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Forecasting and Correlation Dynamics in Regional and Global Currency Trios

Ph.D. Thesis Booklet

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Content

1. Background, Motivation and Research Gaps

1.1. Background

The foreign exchange (FX) market represents the largest and most liquid financial market in the world, with a daily turnover exceeding USD 9 trillion according to the latest Bank for International Settlements survey (BIS, 2025). Unlike many other financial markets, trading takes place in a decentralized environment where exchange rates emerge through the interaction of market participants across different trading venues and time zones. Despite this decentralized structure, FX markets are governed by strict no-arbitrage relationships that impose powerful constraints on the behaviour of exchange rates.

Among these relationships, the principle of triangular arbitrage occupies a particularly important position. For any three currencies, the corresponding exchange rates must satisfy a mathematical identity that prevents the existence of riskless arbitrage opportunities. Consequently, exchange rates within a currency trio cannot evolve independently. Their volatilities, correlations, and dynamic interactions are structurally linked through the triangular relationship (Campa and Chang (1998)). This characteristic distinguishes FX markets from equity, bond, and commodity markets, where correlations are primarily empirical phenomena rather than outcomes of an underlying arbitrage mechanism.

The implications of triangular arbitrage extend beyond market efficiency. Because correlations between currency pairs are determined by volatility relationships, understanding correlation behaviour in FX markets requires a deeper examination of volatility dynamics, market structure, and trading conventions. Market participants rely heavily on correlation estimates when constructing hedging strategies, managing foreign exchange exposure, pricing multidimensional derivatives, and measuring portfolio risk. The

growing globalization of financial markets has further increased the importance of accurately modelling and forecasting exchange rate correlations, as investors are increasingly exposed to multiple currency risks simultaneously.

At the same time, developments in the derivatives market have created new approaches to measuring expected correlation. In addition to traditional time-series models based on historical observations, option prices provide information about future market expectations through implied volatilities and implied correlations. The question of whether option-implied measures provide superior forecasts compared to historical methods remains one of the central issues in the literature on currency correlation forecasting. Although a substantial body of evidence exists for major international currencies (Bollerslev and Engle (1993); Campa and Chang (1998); Walter and Lopez (2000); Castrén and Mazzotta (2005)), substantially less attention has been devoted to smaller regional currency markets.

1.2. Motivation

The motivation for this research originates from both practical market experience and academic inquiry. During early exposure to professional foreign exchange trading, inconsistencies were observed in publicly available forecasts for major currency pairs. Forecasts for exchange rates belonging to the same currency triangle occasionally implied relationships that were inconsistent with the triangular arbitrage condition. While such discrepancies could often be attributed to rounding or reporting errors, they raised a more fundamental question: how can currency markets exhibit substantially different correlation structures while simultaneously remaining consistent with no-arbitrage requirements?

This question naturally led to a broader investigation of the determinants of exchange rate correlation. Existing research has demonstrated that correlation structures vary considerably across currency groups. In particular, notable differences appear between major global currencies, such as the Japanese yen, Swiss franc, and

British pound, and regional currencies, including the Hungarian forint, Czech koruna, Polish zloty, Swedish krona, and Norwegian krone. These differences are visible not only in observed correlation levels but also in volatility patterns and market turnover distributions.

A further source of motivation emerges from the relationship between market microstructure and exchange rate dynamics. While numerous studies identify liquidity provision, information asymmetry, and trading intensity as determinants of volatility, considerably less research examines how market microstructural characteristics influence long-term correlation structures. In particular, differences in quotation conventions and the extent to which exchange rates are quoted directly or synthetically may represent an important but insufficiently explored determinant of correlation outcomes. Understanding this mechanism offers the possibility of linking observed market behaviour to a coherent theoretical framework.

1.3. Research Gaps

Despite substantial progress in the literature on exchange rate volatility and correlation, several important research gaps remain unresolved.

Gap 1: Limited evidence from regional currency markets

The majority of empirical studies focus on major global currencies. Consequently, many established conclusions regarding correlation forecasting, volatility dynamics, and market integration are derived from highly liquid currency pairs involving the US dollar, euro, Japanese yen, British pound, or Swiss franc.

Regional European currencies differ from major currencies in several dimensions, including liquidity conditions, turnover distribution, quoting conventions, and market depth. These characteristics may influence both volatility behaviour and correlation structures. However, systematic evidence comparing the forecasting performance of correlation models across major and regional currency trios remains

scarce. As a result, an important gap exists regarding the applicability of existing theoretical and empirical findings to regional FX markets.

