle risk premium from expected physical volatility behavior.

In short, this paper contributes to the literature by providing new empirical evidence that the slopes of currency implied volatility term structures have predictive power for the exchange rate behavior from both cross-section and time-series perspectives. Intriguingly, as mentioned, the direction of the prediction is not the same for developed and emerging markets. For developed markets, a high slope means low future returns, while for emerging markets this means high future returns.

In the next section, we describe the data. Section 3 describes the method used to estimate the implied volatility term structure. Sections 4 and 5 present the empirical results from time-series and cross-section perspectives, respectively. Finally, section 6 concludes the paper.

2. Sample

Our currency sample consists of implied volatility from OTC (over-the-counter) exchange rate options. These are not actual trades, but estimates collected from JP Morganôs data query application. We collect volatility surfaces of 18 different currencies relative to the US dollar. The interest rates, in turn, are Libor-like for each country obtained from Bloomberg. We also obtain the spot exchange rates from Bloomberg. We use daily data from 2002 to 2016.

The group of currencies is divided into developed and emerging markets, as listed: Australian dollar (AUD), euro (EUR), British pound sterling (GBP), New Zealand dollar (NZD), Canadian dollar (CAD), Swiss franc (CHF), Danish krone (DKK), Japanese yen (JPY), Norwegian krone (NOK) and Swedish krona (SEK) ï the G10 currencies. For emerging market currencies, we use the countries classified as emerging markets by S&P Dow Jones Indexes, available at S&P Global (2016), for which the option data are available. Following that criterion, we use the Brazilian real (BRL), Chilean peso (CLP), Czech Republic koruna (CZK), Hungarian forint (HUF), Mexican peso (MXN), Polish zloty (PLN), Thai baht (THB) and South African rand (ZAR). We use options with three moneyness levels: put and call options with deltas of 10, and the ATM option. The implied volatility term structure is calculated using 10 vertices or time to maturities, similar to Chalamandaris and Tsekrekos (2010). The vertices are the following: one week; one, two, three, six and nine months; and one, two, five and ten years. We calculate the

term structure of these implied volatilities using the OTC currency options with maturities matching the aforementioned vertices.

3. Implied Volatility Term Structure

In this section, we describe how we estimate the implied volatility term structure. This slope can be interpreted as a measure of volatility risk premium, since longer options embed more risk to sellers.

To calculate the implied volatility slope and level, we estimate the following linear equation for each currency *i* and for each day *t* in our sample:

$$IV_{i,j,t} = \alpha_{i,t} + \beta_{i,t} * Mat_j + \varepsilon_{i,j,t}, \quad (1)$$

where

$IV_{i,j,t}$ is the implied volatility for currency *i*, with maturity Mat_j on date *t*;

Mat_j is the j^{th} maturity in years;

$\alpha_{i,t}$ is the estimated average level of the volatility term structure for currency *i* on date *t*; and

$\beta_{i,t}$ is the estimated slope of the volatility term structure for currency *i* on date *t*.

We run this regression using three types[4] of implied volatility: ATM, left tail with delta 10 and right tail with delta 10. The ATM is just the implied volatility of options with strike near the spot level, and gives information about the center of the risk-neutral distribution. The left tail and right tail with delta 10 are the slopes of the implied volatility calculated with call and put options with delta equal to 10, depending on the exchange rate quoting convention. The left tail is formed by options that protect against a local currency depreciation (for the right tail, it is the opposite). For a local currency depreciation, the left tail is comprised of put options with delta 10 for currencies that

[4] We have also considered results for a model-free implied volatility, which would use data from all moneyness. However, we find more informative to show results for each region of the implied volatility curve, instead of the aggregated volatility. Furthermore, results for ATM and model-free are similar to each other.

follow the indirect quote pattern (AUD, EUR, GBP and NZD) and call options with delta 10 for all the remaining currencies. The right tail works in the opposite direction.

To illustrate the time series of these three types of implied volatility, we plot the median of their level and slope in Figure 1 and Figure 2 for developed and emerging market currencies, respectively. In 2008, due to the global financial crisis (GFC), levels increase and slopes decrease substantially. The level of implied volatility for emerging markets is much higher, especially during the crisis, which is intuitive since risk aversion in these countries tends to be higher during turbulent times. The negative slopes during crisis may be interpreted as a temporary spike of physical volatility, which will subsequently be reversed. Then, short-term physical volatility is high, but it is expected to reverse to its (lower) long-term average.

Figure 1 ï Implied volatility time series for the G10 currencies

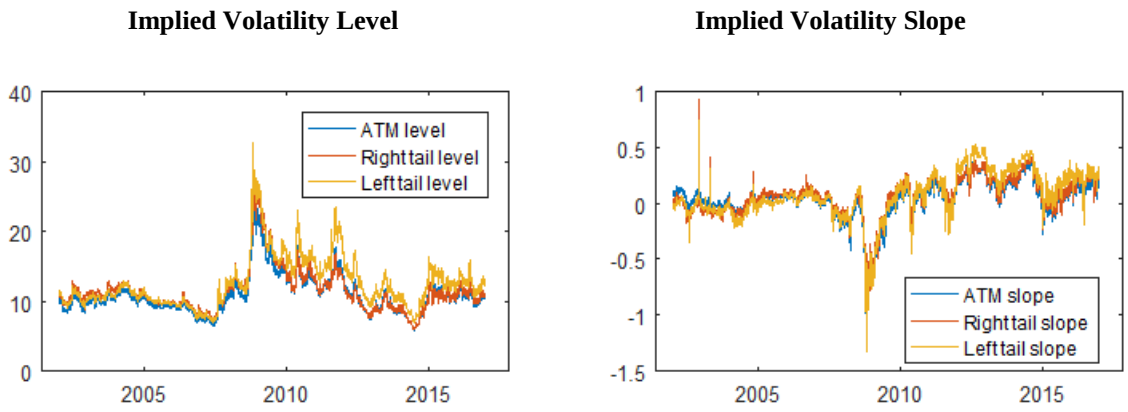
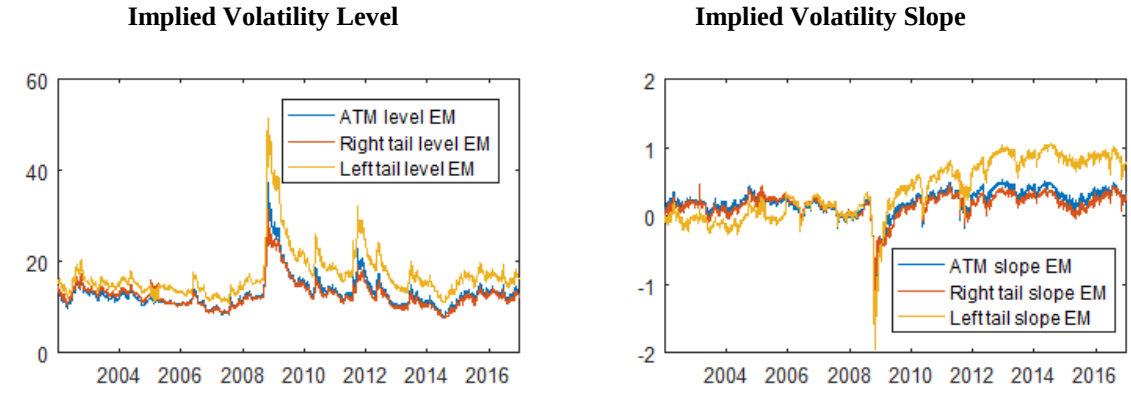


Figure 2 ï Implied volatility time series for emerging market currencies



The use of several types of implied volatility is justified by the fact there is no consensus in the literature regarding the best implied measure in terms of predictive

ability. Londono and Zhou (2017) and Ornelas (2017), for instance, provide empirical results showing that VRPs calculated with model-free implied volatility are worse than ATM implied volatilities for currency prediction. Furthermore, by splitting model-free implied volatility into middle, left and right of the distribution, we can gather further insights of the origins of the slope predictability. Unreported predictability exercises using model-free volatilities are in general weaker than those with ATM.

