Modeling Foreign Exchange Market in Croatia
- research in progress -

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1. Introduction

Every working day the central bank of the Republic of Croatia (Croatian National Bank; further: CNB) announces the official list of domestic currency exchange rates (the so called CNB FX rates list). Therein, the unit values of selected world currencies are expressed in units of the domestic currency, Kuna. On the next day (or several days, if there is a weekend or a holiday) the Kuna value of foreign currency stocks and transactions is calculated using the exchange rates from the CNB FX rates list formed the day earlier. EUR/HRK exchange rate from the CNB FX rates list, the so called CNB middle FX rate, has very important role in the Croatian economy. Due to a number of factors, Kuna has never been accepted as a measure of real value in Croatia as those were usually expressed in German Marks (DEM), and since 2002 in Euros. Also, the largest share of financial obligations of natural persons, legal persons and even general government is denominated in Euros, but payments are usually executed in Kuna, using the CNB middle FX rate on the maturity day for conversion. Finally, Republic of Croatia has the managed-float exchange rate regime, results of which are usually evaluated through the movements of the CNB middle FX rate.

The ubiquity of the CNB middle FX rate in country's every-day economic activity requires the creators of economic and especially monetary policy in Croatia to frequently revise their understanding of economic forces that influence the Kuna exchange rate. This is necessary for the effectiveness of the CNB monetary policy measures for managing Kuna exchange rate, with the objective of achieving the primary goal of the monetary policy: the price stability. The knowledge of all factors that influence the Kuna exchange rate is also very important in risk-managing activity of enterprises. This is particularly important for commercial banks' foreign exchange risk supervision, which is also the central bank's task, since the CNB is also responsible for banking supervision in Croatia.

The CNB middle FX rate is calculated on the basis of foreign currency spot trading on domestic FX market and on the basis of exchange rates used in that trading process. Although there is a theoretical possibility of Kuna trading abroad, the probability that domestic Kuna trading covers almost all Kuna trading is very high. This is because purchases of Kuna by foreign banks make up a very small portion of total trading in the domestic FX market, and, according to some sources, their purpose is to satisfy the demand of foreign investors and tourists and to provide them with a better exchange rate than they can achieve in Croatia. Because of all that, the FX Kuna market analysis is synonymous with the Croatian FX market analysis.

According to the so called microstructure approach to the exchange rate analysis (see for example Sarno and Taylor, 2001), understanding of the Kuna exchange rate, treated as the value of Kuna expressed in certain foreign currency, could be significantly improved with microstructure analysis of the Croatian FX market, where that price is formed. There is a detailed description (model) of currency trading within the context of the microstructure approach to the FX market analysis. The model comprises all aspects of real world trading with certain currency between all participants on all markets where that currency is traded.

However, previous surveys on Kuna exchange rate analysis were mostly oriented on the connection between Croatian balance of payments realization and the exchange rate (Stučka 2003 and Mervar 2003) or on the connection between the exchange rate and prices (Gattin-Turkalj 2002; Billmeier and Bonato 2002) or they analyzed the effectiveness of central bank FX interventions (Lang 2005; Egert and Lang 2006). One recent paper concentrated on early forecasting and preventing of currency crises in Croatia (Krznar 2004), and another one on the long-run HRK/EUR equilibrium exchange rate (Gattin-Turkalj 2005). Among all papers, only one relatively older review (Stučka 2001) has described technical characteristics of the CNB middle FX rate calculation and statistical characteristics of exchange rates realized in the trading between commercial banks and several institutional sectors, which are the basis for the CNB middle FX rate calculation. However, as far as we know, none of these papers has given a detailed description of the trading process in the Croatian FX market nor has it analyzed if this trading process alone has any influence on the Kuna exchange rate determination.