Furthermore, given the mechanical relationship between exchange rate volatility and correlation in currency triangles, it may seem reasonable to view volatility forecasting and correlation forecasting as closely related, if not identical, forecasting challenges. By explicitly comparing the two, the dissertation identifies a number of non-intuitive findings that highlight important differences in their forecasting properties and determinants.

Gap 2: Insufficient understanding of currency-trio dynamics at sub-second frequencies

Most exchange rate research analyses currency pairs individually especially when standard microstructure related works are considered. While this approach is suitable for many applications, it overlooks the fact that exchange rates are connected through triangular arbitrage relationships. Consequently, studying currency pairs in isolation may fail to capture important aspects of price discovery and information transmission within the complete currency triangle.

A large body of microstructure research shows that quoting behaviour is highly heterogeneous across currencies and platforms. Payne (2003) demonstrates that some currency pairs update more slowly and largely follow information generated elsewhere. Berger et al. (2008) and Mancini et al. (2013) document substantial cross-platform differences in liquidity, order flow, and price-updating intensity. These findings complement institutional evidence summarised in King et al. (2011), who emphasise that in regional and emerging-market FX, one or more legs of a triangular system are often synthetically priced and updated less frequently. More recent evidence reinforces this picture of a structured, hub-based market: Hasbrouck and Levich (2019) document that the FX settlement network is organised around vehicle currencies, with most flows routed through a small number of hub pairs; Ranaldo and Somogyi (2021) show that the information content of order flow is strongly heterogeneous across currency pairs; and

Huang et al. (2025) show that dealers' constrained liquidity provision concentrates in specific pairs and times.

Although market microstructure research has extensively examined exchange rate dynamics, most studies rely on frequencies measured in seconds, minutes, or longer intervals. Meanwhile triangular arbitrage relationships imply that FX rates in an FX trio are linearly interdependent, this is not the case within fractions of a second. As a consequence, important aspects of dynamic adjustment may remain hidden when lower-frequency data are employed and can be explored using ultra-high frequency data – that could reveal the sequence of adjustments within the currency triangle. This constitutes a significant gap in understanding the dynamic mechanisms underlying observed correlation structures.

Gap 3: Lack of theoretical models explaining correlation regimes

The literature contains numerous methods for estimating and forecasting correlation. However, most approaches treat correlation as an observed statistical property rather than as an outcome generated by underlying market mechanisms.

Existing explanations often emphasize volatility differences, liquidity conditions, common information shocks, or macroeconomic factors (see, among others: Mueller et al. (2017), Chernov et al. (2024)). While these factors undoubtedly influence correlation outcomes, they do not fully explain the pronounced differences observed across currency groups.

Recent developments in agent-based and market microstructure modelling suggest that quotation architecture, arbitrage mechanisms, and market-maker behaviour may have important effects on realized correlation structures (Ciacci, et al., 2020). The absence of such a framework represents a substantial gap in the literature.

1.4. Positioning of the Dissertation

This dissertation seeks to address these research gaps through three interconnected research pillars.

First, it evaluates the forecasting performance of implied and time-series-based correlation estimates for regional and major currency trios. Particular attention is devoted to assessing whether option-implied information provides forecasting advantages in regional currency markets. Additionally, the forecasting performance of volatility and correlation models are compared driven by the analytical relationship between the two.

Second, it investigates dynamic interactions within currency triangles using ultra-high-frequency data. By applying vector autoregressive and local projection methodologies, the dissertation identifies impulse-response dynamics, directional spillovers, and leader-follower relationships that characterize different market structures.

Third, it further develops a market microstructure-based framework capable of reproducing empirically observed correlation patterns across currency groups. The proposed approach aims to provide a theoretical interpretation of the empirical findings and to demonstrate how quotation practices and arbitrage mechanisms contribute to the formation of different correlation regimes.

2. Data and Methodology

2.1. Introduction

While the first part of the empirical analysis focuses on forecasting currency correlations using daily market data and option-implied expectations, the second part investigates exchange-rate dynamics at ultra-high frequencies in order to uncover the market mechanisms underlying observed correlation structures.

The methodological framework therefore combines three complementary perspectives. First, implied and time-series-based

forecasting models are used to evaluate the predictability of foreign exchange correlations in both major and regional currency markets. Second, ultra-high-frequency econometric techniques are employed to identify impulse-response dynamics and directional spillovers within currency triangles. Third, the empirical findings are interpreted through a market microstructure perspective that links quotation conventions and trading patterns to the observed correlation regimes.

2.2. Data Sources and Sample Construction

2.2.1. Daily market data

The analysis of correlation forecasting relies on daily foreign exchange data obtained from Bloomberg. Spot exchange rates are represented by Bloomberg BGN spot rates (PX_LAST), covering the period between 31 March 2005 and 22 January 2026 of selected major and CEE/Scandinavian regional currencies. The corresponding option market information includes one-month at-the-money implied volatilities, risk reversals, and butterfly quotations of various moneyness to cover substantial part of the volatility smile used in the calculation of implied correlation measures.