Table 1 presents the average level and slope for each implied volatility calculation for all the 18 analyzed currencies and their average realized volatility. The averages are computed in the time series for each currency and each type of implied volatility. As expected, implied and realized volatilities for emerging countries are higher than those for developed markets. The left tail IV is higher than ATM and right tail IV, reflecting a higher probability of large devaluations than appreciations, and/or a higher cost to hedge against devaluation than appreciation of that currency against the US dollar.

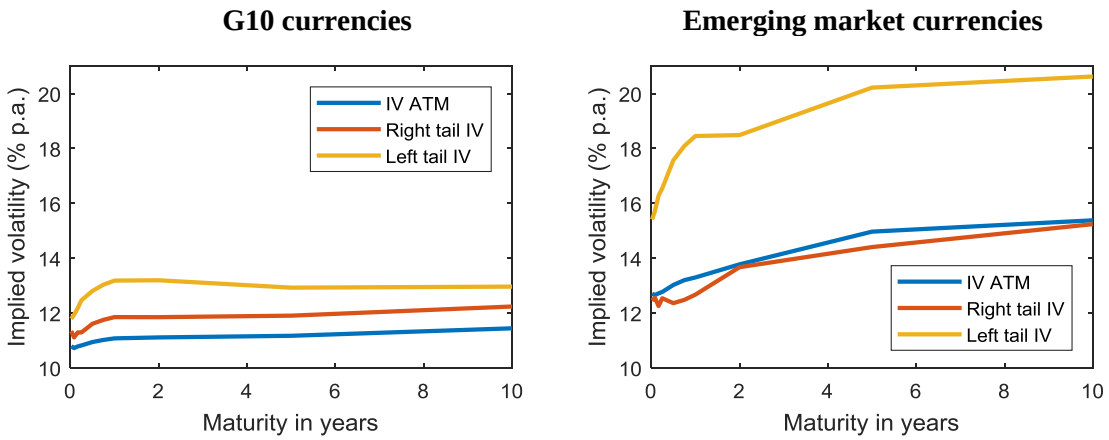
Figure 3, we plot the term structure of implied volatility for developed and emerging markets. For developed markets, the term structure is almost flat, especially for maturities over one year. For emerging markets, the term structure is steep. The slope of emerging markets is about five times greater than the slope of developed markets, when using ATM and left tail volatilities.

It is worth nothing that we use a very simple linear model to characterize the term structure of implied volatility. Further studies may improve this model and use quadratic or other non-linear models, as in the interest rate term structure literature.

Table 1 - Average level and slope for each implied volatility

Currencies		Implied Volatility Level			Implied Volatility Slope			Realized Volatility
		ATM	Left tail delta 10	Right tail delta 10	ATM	Left tail delta 10	Right tail delta 10	
					Panel A			
Developed economies	AUD	11,05	13,66	10,86	0,02	0,14	0,01	11,78
	CAD	8,69	10,01	9,01	0,05	0,10	0,05	8,54
	CHF	9,83	10,83	10,86	0,01	0,00	0,05	10,96
	DKK	9,58	11,09	9,99	0,03	0,05	0,03	9,18
	EUR	9,55	11,00	10,01	0,03	0,06	0,03	9,22
	GBP	8,74	10,31	9,03	0,10	0,13	0,10	8,40
	JPY	9,72	9,89	12,18	0,08	0,05	0,32	9,44
	NOK	11,28	12,90	11,58	0,00	0,02	-0,01	11,52
	NZD	12,09	14,79	11,91	0,01	0,12	0,00	12,28
	SEK	11,18	12,79	11,50	0,01	0,03	0,00	11,30
					Panel B			
Emerging markets	BRL	15,21	20,81	14,09	0,38	0,44	0,37	15,70
	CLP	11,02	14,73	10,76	0,22	0,35	0,14	9,38
	CZK	11,23	13,44	11,49	0,03	0,12	-0,03	11,54
	HUF	13,40	17,69	13,06	0,14	0,29	0,09	13,69
	MXN	10,76	14,33	10,08	0,28	0,43	0,33	9,85
	PLN	12,93	16,36	12,90	0,04	0,16	-0,02	12,93
	THB	6,29	8,16	6,67	0,25	0,39	0,21	4,62
	ZAR	16,23	21,86	15,44	0,19	0,53	0,09	16,68

Figure 3 ï Term structure of implied volatility



These figures show the average annualized implied volatility across currencies as a function of 10 different maturities. The maturities are: one week; one, two, three, six and nine months; and one, two, five and ten years. The left figure shows data for G10 currencies: Australian dollar (AUD), euro (EUR), British pound sterling (GBP), New Zealand dollar (NZD), Canadian dollar (CAD), Swiss franc (CHF), Danish krone (DKK), Japanese yen (JPY), Norwegian krone (NOK) and Swedish krona (SEK). The righ figure show the average of eight emerging market currencies: Brazilian real (BRL), Chilean peso (CLP), Czech Republic koruna (CZK), Hungarian forint (HUF), Mexican peso (MXN), Polish zloty (PLN), Thai baht (THB) and South African rand (ZAR). For each figure, we show three levels of moneyness: ATM (at-the-money), Right tail implied volatility (delta-10 of the negative returns of the currency) and Left tail implied volatility (delta-10 of the positive returns of the currency).

4. Time-Series Predictability

Based on the estimated implied volatility slope, $\hat{\beta}_{i,t}$ in equation 1, we use equation 2 to obtain the coefficients of each slope on the future return of each currency. The regression specification is:

$$Ret_{i,h,t} = \alpha + \gamma_1 * \hat{\beta}_{i,t-1} + \gamma_2 * Ret_{i,h,t-h}, \quad (2)$$

where:

$Ret_{i,h,t}$ is the return for each holding period *h* (three or six months), for each currency *i*, starting at time *t*;

$\hat{\beta}_{i,t}$ is the coefficient estimated in equation 1 for each currency, each day.

The results of equation 2 are in Table 2. Regressions cover from 2002 to 2016 on a daily basis for 18 currencies. Given the strongly overlapping nature of our sample, we use the Hansen-Hodrick t statistics.

Overall, developed markets (Panel A) show mainly negative γ_1 coefficients, while emerging markets (Panel B) show mainly positive coefficients.

