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Foreign exchange option volatilities: Observations, efficiency, and the measurement of financial openness

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Foreign exchange option volatilities: Observations, efficiency, and the measurement of financial openness*

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Abstract

Deviations from efficiency conditions related to the prices of foreign exchange options are investigated. It is observed that systematic biases manifest between the prices of options and the actual at-expiry payouts on those options over long-term horizons. More concretely, a quantifiable wedge is evident between the implied volatility charged by market-makers (time t) and the observed realized volatility over the period the option is active (time $t+1$), based on an expansive dataset covering thirty-five currency pairs representing both developed and emerging economies. Establishing an appropriate measure for realized volatility, the benchmark, is central to this exercise. The standard approach uses daily data and is largely inconsistent with the manner in which foreign exchange option market-makers manage the risk in their portfolios. In practice, the writer of an option will buy or sell the underlying asset multiple times a day in order to hedge the exposure created by the option. Because the number and frequency of these delta-hedge trades are based on intraday fluctuations of spot rates, I propose a calibration improvement to realized volatility measurement that uses high-frequency exchange rate data. Preliminary evidence suggests there is a linkage between the 'implied versus realized volatility' wedge and financial openness, as the wedge approaches zero for countries with fully open borders, and non-zero for currencies of countries where financial openness is subject to regulation and restriction[1]. I conclude with a discussion on the alternate explanations for this wedge. Future research will be devoted to formalizing the linkage, with the ultimate objective of introducing a new *de facto* measure.

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[1]Based on a correlation analysis between normalized wedge values and openness readings from Chinn-Ito index, a *de jure* measure of financial openness.

1 Efficiency in foreign exchange markets

Tests of efficiency in foreign exchange markets are typically associated with the following three parity conditions: purchasing power parity (PPP), uncovered interest rate parity (UIP), and real interest parity (RIP).

Purchasing power parity (PPP) links the changes in exchange rates to those in relative price indices in two countries. The relationship is derived from the basic idea that, in the absence of trade restrictions, prices of similar commodities cannot differ between two countries because arbitragers will take advantage of such situations until price differences are eliminated. This "Law of One Price" leads logically to the idea that what is true of one commodity should be true of the economy as a whole (the price level in two countries should be linked through the exchange rate) and hence to the notion that exchange rate changes are tied to inflation rate differences. The PPP theory has a long history in economics, dating back several centuries, but the specific terminology was introduced in the years after World War I during the international policy debate concerning the appropriate level for nominal exchange rates among the major industrialized countries after the large-scale inflations during and after the war[2]. Today the idea of PPP, in some form, is widely accepted among academic economists as being an anchor for long-run exchange rates, most recently, for instance, a variant involving the Harrod-Balassa-Samuelson model of equilibrium exchange rates has attracted renewed interest as a desirable modification in explaining the excessive strength of the Japanese Yen. The empirical evidence, however, is overwhelmingly against PPP, especially over the short-run. Taylor and Taylor (2004) provide a thorough summary of the PPP debate.

Uncovered interest rate parity (UIP) postulates that the expected change in the bilateral exchange rate between two countries is such that interest rate parity across borders is preserved. Empirically-speaking, however, there is strong evidence that the forward rate is a biased estimate of the future spot rate, or in other words, the higher interest rate currency tends to not depreciate as much as predicted by UIP. In fact, during the years known as the Great Moderation (2002-2007), high-yielding currencies actually appreciated versus lower-yielding counterparts. This result implies apparent predictability of excess returns over UIP. Exploiting this bias has given rise to so-called carry-trade investors who have reaped great profits from the strategy[3]. Along similar lines, multinational corporations, investment managers, and pension funds holding equities, bonds, and other hard assets across Emerging Market (EM) countries have achieved higher total returns by choosing to stay unhedged on the currency component of the investment. Fama (1984) outlines the widely accepted standard procedure to test UIP. Attempts to explain this phenomenon, widely deemed

[2]See Cassel (1918).
[3]See Galati et al. (2007).

one of the remaining puzzles of international finance, by Frankel and Engel (1984), Domowitz and Hakkio (1985), Hodrick (1987), Cumby (1988), Hodrick (1989), Engel (1996), Mark and Wu (1997), and Chinn and Frankel (2002) have involved models of risk premia. Research based on explanations citing peso problems and bubbles, as outlined by Lewis (1995), highlight the empirical limitations, especially involving EM currencies. Moreover, Backus, Gregory, and Telmer (1993), Bansal, Gallant, Hussey, and Tauchen (1995), and Bekaert (1996) have constructed arguments based on consumption-based asset pricing theories. Frankel and Froot (1987) and Bekaert, Hodrick, and Marshall (1997) have used expected utility theory, while Backus, Foresi, and Telmer (2001) incorporate the impact of term-structure models. Most recently Evans and Lyons (2002) suggests a microstructural approach based on the finding that order flow drives exchange rates.