Because option-implied volatility data are unavailable for several exchange rates prior to January 2006, and because the econometric models require a rolling estimation window of 500 trading days, the effective forecasting evaluation sample spans the period between 2 March 2007 and 24 December 2025.

2.2.2. Ultra-high-frequency data

The analysis of exchange-rate dynamics relies on tick-by-tick bid-ask quotations obtained from two publicly available data providers: TrueFX and Dukascopy Bank SA. Both sources provide millisecond-resolution quotations with comprehensive coverage of major currency markets. Dukascopy data are used for both major and regional currency trios, including the EUR-USD-JPY and EUR-USD-HUF

triangles, while TrueFX data serve primarily as a robustness check for major-currency results.

Exchange-rate quotations do not occur at fixed intervals, generating a highly uneven sequence of observations. Previous literature has identified this issue as a major obstacle when applying standard time-series techniques to high-frequency financial data. To address this problem, all tick-by-tick observations are aggregated into a regular time grid with 100- and 200-millisecond intervals. The choice of 100 and 200 milliseconds is motivated by empirical tests demonstrating that substantial information is lost when data are aggregated to one-second frequencies, whereas results remain stable when using 100-200-millisecond intervals.

2.3. Correlation Forecasting Methodologies

A central objective of the dissertation is the comparison of different approaches to forecasting exchange-rate correlations. Four alternative methodologies are considered, including two implied measures and four classes of time-series based forecasting models.

2.3.1. Implied correlation

The first implied measure is based on at-the-money (ATM) option-implied volatilities. Implied volatilities from option prices can be combined to derive a market-implied estimate of future correlation. Unlike historical measures, ATM implied correlation is forward-looking and incorporates market expectation regarding future exchange-rate movements.

To broaden the scope of the analysis, the dissertation also employs a variance-swap-based implied correlation measure. Following the approaches of Demeterfi et al. (1999) and Carr and Madan (2002), the methodology extends beyond ATM options and incorporates information from the entire implied volatility surface. Risk-reversal and butterfly quotations are used to reconstruct implied volatilities

across moneyness levels, allowing the estimation of variance-swap-implied correlations for one month horizon.

2.3.2. Time-series based correlations

The historical correlation model represents the benchmark forecasting approach. Future correlation is predicted using realized correlation observed over a preceding estimation window of identical length. However, the approach implicitly assumes a stable correlation structure and is therefore unable to adapt quickly to changing market conditions.

The Exponentially Weighted Moving Average (EWMA) model extends historical correlation by assigning greater weight to more recent observations. Following the RiskMetrics framework, exponentially declining weights are applied to past returns, allowing the forecast to respond more rapidly to changes in market conditions. In line with the literature, smoothing parameters of 0.94 and 0.97 are employed, while model estimation uses a rolling window of 500 trading days.

To account for conditional heteroskedasticity and asymmetric volatility responses, the dissertation applies the Glosten-Jagannathan-Runkle (GJR-GARCH) specification. The model allows negative and positive shocks to have different effects on future volatility, a feature particularly relevant for regional currency markets where adverse news often triggers disproportionately large volatility responses. The model is estimated over rolling 500-day windows, and volatility forecasts are generated recursively for the subsequent forecast horizon.

The final forecasting methodology is the Heterogeneous Autoregressive (HAR) model proposed by Corsi (2009). The HAR framework incorporates volatility information extracted from multiple time horizons and is motivated by the heterogeneous market hypothesis, which assumes that market participants operate at different investment horizons. The model utilizes daily, weekly, and

monthly realized variance measures and produces direct forecasts of cumulative future volatility.

2.4. Forecast Evaluation Framework

To ensure a comprehensive comparison of forecasting methods, several complementary evaluation metrics are employed. The primary measures include Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE), both of which compare forecasted correlations with realized correlations. RMSE places greater emphasis on large forecasting mistakes, whereas MAE provides a more robust measure in the presence of extreme forecast errors. Because correlation coefficients are naturally bounded between −1 and 1, the analysis also applies Fisher's z-transformation. The associated z-RMSE measure removes the bounded nature of correlation coefficients and stabilizes their variance, allowing more meaningful comparisons across different correlation regimes. A further measure is the Variance-Weighted RMSE (WRMSE), which assigns larger weights to forecast errors occurring during periods of elevated volatility. Finally, forecasting performance is evaluated using a correlation-based quasi-likelihood (QLIKE) loss function, which evaluates the adequacy of the entire dependence structure implied by a forecast and penalizes particularly strongly those forecasts that imply excessive confidence regarding future correlation levels.