For developed markets, statistical significance using ATM slope is restricted to the three commodity currencies (AUD, CAD and NZD). However, we have most of the currencies with statistically negative coefficients of the tail results. Results for the right tail slope considering a 6-month holding period are remarkably good, with 8 out of 10 currencies with statistically negative coefficients.

For emerging markets, most coefficients are positive, but statistical significance is weak, except for the left tail slope results, where all coefficients are positive and 5 out of 8 are statistically positive for 6-month returns. The statistically significant results only on the left tail slope for emerging markets may be an indication that hedge demand is important only against emerging market currencies devaluation vis-¨-vis the US dollar, while the risk of emerging market currencies appreciation is less important, or at least has less volatility premium. This contrasts with results for developed currencies, where both tails have several statistical significant results, although with negative signs. We also check whether the IVTS of commodity currencies can predict emerging market currencies. The results in Appendix II show that currencies from Brazil, Chile and South Africa can be predicted by commodity currencies.

Still in Panel B, the South African rand has a remarkably good predictive ability, having significant coefficients in all cases. The Chilean peso is the only emerging currency with mainly negative coefficients, but with no statistical significance.

Table 2 ï Exchange rate return regression results

Dependent Variable		ATM		Left tail		Right tail	
(Currency Returns)		Coefficients					
		3 Mo	6 Mo	3 Mo	6 Mo	3 Mo	6 Mo
		Panel A					
Developed economies	AUD	-6.83**	-14.22***	-5.61***	-11.87***	-7.65***	-15.99***
	EUR	-2.80	-5.52	-2.98	-5.91	-4.66**	-9.51*
	GBP	1.03	0.42	-0.04	-1.33	-0.92	-4.22
	NZD	-4.78	-13.38***	-4.16*	-10.15***	-6.03	-16.23***
	CAD	-5.62*	-13.32**	-4.70**	-11.54***	-5.76*	-13.90***
	CHF	-0.44	-2.29	-0.72	-2.94	-1.64	-4.39
	DKK	-3.57	-6.54	-4.45**	-8.39*	-5.72***	-10.70**
	JPY	-2.65	-6.10	-2.47	-5.83	-2.52	-5.71*
	NOK	-4.52	-8.42	-5.09**	-9.65**	-6.88***	-13.04**
	SEK	-5.18*	-8.99	-5.21**	-9.61**	-7.48***	-13.73***
		Panel B					
Emerging markets	BRL	3.99	3.40	3.14***	5.88*	1.86	-0.31
	CLP	-2.19	-6.49	1.64	2.33	-2.07	-7.93
	CZK	3.29	5.24	2.82	5.91**	4.04	6.08
	HUF	2.75	5.30	1.86	4.02*	3.12	6.53
	MXN	-1.46	2.12	0.04	3.24	-2.19	-3.39
	PLN	1.02	2.90	1.15	3.14	2.77	5.33
	THB	1.64	2.46	1.97**	4.09***	1.46	1.89
	ZAR	7.17***	16.36***	3.44***	7.38***	8.22***	18.60***

This table shows results of 144 regressions: $Ret_{i,h,t} = \alpha + \gamma_1 * \beta_{i,t} + \gamma_2 * Ret_{i,h,t-h}$ *. The dependent variables are the returns of the currencies for three and six months. Each regression has as independent variables the slope of an implied volatility term structure, the lagged dependent variable and a constant. All the independent variables are lagged. The independent variables are the slope of at-the-money implied volatility, the slope of the left-tail 10-delta implied volatility, and the slope of the right-tail 10-delta implied volatility. Estimates of the constants and lagged dependent variable coefficients are omitted. The statistics marked in *, ** and *** are significant at least at 1%, 5% and 10%. The t-statistics are Hansen-Hodrick HAC with h+1 lags, where h is the size of the return window. The sample period is from 2002 to 2016, on a daily overlapping basis.*

In order to evaluate the economic magnitude of the impact of the IV slope on the currency returns, we multiply the average slope presented in Table 1 by the coefficients in Table 2, for some currencies. Note that the average slope is a small number, for instance, 0.02 for AUD, which means 0.02 annual volatility increase for each year of option maturity. Thus, if we multiply 0.02 by the coefficient of 6-months returns of ATM slope for Australian dollar (-14.22) we would have 28.44% smaller returns. Applying the same analysis for the Canadian dollar, an expansion of 0.05 in the right tail slope yields a 66% reduction in the 6-month currency return. These results show that indeed the currency returns seem sensitive to changes in the IV slope.

Overall, the results in Table 2 are puzzling given the inverse relationship if we consider developed or emerging markets. Economic intuition for this result could be related to the different importance of the volatility risk premium for developed and emerging markets. For emerging markets, risk premium is more important than physical volatility expectations. Therefore, a very positive slope would mean a higher risk premia. This means currencies are discounted, and then should recover in the future. This is the essence of Bollerslev et al. (2009) theoretical model and explains positive coefficients for emerging markets in Panel B. However, for developed economies, the effect of risk premia is probably lower, and the slope is showing mainly information about physical volatility. Thus, a positive slope would mean an expectation that physical volatility will increase and then currency will lose value. This may explain the negative values of the coefficients for developed markets in Panel A.

In Appendix I, we develop two theoretical models to characterize the economic intuition behind those results. The first model describes the dynamics of physical volatility only, and its results are consistent with the negative relationship of slope and future returns we find for developed markets. The second model assumes different dynamics for physical and risk-neutral volatilities. In this case, if we assume that market price of risk has a stronger effect than physical volatility does, a positive relationship of slope and future returns arises from the model. This is consistent with our empirical results for emerging markets.

5. Cross-Section predictability - Portfolios Based on Sorts

In this section, we build portfolios of currencies based on the slopes $\beta_{i,t}$ of the implied volatility term structure. Given that time-series relationship is negative for developed countries and positive for emerging markets, we split the analysis.

For developed markets, we build long-short (cash neutral) portfolios going short on the top 20% slopes, and going long on the bottom 20% slopes. For emerging markets, we build portfolios going long on the top 25% slopes, and going short on the bottom 25% slopes. Therefore, on both cases we build portfolios composed by two long currencies with equal weights and two short currencies, also with equal weights. We form these portfolios on a daily basis and hold them for three months (63 overlapping business days).

Thus, each portfolio has a weight of 1/63. We assume daily rebalancing to keep this weight.

Our main objective is to evaluate the performance of these portfolios as an exchange rate investment strategy. We built these portfolios using again three types of implied volatilities slopes: ATM, left tail and right tail.

In order to benchmark this strategy against other known currency strategies, we also build portfolios based on interest rates (the carry trade portfolio), on the risk-reversal average level for the 10-delta; and on the one-year VRP. They have the same characteristics of the slope portfolios in terms of rules of formation, rebalancing, etc., except that the criterion for sorting is different.

The carry trade portfolio is built by sorting currencies by its 3-month interest rate, and going long in the currencies with the highest interest rates, and short in those with the lowest rates. Previous papers that study carry trade strategy include Burnside et al. (2011) and Menkhoff et al. (2012). The risk-reversal[5] portfolio is based on the difference between the level ($\alpha_{i,t}$) of the 10-delta term structure volatility for the right tail and the same level for the left tail. Usually this strategy is based on options with some specific maturity (for instance, one year in Della Corte et al., 2016), but we generalize it in order to capture information from several maturities. Finally, the VRP portfolio is based on the difference between a one-year implied volatility and the realized volatility in the previous year, calculated with daily returns. This strategy buys currencies with low VRP and sells currencies with high VRP, and is based on Della Corte et al. (2016).