Real interest parity (RIP) argues that real interest rates should be equalized across borders, assuming agents form their expectations rationally and there is no barrier to trade or capital flow. Although empirical evidence in favor of RIP is once again limited, the concept has taken on increased importance in today's global interconnected world in which linkages among national financial markets have gradually strengthened, and an integrated international capital market has emerged. Early work by Cumby and Obstfeld (1984), Mishkin (1984), Cumby and Mishkin (1986), Blundell-Wignall and Browne (1991), and Taylor (1991) do not support RIP, however all implicitly assume real interest rates are stationary. In contrast, recent studies that assume real interest rates are nonstationary, have found strong comovement between interest rates across borders using cointegration techniques. Goodwin and Grennes (1994), Modjtahedi (1987) and Kugler and Neusser (1993) found the U.S. real interest rate to have a predictive content for other OECD countries, and Ferreira (2003) also found support for RIP between developing and emerging countries.

In addition, RIP serves as the formal definition for financial integration. If a particular country's interest rate demonstrates parity with the world interest rate, then it can be established that this country has achieved integration with the global economy. Often in macroeconomic literature, the terms financial openness and financial integration are used interchangeably. Hong-Giang Le (2000), however, provides a formal definition of the difference between both concepts using a slight modification of the neoclassical growth model[4]. Financial openness which we will address in this paper, then, can be thought of as the means to an end goal, financial integration[5], one of three key central bank policy objectives that encompass the policy Trilemma[6].

[4]Based on the original work by Benge and Wells (1998).
[5]Perfect financial integration is defined as the situation in which parity of real interest rates is guaranteed across borders.
[6]See Aizenman (2010).

2 Efficiency of financial asset option prices

Tests for efficiency related to the prices of financial asset options can be broken down into two types. The first set of tests evaluates whether the expectations hypothesis holds for the term structure of options prices. It is the analogue of the question addressed in Froot (1990) and Campbell and Shiller (1991) for the term structure of interest rates. Stated differently, the research objective is to ascertain whether longer-dated options provide an accurate predictor of the future prices of shorter-dated options. Campa and Chang (1995) evaluate foreign exchange options and find support for the expectations hypothesis, albeit based on a limited dataset covering only a handful of currency pairs and a narrow time window. Arguments against have cited misspecifications in the term structure of implied volatility and difficulties with accurately proxying expected future volatilities.

The second type of test investigates whether the price of an option is consistent with the risk being hedged by its holder. Or equivalently, to what extent do implied volatilities (time t) predict the observed standard deviation of financial asset prices over the tenor of the option (time $t + 1$)? Early work by Latane and Rendleman (1976) and Chiras and Manaster (1978) conclude that implied volatility on equity options is a more accurate measure than historical based estimates, suggesting that option prices are deemed fair and commensurate with the underlying risk. Jorion (1995) reaches the same conclusion for currency markets. Other studies have disagreed however, using a variety of datasets and quantitative approaches. Day and Lewis (1992), Lamourex and Lastrapes (1993), and Canina and Figlewski (1993) conclude that biases exist between prices and the risk being hedged.

Along these lines, I will investigate the efficiency of foreign exchange option prices using an expansive dataset covering thirty-five currency pairs, representing both developed and emerging economies. Note, it is typical in this literature to use the terms 'implied volatility' and 'option price' interchangeably, although the latter is commonly used within econometric specifications and empirical testing analyses[7].

3 About implied volatility

Implied volatility, the principal driver of currency option prices, represents the market's best guess (time t) about future realized volatility (time $t+1$). The higher (lower) the implied volatility, the greater (lower) the perceived risk in the currency, and thus the more (less) expensive the option.

[7] Working directly with implied volatility as opposed to outright prices expressed in raw dollars or as a percentage of notional amounts is consistent with the way foreign exchange options trade in over-the-counter markets.

Figures 1 and 2 show implied volatility versus realized volatility for options on the EURUSD (number of US dollars per 1 euro) and USDCNY (number of Chinese renminbi per 1 dollar) exchange rates, respectively. It is visually evident that over the period depicted, implied volatility in period t tracks realized volatility over period $t+1$ quite closely for EURUSD, while consistently overshooting in the case of USDCNY. Whenever realized volatility exceeds implied volatility, we can interpret this to mean that the true risk exceeded the perceived risk, and thus the option price would have been too low. If implied exceeds realized however, the price paid for the option would have been too high, as compared to the actual outcome. A key objective of this study is to investigate why this situation seems to be the norm for options on the Chinese renminbi, and if possible to extrapolate intuition gained to other areas.