2.5. Econometric Analysis of Exchange-Rate Dynamics

2.5.1. Vector Autoregressive (VAR) models

The central tool used to investigate high-frequency exchange-rate interactions is the Vector Autoregressive (VAR) model. In the VAR framework, each exchange-rate return is explained by its own lagged values together with lagged values of the remaining exchange rates within the currency triangle. The methodology is particularly appropriate for identifying dynamic interactions because the triangular arbitrage relationship implies that exchange-rate

adjustments occur sequentially rather than simultaneously. At sufficiently high frequencies, these adjustment patterns become observable and can be exploited to uncover the direction and timing of information transmission.

2.5.2. Impulse-response analysis

The moving-average representation of the VAR model enables the computation of impulse-response functions (IRFs). IRFs measure the effect of an innovation in one exchange-rate return on the current and future returns of all exchange rates within the system. The dissertation employs non-orthogonal impulse-response functions. In principle, such responses should be interpreted as innovations in the disturbance term of a VAR equation rather than isolated structural shocks. However, because contemporaneous correlations among the ultra-high-frequency return innovations are found to be extremely small, orthogonalized and non-orthogonalized responses are virtually identical in practice. Consequently, the estimated impulse responses can be interpreted as close approximations of isolated exchange-rate shocks.

2.5.3. Local Projection methodology

To ensure robustness, the dissertation complements VAR analysis with Local Projection (LP) models following Jordá (2005). LP models estimate the response at each forecast horizon directly rather than deriving it through repeated VAR iteration. The main advantage of LP is its robustness to model misspecification. While VAR models tend to exhibit lower variance and higher efficiency under correct specification, LP methods are generally less sensitive to specification errors. Comparing results from both approaches therefore provides an important robustness check. The empirical results demonstrate a high degree of consistency between VAR-based and LP-based impulse-response functions, strengthening confidence in the underlying findings.

2.5.4. Spillover topology

The final methodological component transforms estimated local-projection responses into directed spillover networks. Horizon-specific coefficient matrices are interpreted as weighted networks in which nodes represent exchange rates and links represent directional shock transmission. These matrices summarize the overall transmission of shocks within a currency triangle and allow the identification of net transmitters and net receivers of information. The approach is conceptually related to connectedness measures developed in the financial network literature, but relies on cumulative local-projection responses rather than forecast-error variance decompositions. A VAR(5)-based approach of spillover topology is also applied to compare four different currency trading regimes – two of them being candidates to reproduce the FX triangle-dynamics observed in regional currency markets. The resulting spillover topologies constitute a key element of the dissertation highlighting the close relationship between regional spillover topologies and the synthetic quotation mechanism – the later being a central concept of the thesis.

3. Results and Discussion

This section presents the empirical findings of the dissertation, organized by the four main research hypotheses.

3.1. Hypothesis 1: Forecast Accuracy of Regional Currency Correlations

The first research pillar compared the forecasting performance of option-implied measures against traditional time-series models for the Central and Eastern European (CEE) and Scandinavian regional markets.

3.1.1. Dominance of Historical Methods in Regional Markets

As stated in Hypothesis 1 (H1), the results demonstrate that in regional currency markets, implied correlation forecasts do not provide more accurate predictions than time-series-based estimates.

As shown in Table 1, the EWMA (0.97) specification consistently yielded the lowest Root Mean Square Error (RMSE) for the majority of regional currency pairs. This contrasts sharply with major currency trios, where ATM-implied correlations were the clear winners. This finding suggests that the informational advantage of option-implied measures — which aggregate forward-looking market expectations — is diminished in less liquid regional option markets.