Therefore, the contribution of this paper to the understanding of Kuna exchange rate determination is exactly its detailed description of the Croatian FX market microstructure (hence, Kuna FX market microstructure) and on that basis established econometric analysis of the influence that this microstructure has on every-day formation of the CNB middle FX rate. Galati (2000) gives the starting point for this analysis because it is the first paper to test the theoretical relationship between exchange rate volatility, trading volume and bid-ask spreads for emerging countries' currencies (previous papers were usually focused on major world currencies). That paper has confirmed that even for emerging countries currencies the unexpected component of trading volume is positively correlated with the unexpected component of exchange rate volatility, as predicted by the Mixture of Distributions Hypothesis which states that unpredictable inflow of new, publicly available information on the market simultaneously influences both variables (Clark 1973). Second result of the same research is that it confirmed positive correlation of expected exchange rate volatility with the bid-ask spread, consistent with inventory cost models according to which the bid-ask spread is the premium that the dealer charges for his exposure to the risk of accumulating excess inventory of instruments he trades in (O'Hara and Oldfield 1986, among others).

Empirical analyses that are focused on the microstructure of FX markets of emerging countries' currencies could be found for currencies of India (Bhanumurthy 2000), Jamaica (Walker 2002) and Tunisia (Kouki 2003). In case of India, the focus of the analysis was a little different, but one of the results was that the volatility of Indian currency exchange rate is positively correlated with its bid-ask spread. Analysis for Tunisian and Jamaican currencies gives the same result. However, in Tunisian case, statistically significant correlation was found neither between the unexpected trading volume and unexpected exchange rate volatility nor between the expected trading volume and the bid-ask spread. In Jamaican case, statistically significant negative correlation between the unexpected trading volume and the unexpected exchange rate volatility was found, opposite to the Mixture of Distributions Hypothesis, but consistent with the theoretical model that predicts a reduction of financial instrument price variability if number of market participants increases. (Tauchen and Pitts, 1983).

Although the investigation of correlations between trading volume, exchange rate volatility and bid-ask spreads became starting point of microstructure approach to exchange rate analysis, there are a few more important questions within this domain which empirical analysis attempts to answer. One of them is how different market participants or different trading instruments influence the mentioned three key features of the FX market microstructure. Such research of the Swedish FX market (Bjonnes, Rime and Solheim 2003) has shown that trading volume between the largest banks has crucial influence on the Swedish Crown (SKK) exchange rate volatility that was interpreted as a sign that such FX market participants are better informed. Same research has shown that the SKK trading volume between domestic banks has more significant influence on the exchange rate volatility than trading volume between foreign banks that was interpreted as an indication that the SKK exchange rate depends mostly on domestic economic conditions.

This paper presents the preliminary results of the first analysis of the Croatian FX market microstructure (Kuna FX market microstructure). The paper gives answer to questions similar to those in the studies mentioned above, within the limits posed by the availability of the FX trading volume data for the Croatian FX market. Due to those limits and due to the structural breaks in the CNB middle FX rate time series, the descriptive part of this study covers period from the introduction of Kuna as Croatian currency in 1994, while the econometric analysis is based on the FX market daily data starting with 1 January 2002, when the CNB middle FX rate took the HRK/EUR form (before it had the HRK/DEM form).

The paper is structured as follows: after this introduction, there is a review of theoretical and empirical literature on the FX market microstructure. The third section presents detailed description of Kuna trading between different participants in the Croatian FX market. Fourth section presents an overview of characteristics of the unique data set used, that really made this analysis possible. Section five presents the development of econometric models with the purpose to help in finding answers on the questions from this introduction. Section six concludes and gives directions for further research of microstructure characteristics of the Kuna FX market.

2. Literature review

Three Approaches to FX: Goods, Assets, and Microstructure

Before the 1970s, the dominant approach to exchange rate determination was the goods market approach. According to this approach, demand for currencies comes primarily from purchases and sales of goods. For example, an increase in exports increases foreign demand for domestic currency to pay for those exported goods. In this simple form, the implication is rather intuitive: countries with trade surpluses experience appreciation (which comes from the currency demand created by the surplus). Despite the intuitive appeal of this approach, however, it fails miserably when one looks at the data: trade balances are virtually uncorrelated with exchange rate movements in major-currencies FX markets. This negative result is perhaps not surprising given that trade in goods and services accounts for only a small fraction of currency trading - less than 5 percent of the average $1.5 trillion of FX traded daily (according to 2001 data).