Figure 1: EURUSD implied versus realized volatility

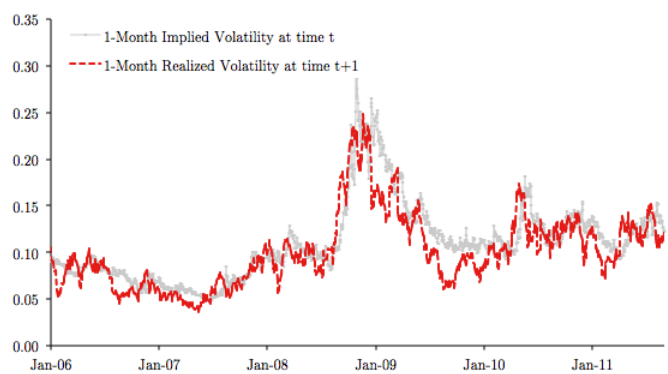
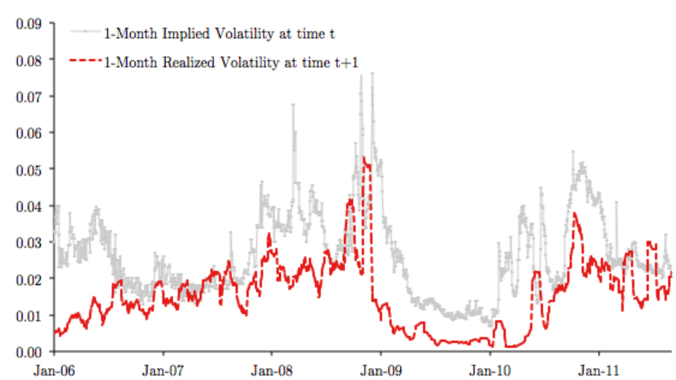


Figure 2: USDCNY implied versus realized volatility



Implied volatility is determined not by a single formula or methodology, but by a wide set of factors including but not limited to those listed in Table 1. This is analogous to the manner in which flood insurance rates are set for instance. Factors range from the location, design and age of the structure, to the recorded history of rains, earthquakes, and tsunamis for a particular region. Fear, such as that which follows a highly publicized natural disaster, also plays a role in the premium pricing, albeit an unquantifiable one.

Table 1: Factors that impact the level of implied volatility

Description	Is impact quantifiable?
Historical realized volatility	Yes
Supply and demand dynamics	Yes
Global currency / flows	Yes
Correlation to other currency / asset prices	Yes
Option risk reversal (Preference of calls versus puts)	Yes
Tax, accounting, disclosure regulation	No
Existence of dual-currency market	No
Currency convertibility restrictions	No
Capital account restrictions	No
Event risk (geopolitical, social unrest, etc.)	No

At the extremes, a currency pair that trades continuously, free of restriction with ample liquidity on a global scale such as the EURUSD exchange rate would be expected to generate a reading of $\psi = 1$ over the long run, while a currency that trades with heavy restriction, limited access, convertibility and liquidity such as the Chinese renminbi would be expected to generate a reading of $\psi \neq 1$ in the following formulation:

$$Y_t = \psi \tilde{X}_{t+1} + \mu_t \tag{1}$$

where Y_t is implied volatility at time t, X_{t+1} is realized volatility over $t+1$, the period over which the option is active, ψ is the wedge between implied and realized, and μ are the i.i.d. errors. The wedge between implied volatility charged by market-markers and realized volatility over the protection period is then more prevalent for options that insure against currency risks that can be characterized as less quantifiable and riddled with unknown unknowns. It should be noted that all options considered for this study trade on a global scale, despite the access and convertibility restrictions imposed on some of the underlying currencies themselves. Active derivative markets exist for such currencies, enabling multinational corporations to hedge foreign exchange risks and hedge funds to express speculative views. Options on restricted currencies trade on a non-deliverable basis[8].

[8] This includes non-deliverable forwards (NDFs) and non-deliverable options (NDOs). At expiry, the holder of an in-the-money call option that trades on a non-deliverable basis is entitled to the favorable cash-settlement between the strike and the prevailing spot exchange rate. The holder cannot take delivery of the currency at a lower price as is the case for standard options. Note, however, that the profit is the same under both settlement scenarios.

4 A suitable measure of realized volatility

As established, implied volatility is an observed variable determined by the market, while realized volatility is latent. Establishing an appropriate measure for realized volatility, the benchmark, is central to this study. The standard formula for realized volatility, X, uses one spot observation per day in the following:

$$X = \sqrt{\tfrac{260}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{2}$$

where n is the number of days in the sample, the annualization factor is 260 for the approximate number of business days in a given year, and x_i are the 1-day log returns[9].