Table 1: RMSE of one-month FX correlation forecasts, 2007–2025

FX – Pair	Historical	EWMA_94	EWMA_97	GARCH	HAR	ATM_imp	VS_imp
EURCHF_EURUSD	0,348	0,316	0,302	0,462	0,456	0,301	0,304
EURCHF_USDCHF	0,335	0,312	0,313	0,399	0,397	0,274***	0,278
USDCHF_EURUSD	0,183	0,181	0,188	0,225	0,191	0,152***	0,160
EURGBP_EURUSD	0,317	0,285	0,271	0,329	0,294	0,245	0,244***
EURGBP_GBPUSD	0,301	0,266	0,250	0,281	0,285	0,229***	0,230
GBPUSD_EURUSD	0,237	0,208	0,197	0,221	0,206	0,178***	0,178
EURJPY_EURUSD	0,333	0,300	0,285	0,314	0,299	0,242***	0,243
EURJPY_USDJPY	0,255	0,229	0,221	0,223	0,252	0,205**	0,209
USDJPY_EURUSD	0,360	0,321	0,303	0,324	0,327	0,268***	0,270
EURCZK_EURUSD	0,346	0,306	0,282***	0,431	0,423	0,313	0,310
EURCZK_USDCZK	0,278	0,251	0,235	0,338	0,317	0,230	0,245
USDCZK_EURUSD	0,099	0,090	0,087	0,100	0,103	0,093	0,100
EURHUF_EURUSD	0,312	0,294	0,276***	0,374	0,364	0,316	0,291
EURHUF_USDHUF	0,184	0,161	0,149**	0,170	0,171	0,167	0,149
USDHUF_EURUSD	0,137	0,169	0,166	0,172	0,155	0,118	0,126
EURPLN_EURUSD	0,324	0,298	0,279***	0,370	0,346	0,306	0,336
EURPLN_USDPLN	0,237	0,208	0,194	0,232	0,218	0,187	0,205
USDPLN_EURUSD	0,124	0,115	0,108	0,136	0,128	0,110	0,116
EURNOK_EURUSD	0,316	0,287	0,274	0,378	0,369	0,282	0,292
EURNOK_USDNOK	0,199	0,177	0,168	0,199	0,202	0,165	0,169
USDNOK_EURUSD	0,185	0,170	0,163	0,195	0,205	0,148***	0,149
EURSEK_EURUSD	0,351	0,311	0,288	0,372	0,350	0,296	0,302
EURSEK_USDSEK	0,247	0,215	0,200	0,245	0,242	0,195	0,196
USDSEK_EURUSD	0,156	0,137	0,129	0,148	0,137	0,120***	0,122

Source: Author's own work

3.2. Hypothesis 2: Discrepancy in Volatility and Correlation Rankings

Hypothesis 2 (H2) proposed that the ranking of forecasting methodologies would be identical for both volatility and correlation forecasting due to their theoretical linkage via triangular arbitrage. This hypothesis was rejected.

3.2.1. The Conflict in Ranking

While implied measures were the superior predictors for exchange rate volatility across almost all currencies (as seen in Table 2), they failed to maintain this superiority in correlation forecasting for regional markets. The resolution of this contradiction highlights the importance of volatility-variance ratios for correlation forecasting.

Table 2: RMSE of one-month FX volatility forecasts, 2007–2025

FX	VS_imp	ATM_imp	EWMA_94	EWMA_97	GARCH	HAR
EURCHF	0,0150	0,0150**	0,0193	0,0194	0,0163	0,0181
EURCZK	0,0080	0,0075	0,0076	0,0077	0,0076	0,0108
EURGBP	0,0058**	0,0060	0,0072	0,0071	0,0069	0,0124
EURHUF	0,0096	0,0083	0,0090	0,0088	0,0095	0,0157
EURJPY	0,0105	0,0105**	0,0115	0,0115	0,0110	0,0192
EURNOK	0,0093***	0,0094	0,0105	0,0104	0,0102	0,0156
EURPLN	0,0097	0,0094	0,0087	0,0087	0,0092	0,0142
EURSEK	0,0058**	0,0058	0,0062	0,0062	0,0063	0,0116
EURUSD	0,0131	0,0062	0,0064	0,0064	0,0063	0,0138
GBPUSD	0,0073**	0,0074	0,0096	0,0094	0,0090	0,0156
USDCHF	0,0135**	0,0135	0,0175	0,0170	0,0154	0,0200
USDCZK	0,0089	0,0089***	0,0099	0,0100	0,0101	0,0182
USDHUF	0,0107	0,0095***	0,0108	0,0109	0,0112	0,0232
USDJPY	0,0090***	0,0090	0,0100	0,0098	0,0097	0,0173
USDNOK	0,0097***	0,0098	0,0113	0,0112	0,0113	0,0203
USDPLN	0,0119	0,0116	0,0119	0,0120	0,0119	0,0219
USDSEK	0,0076***	0,0078	0,0086	0,0086	0,0088	0,0182

Source: Author's own work

3.2.2. Error Decomposition Analysis

To understand why the best volatility forecaster was not the best correlation forecaster, a squared error decomposition was performed.

The analysis revealed that correlation forecast errors are primarily driven by the volatility ratio that includes the synthetically derived leg – the USD cross (the c component in the triangle).

The results in Table 3 show that the c^2 component accounts for the largest share of the error. In regional markets, the high uncertainty in forecasting the volatility of the illiquid USD cross-rate (e.g., USDHUF) disproportionately degrades the accuracy of the implied correlation forecast.