In the 1970s, the asset (macro) market approach emerged. It built from the earlier approach by recognizing that currency demand comes not only from purchases and sales of goods, but also from purchases and sales of assets. For example, in order to purchase a Japanese government bond, a U. S. investor first purchases the necessary Jen. In addition, the investor's dollar return will depend on movements in the Jen, so his demand for the bond depends in part on his desire to speculate on those currency movements. Therefore, equations of exchange rate determination within the asset approach take the form $\Delta P_t = f(\Delta i, \Delta m, \ldots) + \varepsilon_t$, where ΔP_t is the change in the nominal exchange rate over the period. The driving variables in the function $f(\Delta i, \Delta m, \ldots)$ include changes in home and foreign nominal exchange rates Δi, changes in home and foreign money supply Δm and other macro determinants, denoted here by the ellipsis.[1] Changes in these public - information variables are presumed to drive price solely. Any incidental price effects that might arise are subsumed in the residual ε_t.

Disconcertingly, empirical work does not support the asset market approach either. The macroeconomic variables that underlie the approach do not move the exchange rate as predicted (long literature documents that these macro determinants account for only a small portion - less than 10 percent - of the variation of floating exchange rates). The classic reference is Messe and Rogoff (1983a) where they show that asset approach models fail to explain major-currency exchange rates. In his later survey, Messe (1990) summarizes by writing that "the proportion of exchange rate changes that current models can explain is essentially zero". The literature documenting this poor empirical performance is vast (for example Frankel and Rose 1995; Isard 1995; and Taylor 1995).

Lyons (2001) notes that the FX market enormous trading volume is problematic for the asset approach. Explaining volume is difficult because actual transactions are awarded no role in mapping macroeconomic variables into exchange rate behavior. Rather, because all macroeconomic news is publicly available, when news occurs, the exchange rate is presumed to jump to the new consensus level and this process does not require any trading.

[1] The precise list of determinants depends on which model within the larger asset approach is selected. Here interest is simply a broad - brush contrast between the asset and microstructure approach. For specific models see Frenkel (1976), Dornbusch (1976) and Mussa (1976), among many others.

As a result of asset approach shortages, a new approach to exchange rates, the microstructure approach, emerged. A core distinction between a microstructure approach to exchange rates and the traditional asset (macro) approach is the role of trades in price determination. In macro models, trades have no distinct role in determining price. In microstructure models, trades have a leading role - they are the proximate cause of price adjustment. What distinguishes the microstructure approach is that it relaxes three of the asset's approach most uncomfortable assumptions:

1. Information: microstructure models recognize that some information relevant to exchange rates are not publicly available.
2. Players: microstructure models recognize that market participants differ in ways that affect prices.
3. Institutions: microstructure models recognize that trading mechanisms differ in ways that affect prices.

Empirically, it is simply not true that all information used to determine market-clearing exchange rates are publicly available (Lyons 2001). Regarding this, FX traders at banks regularly see trades that are not publicly observable. This information forecast subsequent exchange rates (e. g., seeing the demands of private participants or central banks before the rest of the market). Regarding differences across market participants, traders with common information regularly interpret it differently. Another example of differences across market participants is motives for trade: some traders are primarily hedgers, whereas others are primarily speculators (and even among the letter, speculative horizons can differ dramatically). Regarding trading mechanisms that affect prices, it is most related with markets where transparency is low (e. g., where individual transaction sizes and prices are not generally observable). Low transparency can slow the updating of beliefs about appropriate prices, thereby altering the path of realized prices.