This widely accepted textbook approach is problematic for a number of reasons. For one, currency options are quoted on a 365-day basis, thus representing a mismatch in day count. For instance, an option quoted and dealt on Friday for expiry the following Monday has 3 days of time value, comprised of one business day and two-weekend dates. The standard deviation formula over this same time period in contrast would pick up a single observation, the change in price from close of business Friday to close of business Monday. Another issue arises due to the low granularity of daily spot data. While developed market currencies like the euro, the British pound, and the Swiss franc trade 24-hours a day, most EM currencies trade only during local business hours. Thus, using only a single observation per day grossly under-represents actual price action. In addition, once-per-day readings are typically gathered at 5pm Eastern Standard Time (EST), the close of business in New York. Many Asian currency markets have been closed for hours at 5pm EST, since close of business in Asian time zones. The price reflected on the screen, however, may have gravitated away from the actual closing price due to positioning, rebalancing of overnight order books, and supply and demand conditions in offshore non-deliverable markets. This market dynamic has the potential to introduce systematic bias.

In order to correct the deficiencies described, I propose calibration methodology for realized volatility using high-frequency exchange rate data based Andersen et al. (2003), noting that there are diminishing returns to the amount of data used. The higher the frequency of observations, the greater the amount of noise that is introduced into the calculation. In the limit, a price change registered in the time series may come from a change in the bid or ask price for a particular dealer, not necessarily from a trade that constitutes volatility. Using market price data captured every 30 minutes strikes an appropriate balance between added granularity and administrative burden. In addition, the data is subject to a substantial amount of filtering

[9]See Chapter 11 in "Options, Futures & Other Derivatives", fourth edition, by John C. Hull.

to attain the proper calibration[10]. The revised standard deviation, $\tilde{X}$, is derived from the following:

$$\tilde{X} = \sqrt{\frac{365}{T} \sum_{i=1}^{\tilde{n}} \left[ln \left(\frac{S_i}{S_{i-1}} \right) \right]^2} \tag{3}$$

where T is the number of calendar days in observation period, S is the spot rate, and $\tilde{n}$ is the number of 30-minute intervals in T.

This approach has the added benefit that it more closely mimics the way market-makers manage the gamma risk in currency option portfolios. As spot exchange rates move, the writer of the option must buy and sell the underlying currency according to changes in the expected payout of the option. Such rebalancing generally occurs multiple times a day in actual practice, and thus a volatility measurement methodology that uses multiple observations per day is more consistent with this process versus using a single rate per day, the standard textbook approach aforementioned.

5 Data

Currencies and currency derivatives trade either directly between counterparties, a medium referred to as over-the-counter (OTC), or in centralized exchanges. A great majority of volumes are executed directly between counterparties at a ratio of 5-to-1 versus centralized exchanges[11], and thus OTC data is more appropriate for this analysis. With regard to options, one key difference that also makes OTC data better suited than the alternative for empirical academic work has to do with standardization, or more importantly the lack of it. In OTC markets, option prices are quoted in terms of implied volatilities, as opposed to money prices for specific strikes as in centralized exchanges. Traders, hedgers, and speculators can fully customize the desired risk profile by specifying all critical details of an option (currency pair, notional size, direction, strike, expiry date) and will agree to the price generated by the Garman-Kohlhagen formula, the extension of Black Scholes for currency options. In other words, the money price is a formality in OTC trading. Implied volatility will determine if a transaction is made, and thus implied volatility curves are very closely tracked and analyzed by buyers and sellers alike. This is not the case in centralized exchanges, where market participants follow prices for standardized contracts that have been pre-fabricated by the exchange.

[10]Changes in order of magnitude of $\frac{Y}{\sqrt{260 \times 48}}$ are ignored and do not enter into the calculation. This amounts to about 10 pips for medium volatility currencies

[11] According to data on OTC volumes as reported in the 2010 BIS Triennial Central Bank Survey on FX and Derivatives.

The implied volatility there is a by-product, not the principal driver in dealing.

Implied volatilities are quoted in annualized percentage terms across the curve. The benchmark 'on the run' tenors are 1-week, 2-week, 1-month, 2-month, 3-month, 6-month, 1-year, and then annually to 5-years for major currencies. Longer tenors are available, but trade with limited liquidity. For each currency pair, I will use implied volatilities for 1-month options. This tenor is the most actively traded, has the greatest liquidity and the narrowest spreads. This data is available daily.

For realized volatility calculations, I will use spot prices captured every 30-minutes (i.e. 48 observations per day, 336 observations per week, 17520 per year). Even though technically currency markets are closed between Friday 5pm EST until Asian markets open on Monday morning local time (Sunday late afternoon EST, New York), this block of time will be included in the time series to ensure consistency with implied volatility quotes. Recall the filtering process will ensure such inclusion will not result in added noise, yet would capture the impact of important news events which may trigger trading during off-market hours.

In order to avoid the pitfalls that arise from using overlapping data such as inefficient estimators, correlated errors, and artificially small standard errors[12], I will construct regressions based on disjoint observations, monthly snapshots of 1-month implied versus realized volatilities.

There is 3 to 4 years of reliable data for the expanded set of 35 currencies below, representing both developed and emerging economies. Note all spot exchange rates and implied volatilities are quoted against the USD, standard market convention.