Table 3: Decomposition of total squared forecast error – one-month correlation estimates between EURCCY-EURUSD

		a^2	b^2	c^2	2ab	-2ac	-2bc	sum
HUF	EWMA_97	0,1334	0,1493	0,3565	-0,2114	0,0531	-0,1272	0,3536
	ATM implied	0,1028	0,1495	0,5201	-0,1794	-0,0104	-0,1504	0,4322
PLN	EWMA_97	0,0858	0,2462	0,3851	-0,2433	0,0052	-0,1597	0,3193
	ATM implied	0,0794	0,2551	0,4989	-0,2362	0,0359	-0,2552	0,3779
NOK	EWMA_97	0,1232	0,1309	0,3388	-0,2025	-0,0192	-0,0811	0,2901
	ATM implied	0,1087	0,1125	0,3700	-0,1737	-0,0536	-0,0628	0,3009
SEK	EWMA_97	0,0725	0,1861	0,3694	-0,1957	0,0536	-0,1631	0,3229
	ATM implied	0,0598	0,1541	0,3962	-0,1554	0,0262	-0,1386	0,3422
JPY	EWMA_97	0,1558	0,0643	0,3570	-0,1783	-0,1147	0,0447	0,3288
	ATM implied	0,1145	0,0539	0,2649	-0,1354	-0,0846	0,0196	0,2330
GBP	EWMA_97	0,0800	0,1005	0,3401	-0,1493	-0,0709	-0,0094	0,2910
	ATM implied	0,0605	0,0859	0,2687	-0,1198	-0,0462	-0,0177	0,2315

Note: In theory, the "sum" column should be consistent with the RMSE numbers shown in Table 1 satisfying the following relationship: $RMSE^2$=1/4 x (sum). Minor inconsistencies occur as correlation forecast are compared against realized correlations meanwhile volatility decomposition is applied against realized volatilities. Based on Equation (1)-(4) realized correlations should be fully consistent with realized volatilities however this is not perfectly satisfied on empirical data.

Source: Author's own work

3.3. Hypothesis 3: Microstructural Asymmetries in Currency Triangles

Research pillar two examined ultra-high-frequency dynamics at 100- and 200-millisecond intervals. Hypothesis 3 (H3) argued that regional triangles exhibit stronger directional spillover and weaker reverse feedback than major triangles. The results strongly support H3.

3.3.1. Symmetric vs. Hierarchical Topologies

Vector Autoregressive (VAR) and Local Projection (LP) models revealed a fundamental divide in market architecture:

Major triangles (JPY, GBP, CHF): dense, bidirectional spillover patterns. A shock to any leg (e.g., EURJPY) transmits significant information to the other two legs, which then feed back into the global pair (EURUSD).

Regional triangles (HUF, PLN, SEK, NOK): a hierarchical "terminal-node" topology. The global leg (EURUSD) and the liquid regional leg (EURCCY) influence the third leg (USDCCY), but feedback from the regional legs back to EURUSD are either economically negligible or can be explained by strong autocorrelation of very high-frequency returns.

3.3.2. Evidence for Synthetic Quotation

The cumulative spillover matrices provide the "fingerprint" of synthetic quotation in regional markets. For the HUF trio, the feedback from the independently quoted EURHUF into the global EURUSD was measured at a negligible $\Gamma = -0.0184$ (threshold < 0.05) as seen in Table 4.

Table 4: Cumulative 3 × 3 Spillover Matrices: Major vs. Regional Trios

Major Trio: EUR–USD–JPY				Regional Trio: EUR–USD–HUF			
Shock →	EURUSD	USDJPY	EURJPY	Shock →	EURUSD	USDHUF	EURHUF
→ EURUSD	1.0000	-0.8901	**1.0136**	→ EURUSD	1.0000	-0.2061	**-0.0184**
→ USDJPY	-0.7499	1.0000	0.1136	→ USDHUF	-1.3005	1.0000	0.4874
→ EURJPY	0.5408	0.2588	1.0000	→ EURHUF	-0.1640	0.3091	1.0000
Satellite: EUR–USD–NOK				**Satellite: EUR–USD–SEK**			
Shock →	EURUSD	USDNOK	EURNOK	Shock →	EURUSD	USDSEK	EURSEK
→ EURUSD	1.0000	-0.4100	**0.0314**	→ EURUSD	1.0000	-0.5734	**-0.0163**
→ USDNOK	-1.1008	1.0000	0.9218	→ USDSEK	-1.1517	1.0000	1.0433
→ EURNOK	0.0314	0.4043	1.0000	→ EURSEK	-0.0163	0.2331	1.0000

Source: Misik and Szabó (2026)

These results, corroborated by the bank questionnaire on quotation approaches in various currency markets involving six major London-based banks, confirm that regional market makers quote the USD-cross rate as a mechanical function of the other two legs to avoid arbitrage, thereby creating the observed correlation structures by design rather than through independent price discovery.

