Studies in EMPIRICAL ECONOMICS

Luc Bauwens
Winfried Pohlmeier
David Veredas
Editors

High Frequency Financial Econometrics

Recent Developments

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With 57 Figures and 64 Tables

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Prof. Luc Bauwens
CORE
Voie du Roman Pays
1348 Louvain-la-Neuve
Belgium
bauwens@ucl.ac.be

Prof. Winfried Pohlmeier
Department of Economics
University of Konstanz
78457 Konstanz
Germany
winfried.pohlmeier@uni-konstanz.de

Prof. David Veredas
ECARES
Université Libre des Bruxelles
30, Avenue Roosevelt
1050 Brussels
Belgium
dveredas@ulb.ac.be

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Luc Bauwens · Winfried Pohlmeier · David Veredas

Editor's introduction: recent developments in high frequency financial econometrics

> *"But there are several aspects of the quantitative approach to* ***finance****, and no single one of these aspects, taken by itself, should be confounded with* ***financial econometrics****. Thus,* ***financial econometrics*** *is by no means the same as* ***finance*** *statistics. Nor is it identical with what we call general* ***financial*** *theory…Not should be* ***financial econometrics*** *a synonymous with the application of mathematics to* ***finance****. Experience has shown that each of these three view-points, that of statistics,* ***financial*** *theory, and mathematics, is a necessary, but not sufficient, condition for a real understanding of the quantitative relations of modern* ***financial*** *life. It is the unification of all the three that is powerful. And it is this unification that constitutes* ***financial econometrics****."*

This paragraph is a virtual copy of the one in p. 2 of Frisch's Editor Note on *Econometrica* Vol. 1, No. 1. The only difference is that economics has been replaced by finance, economic by financial, econometrics by financial econometrics.

It was written 74 years ago but it fully reflects the spirit of this special issue. High frequency finance is an archetypical example of Ragnar Frisch's words. It represents a unification of (1) financial theory, in particular market microstructure, (2) mathematical finance, exemplified in derivative markets, and (3) statistics, for instance the theory of point processes. It is the intersection of these three components that yields an incredibly active research area, with contributions that enhance the understanding of today's complex intra-daily financial world.

> *"Theory, in formulating its abstract quantitative notions, must be inspired to a larger extent by the technique of observations. And fresh statistical and other factual studies must be the healthy element of disturbance that constantly threatens and disquiets theorists and prevents them from coming to rest on some inherited, obsolete set of assumptions."*

Here again high frequency finance is fully reflected in Ragnar Frisch's words. Its *modus vivendi* is a perfect combination of observed real facts, market microstructure theory, and statistics and they all form a system in which each

component nicely dovetails with the others. Market microstructure theory deals with models explaining price and agent's behavior in a market governed by certain rules. These markets have different ways to operate (with/without market makers, with/without order books), opening and closing hours, maximum price variations, minimum traded volume, etc. On the other hand, empirical analysis deals with the study of market behavior using real data. For example, what are the relations between traded volume, price variations, and liquidity? What are the potential problems? Last, statistically speaking, high frequency data are realizations of so-called point processes, that is, the arrival of the observations is random. This, jointly with the fact that financial data has pathological and unique features (long memory, strong skewness, and kurtosis) implies that new methods and new econometric models are needed.

The econometric analysis of high frequency data permits us to answer to questions that are of great interest for policy markers. For instance, how much information should regulators disclose to market participants? Or, how do extreme movements in the book affect market liquidity? Or is a market maker really necessary?

On the other side, the practitioners, the traders that participate in the market every day, also have a growing interest in the understanding of financial markets that operate at high frequency. For instance, trading rules may be constructed based on the markets conditions that, in turn, may be explained with financial econometrics.

This volume presents some advanced research in this area. In order to document the potential of high frequency finance, it is our goal to select a wide range of papers, including studies of the order book dynamics, the role of news events, and the measurement of market risks as well as new econometric approaches to the analysis of market microstructures.