Figure 4 and Figure 5 show the performance of the proposed strategy using the three aforementioned methods to calculate the implied volatility slope and the three benchmark strategies (carry trade, risk reversal and VRP). For the G10, the proposed strategy using the right tail IV slope performs better in most part of the sample, followed by ATM IV slope. As for the benchmark strategies, the carry trade and the risk reversal show the worst performances in part of the sample. For emerging markets, the risk reversal performs better than the other strategies, followed by left tail and ATM.

[5] The predictability of risk-reversals have been assessed by C§stren (2006) and McCauley and Melick (1996).

Therefore, there is evidence pointing to a good performance of the proposed strategy when compared to the benchmark ones.

Analyzing the pattern of returns in Figure 4 (developed economies) before and after the 2008 GFC, we can see some clear changes. During the crisis, all the strategies performed poorly. However, the right tail IV calculation strategy, for instance, which had a mediocre performance before the crisis, turned out to be the best one in terms of returns after this period. Moreover, the ATM IV slope strategy improved its performance from one of the worst portfolios before the crisis to one of the best afterwards. One possible economic explanation for these changes is that, after the crisis, physical volatility expectation started accounting for a larger chunk of the implied volatility in developed economiesô currencies. Besides, the benchmark strategiesô returns, such as those of the carry trade, decreased possibly due to unconventional monetary policy following the financial crisis, which probably led to lower interest rate differentials between countries. As for emerging markets, shown in Figure 5, there are no clear changes in patterns before and after the crisis.

Table 3 shows the moments of the portfolios returns. We consider the currency return[6] on the left and the total return (currency plus interest rate) on the right. When analyzing currency returns, the ATM slope portfolio has a higher Sharpe ratio than all benchmark portfolios. For developed markets, among slope portfolios, only the left tail slope has a poor performance, being surpassed by the VRP strategy. For emerging markets, the right tail slope has a lower Sharpe ratio than the risk reversal, but beats the other strategies. All the others surpass the three benchmarks. These interesting results for currency returns of the IV slope portfolios show the superior ability of this information to forecast exchange rate variations from a cross-section perspective, when compared to traditional benchmarks.

When adding interest rates and considering total returns (right side of Table 3), the performance of the carry trade portfolios improves, especially for emerging markets. In fact, all emerging portfolios show a positive result. For developed portfolios, only the ATM and the left tail slope have a negative carry. Even with this negative carry, except

[6] Currency returns are calculated based only on the exchange rate variations.

for the VRP slope portfolio, the ATM slope portfolio beats all developed market benchmarks in terms of Sharpe ratio. The same happens with the right tail slope portfolio.

The carry trade portfolio is leader when considering emerging markets total returns, mainly because of the interest gains. The risk-reversal also has a very high carry, which improves its Sharpe ratio.

Analyzing portfolios under the risk perspective, we see that slope strategies have lower volatility than the benchmarks in all cases. For developed markets, the proposed strategies show mainly right skewed distributions and, for the ATM strategy, platykurtic kurtosis. For emerging markets, slope portfolios are left skewed, as opposed to the benchmark strategies, but the distributions are mostly platykurtic, in contrast with the leptokurtic benchmarks. Overall, slope portfolios have much lower risk characteristics.

As a robustness test, we have analyzed the 5-year rolling window Sharpe ratio of the currency return of all the strategies. The results, presented in Figure 6, show that the proposed strategies indeed perform better than the benchmark ones, especially the ATM and right tail slopes for the G10 currencies. For the emerging markets, the Sharpe ratio indicates competitive results between the proposed strategies and the other ones, with some superiority of the left tail in recent years. Note that the ATM and left tail returns for the emerging markets are statistically different from zero, which is not true for the other strategies, as shown in Table 3.

Table 3 ï Portfolio returns statistics

		Currrency Returns					Total Return				
	Types of portfolios	Aritmetic Mean of Returns	Volatility	Skewness	Kurtosis	Sharpe Ratio	Aritmetic Mean of Returns	Volatility	Skewness	Kurtosis	Sharpe Ratio
		Panel A - Developed markets									
Developed economies	ATM Slope	2.33%	7.00%	0.095	6.4	0.33	2.29%	7.00%	0.098	6.3	0.33
	Left Tail Slope	0.38%	7.63%	1.090	17.5	0.05	-0.61%	7.63%	1.080	17.4	-0.08
	Right Tail Slope	2.80%	8.36%	-0.481	14.7	0.33	4.18%*	8.36%	-0.469	14.7	0.50
	Carry Trade	0.13%	12.49%	-0.930	19.2	0.01	4.14%	12.49%	-0.923	19.2	0.33
	Risk-Reversal	0.22%	12.63%	-0.670	17.4	0.02	3.53%	12.63%	-0.659	17.4	0.28
	VRP	2.02%	11.20%	-0.456	15.4	0.18	3.93%	11.20%	-0.444	15.4	0.35
		Panel B - Emerging Markets									
Emerging markets	ATM Slope	4.67%*	10.74%	-0.026	5.8	0.43	7.42%***	10.74%	-0.027	5.8	0.69
	Left Tail Slope	4.59%*	9.79%	-0.023	5.6	0.47	6.64%***	9.79%	-0.040	5.6	0.68
	Right Tail Slope	4.00%	10.96%	-0.086	6.7	0.36	6.61%**	10.96%	-0.086	6.7	0.60
	Carry Trade	3.05%	11.42%	0.251	9.0	0.27	13.07%***	11.42%	0.267	9.0	1.15
	Risk-Reversal	4.56%	11.50%	0.377	7.6	0.40	11.71%***	11.50%	0.389	7.6	1.02
	VRP	2.19%	12.97%	0.507	6.9	0.17	8.17%***	12.97%	0.517	6.9	0.63

*This table shows the results of the geometric mean of portfolio returns. For each type of portfolio, we test whether the daily return is statistically significant by regressing them on a constant. The statistics marked in *, ** and *** are significant at least at 1%, 5% and 10%. The sample period is from 2002 to 2016, on a daily overlapping basis.*