Therefore, in switch from exchange rate determination asset (macro) approach to micro approach, key feature is the informational role of trading process which is usually analyzed by signed order-flow – series of registered characteristics of trading transactions (time, price, amount, initiator, etc.). Micro approach bases on analyzing how information relevant to the FX price determination, including those which are documented in the signed order-flow, are reflected in spot exchange rate through trading process (analytical models in this approach are reflecting main characteristics of trading well). On the other hand, traditional asset approach models give little attention to how trading on the FX market is conducted. Assumption of those models is that trading details[2] do not have any influence on exchange rate behavior. So, according to micro approach, trading is not irrelevant market activity that can be ignored when observing exchange rate behavior, then it is an integral part of the process through which exchange rate is determined.

Micro-based exchange rate models start from the premise that much of the information about the current and future state of the economy is dispersed across agents (i. e. individuals, firms, and financial institutions). Agents use this information in making their every day decisions, including decisions to trade in the FX market at the prices quoted by dealers. Dealers quote prices (e. g. Kuna per unit of foreign currency) at which they stand ready to buy or sell foreign currency; they will purchase foreign currency at their bid quote, and sell foreign currency at

[2] For example, who quotes prices and how trading takes place.

their ask quote. Agents that choose to trade with an individual dealer (dealer's customers) send him trading orders. If customer order is sale order (dealer purchases FX), it has a negative sign and vice versa. The sum of values of sale and purchase orders sent to dealer during some period is signed order-flow. Importantly, order flow is different from trading volume because it conveys information. Positive (negative) order flow indicates to a dealer that, on balance, their customers value foreign currency more (less) than his asking (bid) price. By tracking who initiate each trade, order flow provides a measure of the information exchanged between counterparties in a series of financial transactions. It is also important to differ between order flow and FX demand and supply because order flow involves only executed but not potential transactions. This fact is very important because within the asset approach only potential (not in real trading realized) FX demand and supply is needed to move exchange rate.

Trading in the FX market also takes place between dealers. In direct interdealer trading, one dealer asks another for a bid and ask quote, and then decides whether he wishes to trade. When the dealer initiating the trade purchases (sells) foreign currency, the trade generates a positive (negative) interdealer order flow equal to the value of the purchase (sale). Interdealer trading can also take place indirectly via brokerages that act as intermediaries between two or more dealers. In recent years electronic brokerages have come to dominate interdealer trading, but the interdealer order flow generated by brokered trades plays the same informational role as the order flow associated with direct interdealer trading.

Within the microstructure approach, models of exchange rate determination are variations on the following general stochastic model:

(1) $\Delta P_t = g(X, \Delta I, \dots) + \varepsilon_t$

where ΔP_t is the change in the nominal exchange rate between two transactions. The driving variables in the function include order flow X (signed so as to indicate direction), the change in the net dealer positions (or inventory) ΔI, and other micro determinants denoted by the ellipsis. Any incidental price effects that might arise are subsumed in the residual (stochastic error) ε_t. Empirical estimates on the relation between ΔP and X are uniformly positive and significant (Lyons 2001), confirming microstructure approach validity in exchange rate analysis. It is noteworthy that these empirical estimates have been possible only a relative short time, since introduction of electronic trading which provides detailed records of order flows. That partly explains relatively late appearance of microstructure approach in financial instruments price determination process, especially in analysis of exchange rate determination which is least transparent among all financial assets price determination processes.

The process of information transition and analysis through order flow on the FX market could be presented as a theoretical model composed from two stages of FX trading mechanism (Lyons 2001, page 8). In the first stage, in which information transition takes place, agents towards doing their business activity and on the basis of noticed changes in fundamental economic factors, send to their dealers' sale or purchase orders. In next stage, in which information analysis takes part, dealers observe received orders obtaining in that way new knowledge that is needed for quoting their own prices (exchange rates) correctly. However, it is important to notice that order flows are not main driving force of exchange rate changes but they are the transitory mechanism of dispersed market trading information to the exchange rate. Reason for information dispersion is in the characteristics of FX market: decentralized structure, missing of regulation and untransparency of trade. That is why micro approach involves into the exchange rate analysis new feature - private information. They can be defined as information which:

1. are not commonly known across the market
2. provide better forecast of future prices than public information alone.