Bauwens, Rime, and Sucarrat shed new light on the mixture of distribution hypothesis by means of a study of the weekly exchange rate volatility of the Norwegian krone. They find that the impact of information arrival on exchange rate volatility is positive and statistically significant, and that the hypothesis that an increase in the number of traders reduces exchange rate volatility is not supported. Moreover, they document that the positive impact of information arrival on volatility is relatively stable across three different exchange rate regimes, and in that the impact is relatively similar for both weekly volatility and weekly realised volatility.

Despite its rather weak theoretical and statistical foundation, chart analysis is still a frequently used tool among financial analysts. *Omrane and van Oppens* investigate the existence of chart patterns in the Euro/Dollar intra-daily foreign exchange market at the high frequency level. Checking 12 types of chart patterns, they study the detected patterns through two criteria: predictability and profitability and find an apparent existence of some chart patterns in the currency market. More than one half of detected charts present a significant predictability. But only two chart patterns imply a significant profitability which is, however, too small to cover the transaction costs.

Tick data is, by market structure, discrete. Prices move by multiples of the tick, the minimum price variation. Two approaches can be taken to account for price discreteness. One, which stems from the realized variance literature, is to consider tick changes as market microstructure noise. The other is to consider price discreteness as structural information. *Bien, Nolte, and Pohlmeier* pursue this second line of

research and propose a model for multivariate discrete variables. Econometric models for univariate discrete price processes have been suggested recently but a multivariate version of it was still missing. The multivariate integer count hurdle model (MICH) proposed by *Bien, Nolte, and Pohlmeier* can be viewed as a combination of the copula approach by Cameron et al. (2004) with the integer count hurdle (ICH) model of Liesenfeld, Nolte and, Pohlmeier (2006), which allows the dynamic specification of a univariate conditional distribution with discrete support. They illustrate the usefulness of the model for estimating the joint distribution of the EUR/GBP and the EUR/USD exchange rate changes at the 1-min level. Their approach leaves the door open to other applications such as the measurement of multivariate conditional volatilities, the quantification of intradaily liquidity and value-at-risk applications, and the joint analysis of several marks of the trading process (volumes, price and volume durations, discrete quote changes).

Escribano and Pascual propose a new approach of jointly modeling the trading process and the revisions of market quotes. This method accommodates asymmetries in the dynamics of ask and bid quotes after trade-related shocks. The empirical specification is a vector error correction (VEC) model for ask and bid quotes, with the spread as the co-integrating vector, and with an endogenous trading process. Contrary to some hypothesis implied from market microstructure theory, they provide evidence against several symmetry assumptions and report asymmetric adjustments of ask and bid prices to trade-related shocks, and asymmetric impacts of buyer and seller-initiated trades. In general, buys are more informative than sells.

Frey and Grammig analyze adverse selection costs and liquidity supply in a pure open limit order book market using the Glosten/Sandas modeling framework. Relaxing some assumptions of Sandas' (2001) basic model, they show that their revised methodology delivers improved empirical results.[1] They find empirical support for one of the main hypothesis put forth by the theory of limit order book markets, which states that liquidity supply and adverse selection costs are inversely related. Furthermore, adverse selection cost estimates based on the structural model and those obtained using popular model-free methods are strongly correlated.

In the mid-1990s, financial institutions started implementing VaR type measures to meet the 1988 and 1996 Basel Accords' capital requirements to cover their market risk. Based on an internal model, they compute the "Value-at-Risk," which represents the loss they can incur over 10 trading days at a 1% confidence level. However, most of these models do not account for the liquidity risk that has been widely documented in the microstructure literature. Due to the price impact of trades, which relies on trade size, there may indeed be a difference between the market value of a portfolio, computed over "no-trade returns," and its liquidation value. *Giot and Grammig* propose an original way to shed light on the liquidity discount that should be part of the evaluation of market risk borne by financial institutions. They quantify the liquidity risk premiums over different time horizons, for portfolios of different sizes, composed of three stocks traded on Xetra. This paper thus not only contributes to the existing literature on market liquidity,

[1] Sandås, P. (2001), "Adverse Selection and Competitive Market Making: Empirical Evidence from a Limit Order Market", *Review of Financial Studies*, 14, 705–734.

but provides also an answer to practitioners' concerns relative to the measurement of market risk.