Table 2: Set of Currencies (All quoted versus USD)

G10	**LATAM**	**ASIA**	**EEMEA**
AUD	ARS	CNY	AED
CAD	BRL	HKD	CZK
CHF	CLP	IDR	HUF
EUR	COP	INR	ILS
GBP	MXN	KRW	PLN
JPY	PEN	MYR	RON
NOK		PHP	RUB
NZD		SGD	SAR
SEK		THB	TRY
		TWD	ZAR

[12]See Harri and Brorsen (2009) for more.

6 Quantification of deviations from efficiency conditions

The results of the regressions of implied volatility at time t versus realized volatility at $t+1$ per the specification in equation 1 are as follows.

Table 3: Tests of implied versus realized volatility (2009-2011)

$$Y_t = \psi \tilde{X}_{t+1} + \mu_t$$

	Currency	ψ	Durbin-Watson	$H_0 : \psi = 1$ $H_a : \psi \neq 1$ (5%)
G10	AUD	0.9151 (0.037)	1.87	Reject
	CAD	0.9306 (0.033)	1.46	Fail to reject
	CHF	0.8305 (0.038)	1.46	Reject
	EUR	0.9931 (0.037)	1.92	Fail to reject
	GBP	0.9885 (0.027)	2.15	Fail to reject
	JPY	0.9735 (0.048)	2.06	Fail to reject
	NOK	0.9501 (0.036)	1.90	Fail to reject
	NZD	0.9134 (0.034)	1.78	Reject
	SEK	0.9004 (0.034)	1.81	Reject
LATAM	ARS	3.6142 (0.714)	0.85*	Reject
	BRL	1.2227 (0.071)	1.84	Reject
	CLP	1.8285 (0.079)	1.79	Reject
	COP	1.7533 (0.110)	1.59	Reject
	MXN	1.0133 (0.064)	1.60	Fail to reject
	PEN	1.6395 (0.189)	1.05*	Reject
ASIA	CNY	1.1754 (0.147)	1.00*	Fail to reject
	HKD	1.0336 (0.090)	0.70*	Fail to reject
	IDR	1.5419 (0.143)	1.20*	Reject
	INR	2.2519 (0.137)	1.28*	Reject
	KRW	1.8380 (0.119)	1.84	Reject
	MYR	1.5939 (0.083)	1.18*	Reject
	PHP	1.6482 (0.139)	1.49	Reject
	SGD	1.0480 (0.059)	1.60	Fail to reject
	THB	1.2267 (0.101)	1.38*	Reject
	TWD	1.9068 (0.102)	1.89	Reject
EEMEA	AED	0.7461 (0.235)	0.32*	Fail to reject
	CZK	1.0192 (0.052)	1.36*	Fail to reject
	HUF	0.9260 (0.039)	1.19*	Fail to reject
	ILS	1.0824 (0.050)	1.63	Fail to reject
	PLN	0.9183 (0.044)	1.64	Fail to reject
	RON	1.2443 (0.057)	1.01*	Reject
	RUB	1.4388 (0.083)	1.75	Reject
	SAR	9.3745 (4.414)	0.24*	Fail to reject
	TRY	1.3344 (0.064)	1.77	Reject
	ZAR	0.9236 (0.042)	1.75	Fail to reject

** Errors autocorrelated at the 5% level*

For each regression, the Durbin-Watson Statistic which tests for the existence of autocorrelation among the errors is reported[13]. In addition, the null hypothesis evaluates whether the wedge between implied and realized volatility exists for each particular currency pair. As initially conjectured, currencies that trade continuously, free of restriction with ample liquidity such as the euro, the Canadian dollar, and the Japanese yen generated readings of $\psi = 1$ or not significantly different than one over sufficiently long periods, while currencies that trade with heavy restriction, limited access, convertibility and liquidity such as the Chinese renminbi, the Peruvian sol, and the Thai baht generated significant readings of $\psi \neq 1$. The specification outlined in equation 1 is suitable for most currency pairs following an investigation of the autocorrelation of error terms. This is confirmed by the results of the Durbin-Watson tests.

The next step is to investigate whether any heterogeneity exists across currency pairs. For instance, sovereign debt woes across the Eurozone may spark a general wave of risk aversion and ultimately impact currency volatility differentials across the board, a contagion effect that is quite common in today's highly interconnected markets. It would be beneficial to identify and isolate such impacts before formulation of rankings, strata and ultimately extrapolation to financial openness. Using the EURUSD exchange rate as the base by which other currency pairs will be measured against, a fixed-effects regression will be fit according to the following formulation:

$$Y_{i,t} = \beta \tilde{X}_{i,t+1} + \eta_i D_i + \mu_{i,t} \tag{4}$$

where Y_t is implied volatility at time t, X_{t+1} is realized volatility over $t+1$, β is the coefficient for the fixed effect common for all currencies i, D represents the binary dummy variables for currencies $i = 2$ to n (recall EURUSD is used as base in a fixed effect regression setting), η is the coefficient of each individual currency, and μ are i.i.d. errors. Table 4 contains the results of this fixed effects regression.