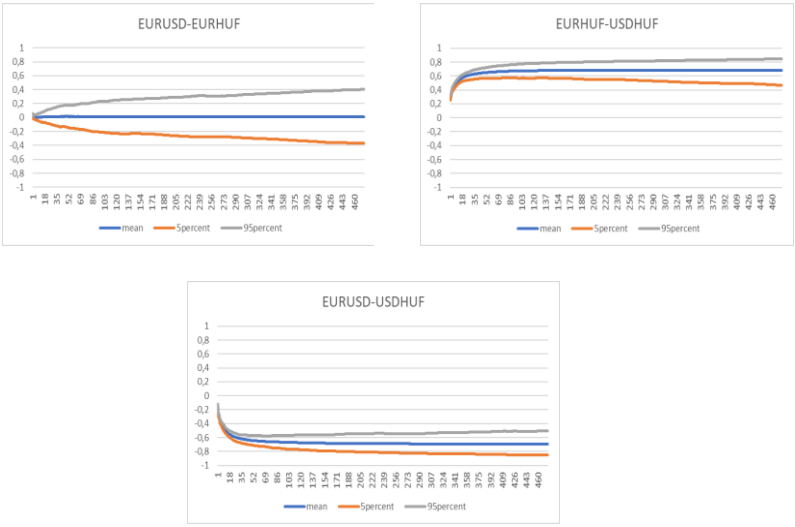
3.4. Hypothesis 4: Performance and Limits of the Modified ABM

The final research pillar tested whether a modified Agent-Based Model (ABM) could endogenously reproduce regional correlation levels. Hypothesis 4 (H4) stated that the model would reproduce ordering and magnitudes but not all signs. This hypothesis was accepted.

3.4.1. Reproduction of Regional Correlation Regimes

By modifying the Ciacci et al. (2020) benchmark to exclude the global leg (EURUSD) from the arbitrage circuit and enforcing an arbitrage-free quotation for the illiquid leg (USDHUF), the model successfully converged to correlation levels characteristic of regional markets.

Figure 1: Confidence intervals of simulated correlations – forint market



Source: Author's own work

As shown in Figure 1, the simulated correlations reached a strong positive level for EURHUF–USDHUF and a strong negative level for EURUSD–USDHUF, matching empirical observations.

3.4.2. The Residual Sign Problem

The primary limitation of the microstructural ABM was its inability to reproduce the weak negative correlation often observed between EURUSD and regional EUR-crosses (e.g., EURHUF). Under realistic assumptions, the model converged to a correlation near zero. This suggests that while the "one-weak, two-strong" geometry is microstructural in origin, the specific negative sign of the weak relationship is likely driven by broader macro-financial factors, such

as risk-on/risk-off sentiment, which the current ABM does not capture.

4. Conclusions

The thesis investigates a distinctive feature of foreign exchange (FX) markets: the correlation structure of currency trios linked through triangular arbitrage. Since exchange rates within a currency triangle are constrained by arbitrage, implied correlations can be derived from option-implied volatilities, providing a forward-looking measure of market expectations. Comparing implied and time series-based forecasts across major and regional FX markets showed that implied correlations do not outperform historical estimates. While implied volatilities generated the most accurate volatility forecasts, EWMA-based methods produced superior correlation forecasts, particularly for regional currency trios. This reflects the fact that correlation estimation depends primarily on relative volatility relationships rather than volatility levels. These findings support H1 and reject H2.

The thesis then examines why correlation structures differ substantially across currency regions despite identical arbitrage relationships. Evidence from FX trading activity suggests that exchange rates play different roles in price discovery. In many regional currency trios, two exchange rates are actively quoted, while the third is largely determined synthetically through arbitrage. This observation forms the basis of H3.

Using ultra-high-frequency data together with VAR, local projection, and directional spillover analyses, the study identifies clear structural differences between major and regional currency trios. Major trios exhibit relatively symmetric interactions among exchange rates, whereas regional trios display asymmetric dynamics consistent with a synthetic-leg structure. The results remain robust across periods and market makers, while competing microstructure explanations fail to reproduce the observed spillover patterns without effectively converging to a synthetic-rate framework.

Interviews with international banks support these findings, confirming that quoting practices vary across currency trios according to trading activity, market relevance, and historical conventions. At the same time, respondents emphasized that quoting practices differ across institutions and evolve over time, implying that correlation structures reflect changing market organization rather than fixed currency characteristics.