So, when dealer gets order from his client, he keeps information about that order for himself. Same thing takes place in the inter-dealer trading where only contract parties know characteristics of mutual orders. This confidentiality is supported by not existing obligation of announcing business information on the FX market, as it is the case on all other segments of financial market.

According to Cao, Evans and Lyons (2002), private information that are carried by the order flows can be separated into two groups: fundamental and non-fundamental. Fundamental information refers to undeclared information about financial instrument yield (in case of shares, usually it is the information about future dividends). Whereas only information of that kind on the FX market is that about interest rates on different currencies and that appearance of confidential interest rates scope information is not common phenomena, follows that on the FX market there is no private information concerning fundamentals. On the other hand, non-fundamental information is connected to variables that have nothing in common with future cash flow, then they affect financial instrument price directly. In the case of exchange rates, such information is, for example, those about FX demand changes induced by reducing FX risk exposure or by speculating. That information usually determines the risk premium that is incorporated into dealer's price. Some examples of such information are dealer's risk preference, his trading restrictions, distribution of risky assets, etc.

Formalization of signed order-flow influence to exchange rate behavior model

Lyons (2001, page 63-112) gives four most frequently used models for exchange rate determination within the microstructure approach:

1. Rational expectations auction model
2. Kyle auction model
3. Sequential-trade model
4. Simultaneous-trade model

Together, these four models span the three categories of markets in which FX trading takes place: auction market, single dealer market and multiple dealer market. The first two models use an auction market structure, whereas the third and fourth use a dealer market structure. Of all these models, only the simultaneous-trade model uses institutional settings similar to those in real FX market. Namely, all three previous models adopt a centralized market structure, which contrasts sharply with the FX market's decentralized, multiple dealer structure. The simultaneous-trade model is designed to fit this FX market structure.

Because of simultaneous-trade model advantages mentioned above, here will be presented one of its variants - a daily frequency model (Lyons 2001, page 176). There are *N* dealers in the model, a continuum of nondealer customers (the public), and an infinite number of trading days. Primary simplification is assumption that within each day there are three rounds of trading:

Round 1: Dealers trade with the public
Round 2: Dealers trade among themselves to share the risk
Round 3: Dealers trade with the public to share the overnight risk

Macro component of the model is based on new, publicly announced information about the home and foreign interest rate difference on day *t*

$$(2) \quad \Delta I_t = \Delta(i_t - i_t^*)$$

where i_t is the nominal interest rate associated to the foreign currency and i_t^* is the nominal interest rate associated to the local currency.[3] Among all other macroeconomic fundamentals, the interest rate differential is privileged for it is a variable with available daily data, and also because it is the main engine of exchange rate variations in macroeconomic models.

As interest rate difference is observed publicly at the beginning of each day before trading, the change of payoff to holding foreign exchange in day *t* (ΔR_t) is also observed publicly at the same time. Therefore, the time-*T* payoff on foreign exchange R_T is composed of a series of daily increments ΔR_t:

$$(3) \quad R_T = \sum_{t=1}^{T} \Delta R_t$$

On the basis of interest rates change in day *t* (ΔI_t) and change of payoff to holding foreign exchange in day *t* (ΔR_t) and other available information, each dealer simultaneously and independently quotes price (exchange rate) to his customers. First-round price of dealer *i* on day *t* is P_{it}^1. Each dealer then receives a net-customer order realization C_{it}^1 that is executed at his quoted price P_{it}^1, where $C_{it}^1 < 0$ denotes a customer sale (dealer *i* purchase). Aggregate public demand in round one could be defined as:

$$(4) \quad C_t^1 = \sum_{i=1}^{N} C_{it}^1$$

Customer orders C_{it}^1 are not publicly observable, they have normal distribution, and they are uncorrelated to ΔR_t.