The coefficient for the fixed effect is significant and dictates that a 1% rise in implied volatility today (expressed in annualized terms), would translate into a 1.5% rise in realized volatility in period $t+1$. By construction, this effect is common across currency pairs. The null hypothesis we are evaluating in this formulation is that $\eta = 0$, while the alternative hypothesis is that $\eta \neq 0$, a two-tailed test. The individual coefficients give us a sense of the residual effect that is germane to each individual currency. Insignificant coefficients describe currency pairs for which the wedge between implied and realized volatility is minimal, net of the fixed effect. This is the case for the currencies of Hong Kong, United Arab Emirates, and Saudi Arabia. The rest of the currencies show significant non-zero coefficients[14], however with differing magnitudes

[13] This is based on Farebrother (1980), Durbin-Watson test for serial correlation when there is no intercept in the regression.
[14] Significance at the 5% level.

expressed in the same units. Placed in this context, it is possible to generate a ranking based on the relative magnitudes of the coefficients. The larger the coefficient, the larger the wedge between implied and realized volatility.

Table 4: Fixed effects regression results (2009-2011)

$Y_{i,t} = \beta\tilde{X}_{i,t+1} + \eta_i D_i + \mu_{i,t}$			
R-Square: 0.9450			
F: 559 (p=0)			
Degrees of freedom: 35			
Total observations: 1175			
		Coefficients	$H_0 : \eta = 0$ $H_a : \eta \neq 0$ (5%)
β	Fixed effect	0.6710	Reject
η	AUD	0.0464	Reject
	CAD	0.0374	Reject
	CHF	0.0307	Reject
	GBP	0.0408	Reject
	JPY	0.0442	Reject
	NOK	0.0513	Reject
	NZD	0.0476	Reject
	SEK	0.0468	Reject
	ARS	0.0811	Reject
	BRL	0.0823	Reject
	CLP	0.0958	Reject
	COP	0.1115	Reject
	MXN	0.0594	Reject
	PEN	0.0697	Reject
	CNY	0.0158	Reject
	HKD	0.0040	Fail to reject
	IDR	0.0909	Reject
	INR	0.0746	Reject
	KRW	0.1112	Reject
	MYR	0.0542	Reject
	PHP	0.0620	Reject
	SGD	0.0315	Reject
	THB	0.0404	Reject
	TWD	0.0475	Reject
	AED	0.0070	Fail to reject
	CZK	0.0649	Reject
	HUF	0.0627	Reject
	ILS	0.0408	Reject
	PLN	0.0631	Reject
	RON	0.0820	Reject
	RUB	0.0728	Reject
	SAR	0.0093	Fail to reject
	TRY	0.0735	Reject
	ZAR	0.0583	Reject

The next step is normalizing the coefficients in Table 4 so that fair comparisons can be made across currencies. A coefficient of 0.04 for a low volatility currency is much more meaningful than a coefficient of 0.04 for a high volatility currency. Thus, I will divide the individual coefficients by the average implied volatility for the period used in the regression (2009-2011). In doing so, the wedge readings will be restricted to the range [0, 1), with the upper-end of the spectrum representing currencies for which the wedge between implied and realized volatility is greatest. Table 5 contains the adjusted normalized results.

Table 5: Normalized values for individual coefficients from fixed effects regression

HIGH		**MEDIUM**		**LOW**	
United States	0.00	Switzerland	0.25	Romania	0.49
Austria	0.00	Sweden	0.28	Brazil	0.50
Belgium	0.00	New Zealand	0.29	Turkey	0.53
Cyprus	0.00	Hungary	0.30	Thailand	0.55
Estonia	0.00	Canada	0.30	Russia	0.57
Finland	0.00	Australia	0.30	Malaysia	0.61
France	0.00	Poland	0.30	China	0.65
Germany	0.00	South Africa	0.31	Chile	0.65
Greece	0.00	Norway	0.32	Philippines	0.65
Ireland	0.00	United Kingdom	0.34	Colombia	0.66
Italy	0.00	Japan	0.35	Taiwan	0.67
Luxembourg	0.00	Czech Republic	0.38	S. Korea	0.68
Malta	0.00	Mexico	0.39	Indonesia	0.69
Netherlands	0.00	Israel	0.41	India	0.73
Portugal	0.00	Singapore	0.41	Peru	0.74
Slovak Republic	0.00			Argentina	0.90
Slovenia	0.00				
Spain	0.00				
Hong Kong	0.00				
UAE	0.00				