Figure 4 ï Portfolio comparison with benchmark strategies ï G10

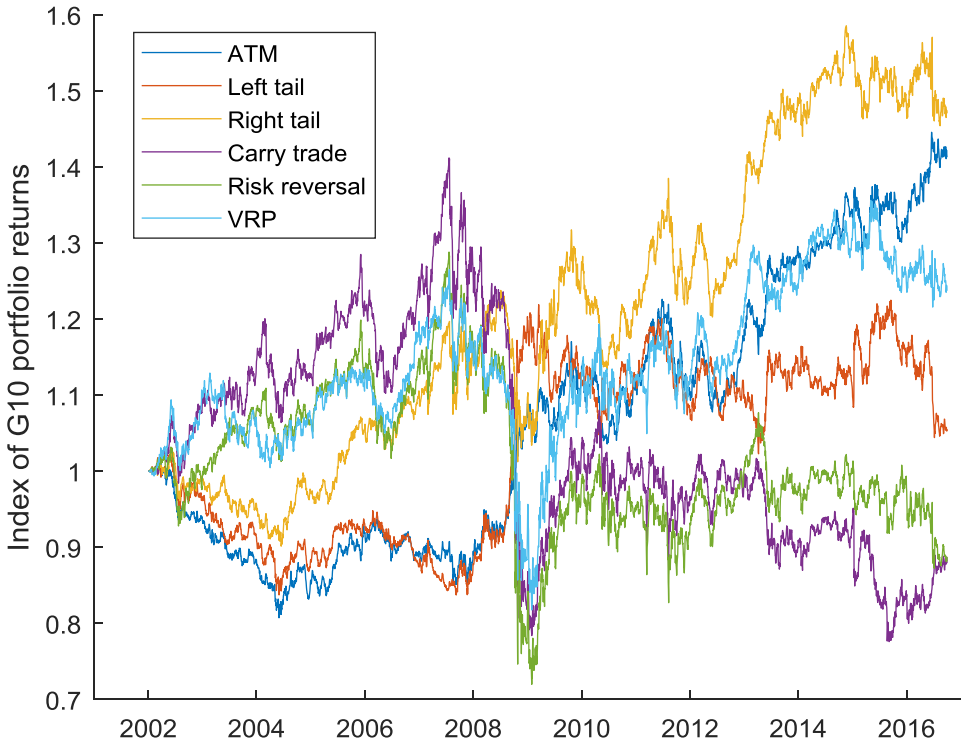


Figure 5 ï Portfolio comparison with benchmark strategies ï Emerging Markets

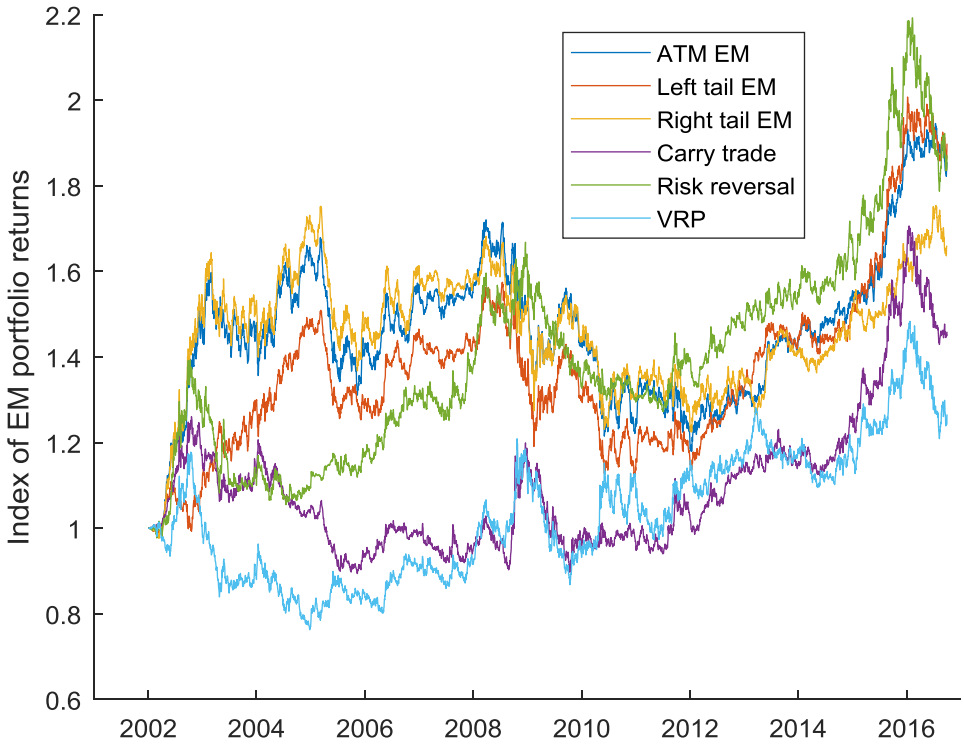
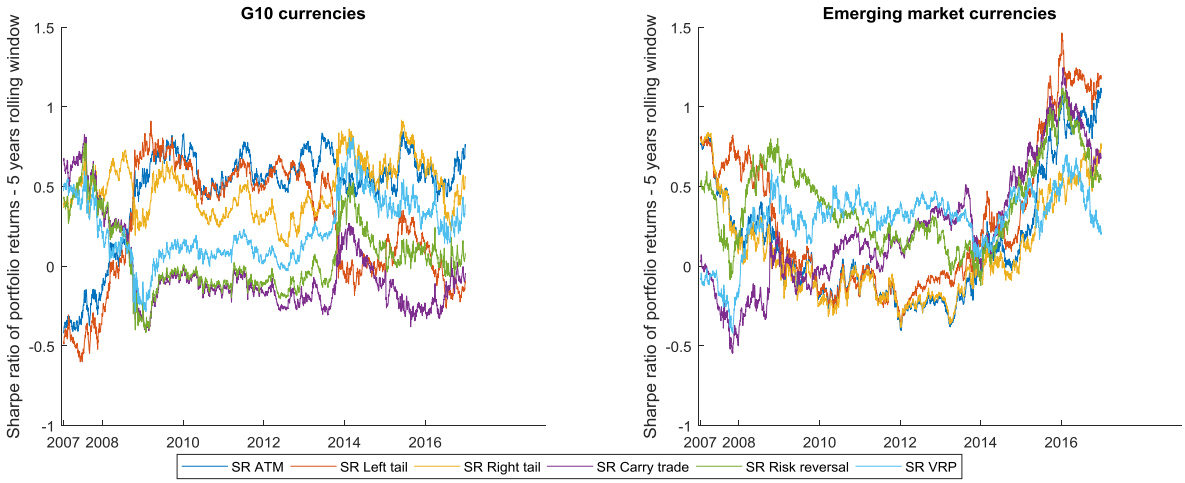


Figure 6 ï Rolling window Sharpe ratio



5.1 Correlations

We also analyze the correlation among portfolios. The correlation matrices are in Table 4. Among slope portfolios, correlation is very high, expect for left and right tail

slope portfolios of developed currencies. This signals a common underlying mechanism between these strategies. On the other hand, slope portfolios correlation with the benchmark strategies are usually low, except for the Right tail slope for developed markets. The left tail slope have remarkably low correlations with benchmark portfolios (ranging from -35% to 14%). The VRP strategy has positive correlation for developed markets and negative for emerging. This may be due to the kind of portfolio construction method: VRP strategy buys low risk premium and sells high risk premium. This is what is done for developed markets slope portfolios, but it is the inverse of the formation rule of the emerging market portfolios.

Given this overall correlation picture, we can say the characteristics of the slope portfolios make them a good candidate for entering in mean-variance currency portfolios.