Finally, the thesis further develops an arbitrageur-based agent model capable of reproducing the distinct correlation regimes observed in FX markets. A symmetric specification replicates the behavior of major currency trios, while asymmetric variants with one synthetically determined exchange rate reproduce the patterns observed in regional and USD-driven markets. Although the models explain most empirical differences, they cannot fully reproduce the persistent weak negative correlations sometimes observed in practice. Overall, the results support H3 and H4, demonstrating that FX correlation structures are primarily driven by quoting conventions, triangular arbitrage, and the relative importance of individual exchange rates, while additional factors such as risk pricing may also influence observed correlations.

Main references

Berger, D. W., Chaboud, A. P., Chernenko, S. V., Howorka, E., and Wright, J. H. (2008). Order flow and exchange rate dynamics in electronic brokerage system data. *Journal of international Economics*, 75(1):93–109.

BIS (2025). Triennial Central Bank Survey of Foreign Exchange and Over-the-counter (OTC) Derivatives Markets in 2025, https://www.bis.org/statistics/rpfx25.htm: *Bank for International Settlements.*

Bollerslev, T. and Engle, R. F. (1993). Common Persistence in Conditional Variances. *Econometrica,* 61(1), pp. 167-186.

Campa, J. M. and Chang, P. H. K. (1998). The Forecasting Ability of Correlations Implied in Foreign Exchange Options. *Journal of International Money and Finance,* 17(6), pp. 855-880.

Carr, P. and Madan, D. (2002). Toward a Theory of Volatility Trading. *Risk Publications,* Volume Volatility, pp. 417-427.

Castrén, O. and Mazzotta, S. (2005). Foreign Exchange Option and Returns Based Correlation Forecasts. Evaluation and Two Applications. *ECB Working Paper,* 447, pp. 1-48.

Chernov, M., Haddad, V. and Itskhoki, O. (2024). What do Financial Markets Say About the Exchange Rate?. *National Bureau of Economic Research,* Volume Working Paper 32436.

Ciacci, A., Sueshige, T., Takayasu H., Christensen, K. and Takayasu, M. (2020). The Microscopic Relationships Between Triangular Arbitrage and Cross-Currency Correlations in a Simple Agent Based Model of Foreign Exchange Markets. *Plos one,* 15(6):e0234709.

Corsi, F. (2009). A Simple Approximate Long-Memory Model of Realized Volatility. *Journal of Financial Econometrics*, 7, 174-196.

Demeterfi, K., Derman, E., Kamal, M. and Zou , J. (1999). *More than You Ever Wanted to Know* About Volatility Swaps.* Available at: https://emanuelderman.com/wp-content/uploads/1999/02/gs-volatility_swaps.pdf

Hasbrouck, J. and Levich, R. M. (2019). FX Liquidity and Market Metrics: New Results Using CLS Bank Settlement Data. *Manuscript.* Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2912976

Huang, W., Ranaldo, A., Schrimpf, A. and Somogyi, F. (2025). Constrained liquidity provision in currency markets. *Journal of Financial Economics,* 167

Jordá, O. (2005). Estimation and Inference of Impulse Responses by Local Projections. *American Economic Review,* 95(1), pp. 161-182.

King, M. R., Osler, C., and Rime, D. (2012). Foreign exchange market structure, players,and evolution. *Handbook of exchange rates*, pages 1–44.

Mancini, L., Ranaldo, A., and Wrampelmeyer, J. (2013). Liquidity in the foreign exchange market: Measurement, commonality, and risk premiums. *The Journal of Finance,* 68(5):1805–1841.

Mueller, P., Stathopoulos, A. and Vedolin, A. (2017). International Correlation Risk. *Journal of Financial Economics,* 126(2), pp. 270-299.

Payne, R. (2003). Informed trade in spot foreign exchange markets: an empirical investigation. *Journal of International Economics*, 61(2):307–329.

Ranaldo, A. and Somogyi, F. (2021). Asymmetric information risk in FX markets. *Journal of Financial Economics,* 140(2), pp. 391-411.

Walter , C. and Lopez, J. A. (2000). Is Implied Correlation Worth Calculating? Evidence from Foreign Exchange Option Prices. *Journal of Derivatives,* 7.(3.), pp. 65-82..

List of own publications related to the topic

Misik, S. (2023). Korrelációbecslés a forintpiacon. *Közgazdasági szemle,* Volume 7-8, pp. 772-794.

Misik, S. and Szabó, D. Z. (2026). Triangular Arbitrage, Market Microstructure, and Correlation Dynamics in Global and Regional Currency Trios. *Manuscript,* Available at: *https://papers.ssrn.com/sol3/papers.cfm?abstract_id=7134042*

Misik, S. (2026). Central Bank Intervention and Subsecond Price Discovery in a Currency triangle. *Economy and Finance,* (forthcoming)