7 Linking foreign exchange volatilities to financial openness

Financial openness refers to the degree to which capital is allowed to flow freely in and out of a country's borders. The post credit-crisis period has seen great proliferation in the methods used by central banks to restrict financial openness as authorities struggle with multiple mandates, a mass reallocation of wealth and capital out of developed into emerging economies, rapid capital flight out of emerging markets during bouts of risk aversion, global investor search for safe-havens, interconnected financial markets, and rising exchange rate volatility. The success of such efforts in meeting stated objectives, however, remains difficult to ascertain. Measurement of financial openness itself remains a challenge. *De jure* and *de facto* measures have been developed to characterize, quantify, compare and contrast the degree of financial openness for a particular country. *De jure* methods[15] are based on known laws and regulatory filings while *de facto* measures[16], in contrast, are derived retrospectively using empirical time series data. There are pros and cons to each approach, and the degree of usefulness varies by application. In one way or another, *de jure* methods use IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER) which measures over 60 different types of controls. Some of the limitations of *de jure* measures of financial openness include: 1) The inevitable interplay between private sector transactions influence and many times work to nullify a country's regulation efforts, 2) The IMF's AREAER includes limitations on FX transactions which may or may not impede capital account transactions, 3) Lags exist between the introduction of new measures and IMF's annual report, and 4) Measures do not address the degree of enforcement or success post implementation. On the other hand, priced-based *de facto* measures are based on the logic that, irrespective of the volume and direction of flows, true integration of capital markets should be reflected in common prices of similar financial instruments across national borders. Isolating the linkage between measurable variables and financial openness is a challenge, however. In addition, deviations from UIP or ICAPM may be attributed to other factors such as market risk aversion. Quantity-based *de facto* measures are based on actual capital flows data, arguably a more direct approach, although such data is highly volatile and subject to measurement error and revisions.

The rationale behind linking volatility differentials to the degree of financial openness for a particular country has to do with the set of factors that drive option prices for that country's currency. My conjecture is that if a country's borders are fully open for trade and commerce, option prices for the currency will be determined by a heavier concentration of factors that can be characterized as quantifiable from table 1. This is measureable risk, which means systematic biases between implied and realized volatility should not persist over long-term horizons. While the outcome is unknown, the odds can be accurately measured and the known risk may be converted to effective certainty via insurance or in this context, the purchase of currency option protection. As openness decreases however, the concentration of factors that drive option prices becomes more skewed towards the 'not easily quantifiable' set. This is immeasurable risk, otherwise known as uncertainty[17]. Proper odds cannot be determined due to insufficient information. Insuring against such unquantifiable risks requires that the insured incur an 'uncertainty premium'. The uncertainty premium manifests itself as the wedge between premiums and subsequent payouts, or equivalently implied volatility

[15]See Grilli and Milesi-Ferretti (1995), Rodrik (1998), Quinn (1997, 2003), Chinn and Ito (2005), Mody and Murshid (2005), Edwards (2005).

[16]See Lane and Milesi-Ferreti (2007), Cheung et al. (2003), De Gregorio (1998).

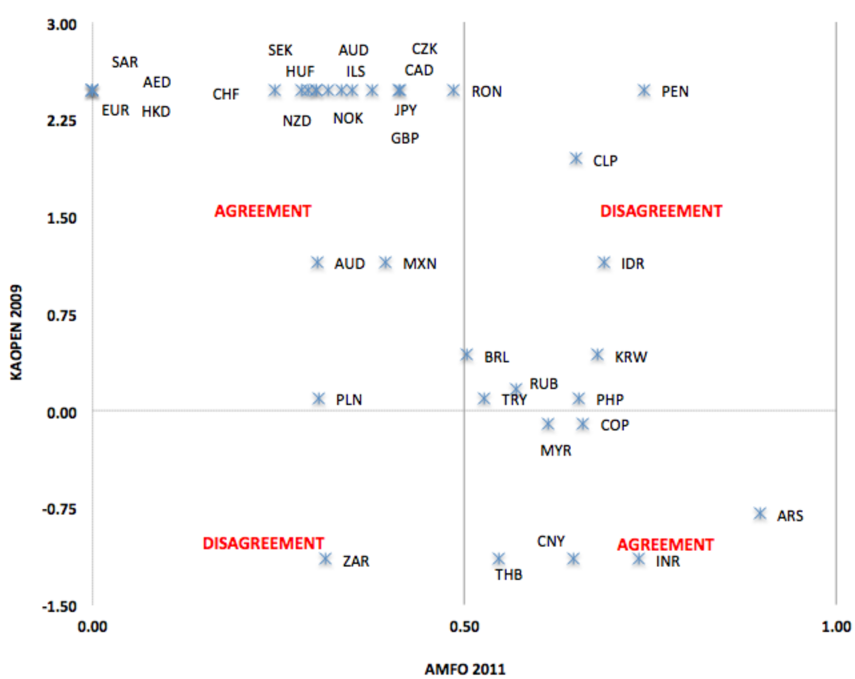
[17]This concept was originally formalized by Frank Knight in his 1921 book "Risk, Uncertainty, and Profit".

charged by market-makers and future realized volatility.