Table 4 ï Correlation matrices

		ATM Slope	Left Tail Slope	Right Tail Slope	Carry Trade	Risk-Reversal	VRP
		Panel A - Developed markets					
Developed economies	ATM Slope		59%	67%	18%	22%	41%
	Left Tail Slope	59%		18%	-35%	-25%	-10%
	Right Tail Slope	67%	18%		56%	62%	67%
	Carry Trade	18%	-35%	56%		91%	74%
	Risk-Reversal	22%	-25%	62%	91%		84%
	VRP	41%	-10%	67%	74%	84%	
		Panel B - Emerging Markets					
Emerging markets	ATM Slope		75%	92%	13%	22%	-26%
	Left Tail Slope	75%		61%	6%	14%	-25%
	Right Tail Slope	92%	61%		9%	16%	-31%
	Model-Free Slope	97%	75%	90%	17%	26%	-21%
	Carry Trade	13%	6%	9%		78%	70%
	Risk-Reversal	22%	14%	16%	78%		72%
	VRP	-26%	-25%	-31%	70%	72%	

5.2 Efficient Frontier

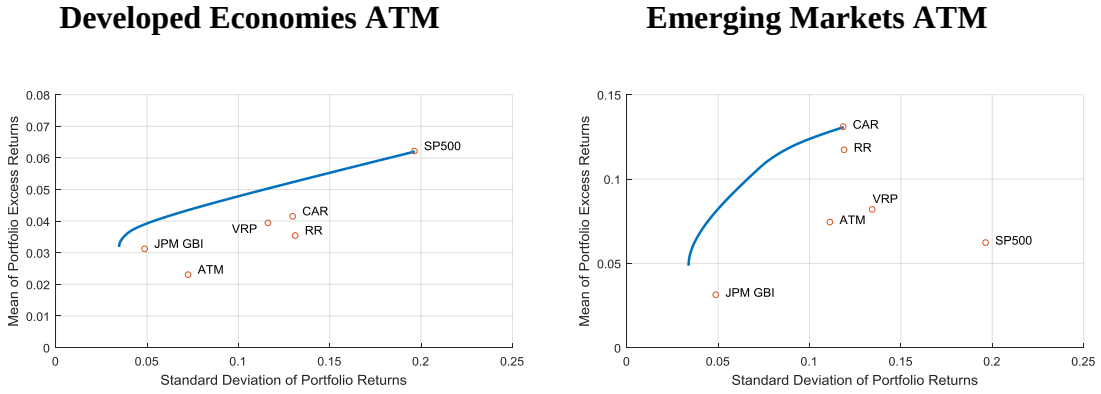
In this section, we evaluate our proposed portfolio strategies from a portfolio optimization perspective. We build the efficient frontier with one of our Slope portfolio, the three currency benchmark strategies ï Carry Trade, Risk-Reversal and VRP ï and two other assets: the S&P500 index as a proxy for US equity, and the US JP Morgan Global Bond Index as proxy for US Government Fixed Income. We compute the excess returns of latter indexes over the Barclays 3-month T-bill index, which we use as proxy for the

risk free rate of return. The exchange rate portfolios are built using long-short (cash neutral) strategies, so they are expressed in excess return by construction. In the optimization procedure, weights for each asset are bounded to the interval [0,1].

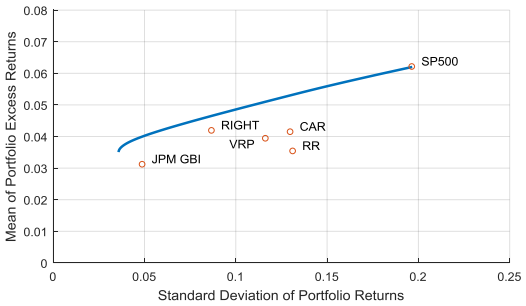
We compute the annualized risk and return for portfolios in the efficient frontier for developed and emerging economies. Figure 7 shows the efficient frontiers containing the developed economies in the left panels and emerging markets in the right panels. The figure also plots each strategy risk-return characteristics. Note that the vertical axis are presented in different scales. On the top panels, we use the ATM slope portfolios for both developed and emerging economies. On the bottom panels, we use the best side, i.e., the right tail slope portfolio for developed and the left tail slope for emerging economies.

We see that emerging market currency portfolios have better returns than developed markets (DM) currency portfolios, US Equity and US bonds. For DM, the currencies portfolios lie between US stocks and bonds, while for the emerging markets, the currency portfolios have better risk-return profiles. In terms of composition, Table 5 shows the weights of each portfolio on the minimum variance portfolio. We see that our slope portfolios have a relevant weight, varying from 10% to 19%. Risk-reversal and carry trade portfolios have small weights, while VRP have relevant weights only for emerging market minimum variance portfolio. As we move to riskier portfolios of the efficient frontiers, our slope portfolios keep relevant weights, except for the ATM slope in the DM. In this way, we can say our slope portfolios are useful from a portfolio optimization perspective.

Figure 7 ï Developed economies and emerging markets efficient frontiers



Developed Economies Right Tail



Emerging Markets Left Tail

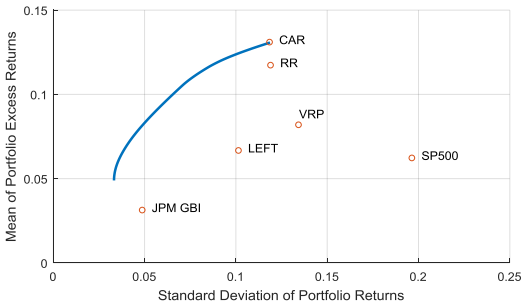


Table 5 ï Minimum Variance Portfolio Weights

Panel A - Developed Markets

With ATM Slope		With Right Tail Slope	
SP500	4.9%	SP500	5.5%
JPM GBI	67.0%	JPM GBI	72.9%
ATM Slope	19.0%	Right Tail Slope	16.0%
Carry Trade	6.3%	Carry Trade	5.6%
Risk-Reversal	2.9%	Risk-Reversal	0.0%
VRP	0.0%	VRP	0.0%

Panel B - Emerging Markets

With ATM Slope		With Left Tail Slope	
SP500	12.6%	SP500	12.4%
JPM GBI	62.4%	JPM GBI	60.5%
ATM Slope	10.5%	Left Tail Slope	12.4%
Carry Trade	3.5%	Carry Trade	4.5%
Risk-Reversal	0.0%	Risk-Reversal	0.0%
VRP	10.9%	VRP	10.2%

5.3 Factor Regressions

In this section, we analyze the proposed IV Slope exchange rate strategies by regressing them on two sets of factors. The first set is composed by the three currency benchmark strategies - Carry Trade, Risk-reversal and VRP ï and an equal-average mean return of the individual currency returns[7]. The second set is composed by the three US

[7] This equal average is calculated for each market, so that is the equal average return of the 10 DM currencies and the equal average return of the eight emerging market currencies.

equity factors as in Fama and French (1993) and a momentum factor. The dependent variable is the total return of the strategies, i.e., the currency and the interest rate returns.

Table 6 shows the results using currency factors on Panel A and US Equity Factors on Panel B. Recall that, for developed markets, the results in Table 3 show statistically positive returns only for the Right Tail portfolio. When the currency factors are added, the Alpha (constant term) is no longer significant, although the t-statistic is 1.57. Two factors are able to explain this term: the mean currency return and the VRP portfolio, both with positive loadings. In Panel B, we see that equity factors are not able to explain the Right Tail portfolio of Developed markets.