Hall and Hautsch study the determinants of order aggressiveness and traders' order submission strategy in an open limit order book market. Applying an order classification scheme, they model the most aggressive market orders, limit orders as well as cancellations on both sides of the market employing a six-dimensional autoregressive conditional intensity model. Using order book data from the Australian Stock Exchange, they find that market depth, the queued volume, the bid-ask spread, recent volatility, as well as recent changes in both the order flow and the price play an important role in explaining the determinants of order aggressiveness. Overall, their empirical results broadly confirm theoretical predictions on limit order book trading.

Liesenfeld, Nolte, and Pohlmeier develop a dynamic model to capture the fundamental properties of financial prices at the transaction level. They decompose the price in discrete components—direction and size of price changes—and, using autoregressive multinomial models, they show that the model is well suited to test some theoretical implications of market microstructure theory on the relationship between price movements and other marks of the trading process.

Intradaily financial data is characterized by its dynamic behavior as well by deterministic seasonal patterns that are due to the market structure. Volatility is known to be larger at the opening and closing than during the lunch time. Similarly for financial durations: they are shorter at the opening and closing, indicating higher activity at these times of the day. Any econometric model should therefore incorporate these features. *Rodriguez-Poo, Veredas, and Espasa* propose a semiparametric model for financial durations. The dynamics are specified parametrically, with an ACD type of model, while seasonality is left unspecified and hence nonparametric. Estimation rests on generalized profile likelihood, which allows for joint estimation of the parametric—an ACD type of model—and nonparametric components, providing consistent and asymptotically normal estimators. It is possible to derive the explicit form for the nonparametric estimator, simplifying estimation to a standard maximum likelihood problem.

Tay and Ting carry out an empirical analysis using high frequency data and more specifically estimate the distribution of price changes conditional on trade volume and duration between trades. Their main empirical finding is that even when controlling for the trade volume level, duration has an effect on the distribution of price changes, and the higher the conditioning volume level, the higher the impact of duration on price changes. The authors find significant positive (negative) skewness in the distribution of price changes in buyer (respectively seller)—initiated trades, and see this finding as support of the Diamond and Verrecchia (1987) analysis of the probability of large price falls with high levels of duration.[2] The analysis is carried out using up-to-date techniques for the nonparametric estimation of conditional distributions, and outlines a descriptive procedure that can be useful in choosing the specification of the relationship between duration, volume, and prices when performing a parametric investigation.

[2] Diamond, D.W. and Verrecchia, R.E. (1987), "Constraints on Short-Selling and Asset Price Adjustment to Private Information", *Journal of Financial Economics*, 18, 277–311.

News is the driving force of price movements in financial markets. *Veredas* analyses the effect of macroeconomic news on the price of the USA 10-year treasury bond future. Considering 15 fundamentals, he investigates the effect of their forecasting errors conditional upon their sign and the momentum of the business cycle. The results show that traders react when the forecasting error differs from zero. The reaction to a positive or negative forecasting error is different and, most importantly, the reaction varies significantly depending on the momentum of the economic cycle. Moreover, the time of the release matters: the closer it is to the covering period, the more effect it has on the bond future.