Along these lines, equations 1 and 3 represent formulations that link the 'implied versus realized volatility' wedge with financial openness, without controlling for other factors that may account for this wedge. Although potential modifications to such formulations would be addressed in future research, this conjecture may be initially validated by running a simple correlation analysis between the normalized coefficient readings in Table 5, with the latest readings available for the Chin-Ito index[18], one of the leading measures of openness. The Chinn-Ito index (KAOPEN), introduced by Chinn and Ito in 2006, is a *de jure* approach based on a set of binary dummy variables that codify the tabulation of restrictions on cross-border financial transactions as reported in the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER). The dummy variable predictors address whether the following is true for each particular country: (1) Presence of multiple exchange rates, (2) Restrictions on current account transactions, (3) Restrictions on capital account transactions, and (4) Requirements of the surrender of export proceeds. Classifications range from -1.83 to 2.47 (lowest degree of openness to greatest) and there are 21 values for 181 countries.

On an aggregate basis, there is a 68% correlation between the normalized wedge readings and KAOPEN[19]. Figure 3 shows a visual representation.

Figure 3: Scatterplot of AMFO and KAOPEN readings



[18]Annual readings available, latest release was 2009.
[19]This is the absolute value of the measure.

Quadrants I and III represent instances where the two measures are divergent. A clear majority of these are in Quadrant I, instances where KAOPEN reports a greater degree of financial openness that would be suggested by the normalized values in this study. One example is Peru. While historically a country with open borders for trade and commerce, in 2010, the Central Bank of Peru announced a set of anti-openness measures specifically aimed at stemming excessive appreciation in the sol. These measures include: 1) Increased capital gains taxes for non-residents, 2) New 30% income tax for settlement of derivative contract with offshore banks, 3) Increased reserve requirements for local banks for new credit lines and foreign currency transactions, 4) New bank limits on net FX positions, 5) Caps on private pension fund overseas investments along with new currency trading limits[20].

Because the KAOPEN index relies on a report published annually by the IMF, there is generally a lag in the release of the latest readings. Thus, the reading for Peru would not reflect the latest policy changes. This is a limitation which in general *de facto* measures of openness look to overcome by construction.

8 Closing comments

The cornerstone of this and subsequent studies is that systematic biases that manifest between the prices of foreign exchange options and the actual at-expiry payouts on these options over long-term horizons[21] may be used to explain financial openness, after controlling for other factors that may account for this wedge. One immediate confounding factor, which has been properly addressed, would arise from unequal access to the respective options markets. It was established that all options considered for this study trade on a global scale, despite the access and convertibility restrictions imposed on some of the underlying currencies themselves. In other words, a hedge fund manager in New York cannot buy and hold Korean won without having a registered entity within the Korean borders and satisfying an onerous set of regulatory hurdles set forth by the central bank. But, he or she would be allowed to buy a call option on the Korean won on a 'non-deliverable basis', and thereby replicate the desired risk profile, without such restrictions. Thus, equal access is achieved across currency pairs, reflecting the opinions of market participants globally. Another possible explanation for the wedge has to do with market size and depth. Options on major currencies such as the euro, the pound, and the yen trade at multiple times the volumes of EM currencies such as the Argentine peso, Taiwan dollar, and Hungarian forint. Lower volumes manifest themselves in larger bid/ask trading spreads, higher transaction costs, and lower liquidity. These factors individually or in

[20] According to HSBC FX Strategy.

[21] Verifiable over a random collection of exchange rate paths, or equivalently a sufficiently long history of past prices.

concert may contribute to the wedge between implied and realized volatility. Counterparty risk may also play a role. While all broker-dealers offer option prices on the major currencies, only the larger broker-dealer counterparties offer prices on the lower volume EM currencies. Credit-default swap (CDS) spreads do not support the too-big-too-fail rationale, meaning that some of the larger counterparties are perceived to carry greater proportional risks on respective balance sheets. Wider CDS spreads translate into higher trading costs that would be allocated disproportionally to the 'lower volume' set of currencies. Furthermore, one-off currency revaluations (and expectations of such) have the potential to cause realized volatility calculations to spike far above implied volatility. When the Swiss National Bank announced instituting a hard peg of the franc versus the euro in September 2011, realized volatility for the 1-month tenor spiked to over 35% on an annualized basis, far outpacing the actual prices paid for options. Outlier observations such as the one described have the potential to distort wedge calculations. Finally the introduction of new regulation such as the Volcker Rule and the Dodd-Frank initiative may have unintended and unquantifiable consequences on the trading of foreign exchange options, potentially showing up in the wedge between prices and subsequent payouts.

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