For emerging markets, results in Table 3 show statistically positive returns for all three slope portfolios, considering total return. This is overall confirmed by results presented in Table 6, showing robustness even after the inclusion of other currencies and equity strategies as covariates. Both Panels A and B of Table 6 show positive and significant Alphas for the ATM and Left Tail portfolios. None of the factors has statistically significant loadings for these portfolios. However, for the Right Tail portfolio, there are some factors with statistically significant loadings, and it has a statistically significant Alpha only when Equity Factors are used. Overall, the demand for hedging against a USD depreciation has additional information only over the equity factors.

Table 6 ï Currency and equity factors

Panel A: currency factors							
Countries		Annual constant	Mean FX	Carry trade	RR	VRP	Rį
	ATM Slope	1.28%	0.11*	0.01	-0.22*	0.41***	22.84%
Developed economies	Left Tail Slope	0.02%	0.02	-0.42***	0.06	0.21**	18.51%
	Right Tail Slope	2.27%	0.13***	0.03	0.11	0.33***	47.10%
	ATM Slope	2.73%*	-0.26	0.27	0.61	-0.64	44.39%
Emerging markets	Left Tail Slope	3.97%**	-0.12	0.15	0.47	-0.52	28.12%
	Right Tail Slope	2.30%	-0.30***	0.29***	0.56***	-0.65***	44.09%
Panel B: equity factors							
Countries		Annual constant	MKT-RF	SMB	HML	MOM	Rį
	ATM Slope	2.38%	-0.01	0.02	0.03	0.00	20.63%
Developed economies	Left Tail Slope	-0.82%	0.00	0.00	0.04***	0.01*	22.46%
	Right Tail Slope	4.38%**	-0.02	0.05	0.03	0.00	33.78%
	ATM Slope	8.02%**	0.01	-0.06	-0.01	0.01	21.17%
Emerging markets	Left Tail Slope	7.18%***	0.01	-0.04	-0.01	0.00	14.35%
	Right Tail Slope	7.16%**	0.01	-0.07*	0.00	0.02	30.92%

6. Final Remarks

This paper provides new empirical evidence that the slopes of currency implied volatility term structures have predictive power for the exchange rates behavior from both cross-section and time-series perspectives. Intriguingly, the direction of the prediction is not the same for developed and emerging markets. For developed markets, a high slope means low future returns, while for emerging markets this means high future returns.

In order to analyze predictability from a cross-section perspective, we build portfolios based on the slope of the term structure, and thus we present a new currency strategy. For developed currencies, we buy the two currencies with the lowest slopes and sell those two with the highest slopes. For emerging market currencies, we buy the two currencies with the highest slopes and sell those two with the lowest slopes. The proposed strategy performs better than common currency strategies - carry trade, the risk reversal and the VRP - based on the Sharpe ratio, considering currency returns, which supports the exchange rate predictability of the IVTS from a cross-section perspective. When we add interest rate returns and consider total return, carry trade and risk reversal strategies of emerging market beat our strategy, but only for emerging markets, due to the high cross-section dispersion of interest rates.

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Appendix I ï Theoretical Models

In this section, we describe two models for volatility behavior. The first model considers only physical volatility and then assumes no volatility risk premium and no market price of risk. The second uses Girsanov Theorem to transform the first model from a physical measure to a risk-neutral measure, introducing, thus, a market price of risk.

A. Model for Physical Volatility

It is widely accepted that (physical) volatility of asset returns follows a mean-reverting process. We may use an Ornsteinï Uhlenbeck[8] process to model volatility behavior over time, similar to Stein (1989):

$$d\sigma_t = \alpha(\bar{\sigma} - \sigma_t)dt + \beta dW_t, \tag{1}$$

where σ_t is the physical volatility at time t; W_t is a Wiener process; α is a mean-reversion speed parameter; $\bar{\sigma}$ is the long-term equilibrium volatility; and β is the volatility of the volatility parameter.

At time *t*, the expected physical instantaneous volatility for time *t* + *T* is given by:

$$E_t[\sigma_{t+T}] = \bar{\sigma} + \rho^T(\sigma_t - \bar{\sigma}), \tag{2}$$

where $\rho = e^{-\alpha} < 1$. If the current volatility σ_t is above its long-run level $\bar{\sigma}$, it tends to decay geometrically back towards the long-run level. The speed of this decay will depend on the mean-reversion parameter α. According to this equation, we have a downward sloping physical volatility term structure in a stressed market, characterized by a short-term volatility σ_t above its equilibrium value $\bar{\sigma}$. In this setup, the normal shape of the

[8] The Ornsteinï Uhlenbeck has the drawback of allowing negative volatilities. An alternative to avoid negative volatilities would be the Feller process: $d\sigma_t = \alpha(\bar{\sigma} - \sigma_t)dt + \beta\sqrt{\sigma_t}\, dW_t$. However, this would introduce more complex calculations and additional restriction the model parameters. As the goal in this section is only to model the term structure behavior of implied volatility, we decide to use the Ornsteinï Uhlenbeck model, which reproduces the main characteristics of our empirical evidence.

physical volatility is a nearly flat curve. This is consistent with the format of Figure 1, i.e., the term structure of implied volatility for developed countries.

We may also calculate the average expected instantaneous volatility from time *t* to *t* + *T* as in Stein (1989):

$$E_t[\sigma_{t,t+T}] = \frac{1}{T}\int_{j=t}^{t+T}[\bar{\sigma} + \rho^j(\sigma_t - \bar{\sigma})]dj = \bar{\sigma} + \frac{(\rho^T - 1)}{Tln(\rho)}(\sigma_t - \bar{\sigma}) \quad (3)$$

Similar to the instantaneous volatility, when current volatility σ_t is above its long-run level $\bar{\sigma}$, the average expected volatility tends to decay geometrically back towards the long-run level.

We can define the following discounted cash flow equation for the price of an asset:

$$P_t = \int_{\tau=t}^{\infty} F_\tau e^{-D_{t,\tau}} d\tau, \quad (4)$$

where P_t is the price of the asset at time *t*; F_t is the instantaneous cash flow[9] at time *t*; $D_{t,\tau}$ is the discount rate for this asset at time *t* with a maturity τ.

Then we assume that the discount rate is a function of the volatility at that time for that maturity, besides other characteristics of the asset:

$$D_{t,\tau} = f(\sigma_{t,\tau}, \varphi)$$
$$\text{with } \frac{\partial f}{\partial \sigma_{t,\tau}} > 0 \quad (5)$$

This discount rate is increasing on the volatility. Then, if the current (short-term) volatility is above the long-term equilibrium level, i.e., $\sigma_t > \bar{\sigma}$, we would have a downward sloping curve, with $E_t[\sigma_{k+e}] < E_t[\sigma_k]$. This means the price P_t will tend to increase since $D_{t,\tau}$ will decrease with the decay of the volatility towards its long-term level. We can conclude that a negative slope will induce a positive return of the asset. This is the result of our empirical investigation for developed currencies on Table 2. However, results for emerging currencies do not fit this model. We believe the reason is that, while for developed currencies modelling only the physical volatility is sufficient, for emerging market currencies the volatility term premium plays an important role. As

[9] This cash flow may be a dividend for a stock, a coupon for a bond or the interest rate for a currency.

we can see in Table 1, the slope of implied volatilities for emerging markets is many times higher than those for developed currencies. This is an indication that risk-premium also needs to be modelled, and therefore we need to consider a model for the risk-neutral world.