Modeling and forecasting the covariance of a large number of financial return series has always been a challenge due to the so-called "curse of dimensionality." For example, the multivariate GARCH models are heavily parameterized or the dynamics of conditional variances and covariances must be restricted to reduce the number of parameters, e.g., through factor structures. As an alternative, the sample covariance matrix has often been used, based on rolling windows, e.g., a monthly covariance is estimated from monthly returns of the last 5 years. *Voev* compare this approach, and variants of it, with others that use higher frequency data (daily data), the so-called realized covariance matrix. In each approach, there are different ways to define forecasts. For example, the realized covariance matrix for month t may serve to predict the covariance matrix of next month. A more sophisticated forecast is obtained by taking a convex combination of the realized covariance of month t and an equicorrelated covariance matrix, a technique known as "shrinkage." The previous forecasts are static. Another method consists in modeling the different elements of the realized covariance matrix by using separate univariate time series models to construct forecasts. This raises the difficulty to obtain always a positive definite forecast. *Voev* measures the deviation of the forecast as a matrix from its target by using the Frobenius norm, where the target or "true" covariance matrix is the realized covariance matrix (observed ex post), and by Diebold–Mariano statistical tests. His main conclusion is that the dynamic models result in the smallest errors in the covariance matrix forecasts for most of the analyzed data series.

Luc Bauwens · Dagfinn Rime · Genaro Sucarrat

Exchange rate volatility and the mixture of distribution hypothesis

Abstract This study sheds new light on the mixture of distribution hypothesis by means of a study of the weekly exchange rate volatility of the Norwegian krone. In line with other studies we find that the impact of information arrival on exchange rate volatility is positive and statistically significant, and that the hypothesis that an increase in the number of traders reduces exchange rate volatility is not supported. The novelties of our study consist in documenting that the positive impact of information arrival on volatility is relatively stable across three different exchange rate regimes, and in that the impact is relatively similar for both weekly volatility and weekly realised volatility. It is not given that the former should be the case since exchange rate stabilisation was actively pursued by the central bank in parts of the study period. We also report a case in which undesirable residual properties attained within traditional frameworks are easily removed by applying the log-transformation on volatilities.

Keywords Exchange rate volatility · Mixture of distribution hypothesis

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1 Introduction

If exchange rates walk randomly and if the number of steps depends positively on the number of information events, then exchange rate volatility over a given period

L. Bauwens · G. Sucarrat (✉)
CORE and Department of Economics, Université catholique de Louvain,
Louvain-la-Nueve, Belgium
E-mail: sucarrat@core.ucl.ac.be, bauwens@core.ucl.ac.be,
URL: http://www.core.ucl.ac.be/~sucarrat/index.html

D. Rime
Norges Bank, Oslo, Norway
E-mail: dagfinn.rime@norges-bank.no

should increase with the number of information events in that period. This chain of reasoning is the essence of the so-called "mixture of distribution hypothesis" (MDH) associated with Clark (1973) and others. Several versions of the MDH have been put forward, including one that suggests the size of the steps depends negatively on the number of traders, see for example Tauchen and Pitts (1983). In other words, an increase in the number of traders, a measure of liquidity, should decrease the size of the steps and thus volatility. Exchange rate volatility may of course depend on other factors too, including country-specific institutional factors, market conditions and economic fundamentals. Bringing such factors together in a general framework and trying to disentangle their distinct effects on exchange rate volatility leads to economic or explanatory volatility modelling as opposed to "pure" forecast modelling, which may remain silent about the economic reasons for variation in volatility.

When Karpoff (1987) surveyed the relationship between financial volatility and trading volume (a measure of information intensity) during the mid-eighties, only one out of the 19 studies he cited was on exchange rates. The increased availability of data brought by the nineties has changed this, and currently we are aware of ten studies that directly or indirectly investigate the relationship between exchange rate volatility and information intensity. The ten studies are summarised in Table 1 and our study of Norwegian weekly exchange rate volatility from 1993 to 2003 adds to this literature in several ways. First, our study spans more than a decade covering three different exchange rate regimes. Second, not only do we find that the impact of changes in the number of information events on exchange rate volatility is positive and statistically significant, recursive parameter analysis suggests the impact is relatively stable across the different exchange rate regimes. Finally, our results do not support the hypothesis that an increase in the number of traders reduces exchange rate volatility.

Another contribution of our study concerns the economic modelling of exchange rate volatility as such. We report a case in which undesirable residual properties are easily removed by applying the logarithmic transformation on volatilities. In particular, we show that OLS-regressions of the *logarithm* of volatility on its own lags and on several economic variables can produce uncorrelated and homoscedastic residuals. Moreover, in the log of realised volatility case the residuals are also normal. When Geweke (1986), Pantula (1986) and Nelson (1991) proposed that volatilities should be analysed in logs it was first and foremost in order to ensure non-negativity. In our case the motivation stems from unsatisfactory residual properties and fragile inference results. Without the log-transformation we do not generally produce uncorrelated residuals, and when we do the results are very sensitive to small changes in specification.

The rest of this paper contains three sections. In Section 2, we review the link between exchange rate volatility and the MDH hypothesis, and discuss measurement issues. We also present our data and other economic variables that we believe may impact on the volatility of the Norwegian exchange rate. In Section 3, we present the models we use and the empirical results. We conclude in the last section, whereas an Appendix provides the details of the data sources and transformations.

Table 1 Summary of empirical studies that investigate the impact of information intensity on exchange rate volatility

Publication	Data	Period	Supportive of MDH?
Grammatikos and Saunders (1986)	Daily currency futures contracts (DEM, CHF, GBP, CAD and JPY) denominated in USD	1978–1983	Yes
Goodhart (1991)	Intradaily quotes (USD against GBP, DEM, CHF, JPY, FRF, NLG, ITL, ECU) and Reuters' news-headline page	14/9–15/9 1987	No
Goodhart (2000)	Intradaily quotes (USD against GBP, DEM, JPY, FRF, AUD) and Reuters' news-headline pages	9/4-19/6 1989	No
Bollerslev and Domowitz (1993)	Intradaily USD/DEM quotes and quoting frequency	9/4–30/6 1989	No
Demos and Goodhart (1996)	Intradaily DEM/USD and JPY/USD quotes and quoting frequency	5 weeks in 1989	Yes
Jorion (1996)	Daily DEM/USD futures and options	Jan. 1985–Feb. 1992	Yes
Melvin and Xixi (2000)	Intradaily DEM/USD and JPY/USD quotes, quoting frequency and Reuters' headline-news screen	1/12 1993–26/4 1995	Yes
Galati (2003)	Daily quotes (USD against JPY and seven emerging market currencies) and trading volume	1/1 1998–30/6 1999	Yes
Bauwens et al. (2005)	Intradaily EUR/USD quotes, quoting frequency and Reuters' news-alert screens	15/5 2001–14/11 2001	Yes
Bjønnes et al. (2005)	Daily SEK/EUR quotes and transaction volume	1995–2002	Yes

2 Exchange rate volatility and economic determinants

The purpose of this section is to motivate and describe our exchange rate volatility measures, and the economic determinants that we use in our empirical study. In Subsection 2.1, we define our volatility measures and present the Norwegian exchange rate data. We make a distinction between period volatility on the one hand and within or intra-period volatility on the other, arguing that analysis of both is desirable since level-expectations may have an impact. In Subsection 2.2, we review the link between volatility and the MDH, and after presenting our quote frequency data we explain how we use them to construct the explanatory variables we include in our volatility equations. In Subsection 2.3, we motivate and describe the other economic determinants of volatility which we include as explanatory variables in the empirical part.

2.1 Period vs. intra-period volatility measures

Conceptually we may distinguish between period volatility on the one hand and within or intra-period volatility on the other. If $\{S_0,S_1,...,S_n,..., S_{N-1},S_N\}$ denotes a sequence of exchange rates between two currencies at times $\{0,1,...,N\}$, then the squared (period) return $[\log(S_N/S_0)]^2$ is an example of a period measure of observ-