B. Model for Risk-Neutral Volatility

Departing from the physical volatility diffusion equation (1), we can use Girsanovôs Theorem to make a transformation from the Physical ($\mathbb{P}$) to the Risk-Neutral ($\mathbb{Q}$) world. We assume a non-negative market price of (volatility) risk λ, possibly time varying. Using Girsanovôs Theorem we have:

$$dW_t^Q = -\lambda dt + dW_t \tag{6}$$

Plugging (6) into (1) and rearranging yield:

$$d\sigma_t = \alpha\left(\bar{\sigma} + \frac{\beta\lambda}{\alpha} - \sigma_t\right)dt + \beta dW_t^Q \tag{7}$$

At time *t*, the expected risk-neutral value of instantaneous volatility for time $t + T$ is given by:

$$E_t^Q[\sigma_{t+T}] = \bar{\sigma} + \rho^T(\sigma_t - \bar{\sigma}) + \frac{\beta\lambda}{\alpha}(1 - \rho^T) \tag{8}$$

Comparing equation (8) with (2) we see an additional third term $\frac{\beta\lambda}{\alpha}(1-\rho^T)$. This term driving the equilibrium shape of the implied volatility term structure upwards. Note that $(1-\rho^T)$ increases with maturity *T*, converging to 1 when *T* is very large. Furthermore, it is increasing in market price of risk λ, which can be viewed as a kind of risk premium. Thus, the higher is λ, the steeper is the implied volatility curve. This curve will also be steeper for a higher volatility of the volatility parameter β, which is a measure of risk. On the other hand, the curve is flatter for higher values of mean-reversion speed α. This also makes sense since a fast reversion is an indicator of lower volatility risk.

Equation (8) allows the term structure of implied volatility to be upward or downward sloping. The upward slope is the usual shape in the equilibrium, because the

physical volatility is flat ($\sigma_t = \bar{\sigma}$) and the third term of (8) produces the positive slope because of the risk premium. This is consistent with emerging markets' steep slopes in Figure 3 and developed markets flat curves. However, a downward slope is possible when a shock kicks short-term volatility well above its equilibrium ($\sigma_t \gg \bar{\sigma}$) so that the risk-premium upward pressure is more than compensated by the shock. An example of this situation would be the 2008 Global Financial Crisis. In this case, the second term of equation (8) would dominate the third term. This is analogous to the inverted interest rate curve, when the expectation of a lower policy rate more than compensates the term premium.

We may also calculate the average risk-neutral instantaneous volatility from time *t* to *t* + *T*:

$$E_t^Q\left[\sigma_{t,t+T}\right] = \frac{1}{T}\int_{j=t}^{t+T}\left[\bar{\sigma} + \frac{\beta\lambda}{\alpha} + \rho^j\left(\sigma_t - \bar{\sigma} - \frac{\beta\lambda}{\alpha}\right)\right]dj = \\ = \bar{\sigma} + \frac{\beta\lambda}{\alpha}\left(1 - \frac{(\rho^T - 1)}{Tln(\rho)}\right) + \frac{(\rho^T - 1)}{Tln(\rho)}(\sigma_t - \bar{\sigma}) \tag{9}$$

The properties and behavior of the average risk-neutral volatility are similar to the instantaneous volatility we have analyzed before.

We can keep the discounted cash flow equation (4), but now the determinants of the discount rate should also consider the market price of risk. Then we assume that this discount rate is a function of the volatility at that time for a given maturity of the market price of risk, besides other characteristics of the asset:

$$D_{t,\tau} = f\left(\sigma_{t,\tau}, \lambda, \varphi\right) \\ \frac{\partial f}{\partial \sigma_{t,\tau}} > 0; \frac{\partial f}{\partial \lambda} > 0 \tag{10}$$

The analysis of the relationship between the slope of the term structure of implied volatility and future returns is now more complex, because it will depend on the relative strength of the forces physical volatility spikes and risk premium changes. In a stress scenario, short-term volatility above its equilibrium ($\sigma_t > \bar{\sigma}$) will pressure the slope

down, but the risk premium and market price of risk will increase, pressuring the slope upwards.

We argue that, for emerging markets, the risk premium effect will dominate, and we will have a steepening of the implied volatility curve. However, for developed economies the effect of the risk premium should be small so that the physical volatility expectations will dominate. Then the curve should suffer a downward movement in this stress scenario. In both cases, the discount rate will rise, increasing future returns. Therefore, in both cases, after a stress scenario, prices are discounted and future returns are positive. The difference is that for emerging markets the stress scenario means a steep implied volatility curve, while for developed markets it means a downward term structure. These theoretical results are in line with our empirical results presented in Table 2.

Appendix II – Commodity currencies predictability

In this appendix, we analyze whether the mean IVTS of commodity currencies (AUD, NZD and CAD) has predictive ability over future returns of emerging market exchange rates. We run 48 regressions using 3- and 6-month returns of emerging markets exchange rates as dependent variables. The independent variables are the lagged dependent variables, the mean IVTS of commodity currencies and a constant.

The results are presented in Table 7. We can see that the IVTS of commodity currencies is statistically significant to predict returns for some resource rich countries, such as Brazil, Chile and South Africa. The last two, which are richer in mining commodities, seem to have even higher statistically significance.

Table 7 – Commodity currencies IVTS regressions results

Currency Returns	ATM		Left tail		Right tail	
	Coefficients					
	3 Mo	6 Mo	3 Mo	6 Mo	3 Mo	6 Mo
BRL	0.07	0.13**	0.05*	0.11**	0.06	0.12*
CLP	0.06***	0.10***	0.05***	0.09***	0.06***	0.11***
CZK	0.02	0.07	0.03	0.09*	0.02	0.07
HUF	0.00	0.04	0.02	0.07	0.01	0.05
MXN	-0.01	0.03	-0.01	0.02	-0.01	0.02
PLN	0.00	0.02	0.02	0.05	0.00	0.01
THB	0.00	0.01	0.01	0.02	0.00	0.01
ZAR	0.06	0.15***	0.06**	0.14***	0.07	0.17***

This table shows results of 48 regressions: $Ret_{i,h,t} = \alpha + \gamma_1 * \beta_t + \gamma_2 * Ret_{i,h,t-h}$ *. The dependent variables are the returns of the emerging market currencies for three and six months. Each regression has as independent variables the mean slope of an implied volatility term structure of commodity currencies (AUD, NZD and CAD), the lagged dependent variable and a constant. All the independent variables are lagged. The independent variables are the slope of at-the-money implied volatility, the slope of the left-tail 10-delta implied volatility, and the slope of the right-tail 10-delta implied volatility. Estimates of the constants and lagged dependent variable coefficients are omitted. The statistics marked in *, ** and *** are significant at least at 1%, 5% and 10%. The t-statistics are Hansen-Hodrick HAC with h+1 lags, where h is the size of the return window. The sample period is from 2002 to 2016, on a daily overlapping basis.*