Round 2 is the interdealer trading round. Each dealer independently quotes his price to other dealers - P_{it}^2 at which he agrees to buy and sell any amount of FX. These interdealer quotes are observable and available to all dealers in the market. Each dealer then simultaneously and independently trades on other dealers quotes. Let T_{it} denote the net interdealer trade initiated by dealer *i* in round two of day *t*. At the close of round 2 all dealers observe the net interdealer order flow on that day:

[3] Evans and Lyons (2002) in ¥/US $ and DM/US $ behavior prediction model use the US daily (overnight) interest rate and the equivalent rates in Japan and Germany.

(5) $X_t = \sum_{i=1}^{N} T_{it}$

So, as opposed to round 1 customer-dealer trades that are not publicly observable, interdealer trades in round 2 are publicly observable. This round 2 order flow information is important to the model because it conveys the size and sign of the public order flow in round 1. The model of that relationship is called "interdealer trading rule":

(6) $T_{it} = \alpha C_{it}$

Each dealer's trade in round 2 is proportional to the customer order he receives in round 1 in a way that depends on constant (positive) coefficient α. This implies that when dealers observe the interdealer order flow, they can infer the aggregate public order flow C_t^1 in round 1 since they are connected as shown in the following relation:

(7) $X_t = \sum_{i=1}^{N} T_{it} = \alpha C_t^1$

Finally, in round 3, dealers share the overnight risk with the non-dealer public. Unlike round 1, the public's motive for trading in round 3 is purely speculative. To start the round, again each dealer independently quotes his price P_{it}^3 at which he agrees to buy and sell any amount.[4] A crucial assumption is that dealers set prices in round 3 such that the public, by absorbing all dealer inventory imbalances, willingly absorbs overnight risk. Consequence of that is that each dealer ends the day with no net position. Price P_{it}^3 is conditioned on the round 2 interdealer order flow X_t which informs dealers of the size of the total inventory that the public needs to absorb.

More precisely, to determine the round 3 price, dealers need to know two things:

1. the total position that the public needs to absorb (which they learn from the X_t) and
2. the public's risk-bearing capacity.

Regarding the latter, the public's capacity for bearing foreign exchange risk is is assumed less than infinite.[5] Consistent with negative exponential utility, the public's total demand for foreign exchange in round 3 (C_t^3) is a linear function of its expected return conditional on public information:

(8) $C_t^3 = \gamma E [\Delta P_{t+1}^3 + \Delta R_{t+1} | \Omega_t^3]$

where positive coefficient γ captures the aggregate risk-bearing capacity of the public. A larger γ means the public is willing to absorb a larger FX position for a given expected return $E [\Delta P_{t+1}^3$

[4] Lyons (1997) gives analitical proof that in round 3 all dealers should quote the same price because in round 3 all dealers are familiar with public informations and aggregate order flows from first and second round of trading.
[5] Lyons assume that foreign and domestic currency assets are not perfect substitutes.

$+\ \Delta R_{t+1}$]. Ω_t^3 is the public information available at the time of trading in round 3 (which includes payoff to holding foreign exchange in day t ΔR_t and interdealer order flow X_t).

Evans and Lyons (1999) show that the price at the end of day t in presented daily frequency model is:

$$(9) \qquad P_t = \sum_{t=1}^{T} \Delta R_t + \lambda \sum_{t=1}^{T} \mathrm{X}_t$$

where λ is a positive constant (which depends on γ and α). Therefore, the change in price from the end of period *t-1* to the end of period *t* is:

$$(10) \qquad \Delta P_t = \Delta R_t + \lambda \mathrm{X}_t$$

Daily payoff increment ΔR_t denotes macro component of price change, while $\lambda \mathrm{X}_t$ denotes its micro component. Term $\lambda \mathrm{X}_t$ is the portfolio shift term. This term reflects the price adjustment required to induce re-absorption of the random order flow C_t^1 that occurred at the beginning of the day (portfolio balance effect). The public's total demand in round 3, C_t^3, is not perfectly elastic, and λ insures that the round 3 price provides realization of the following term:

$$(11) \qquad C_t^1 + C_t^3 = 0$$

Relationship between volume, volatility and spreads in microstructure literature

For several reasons, the empirical microstructure literature on the foreign exchange market has long been interested in the relationship between risks and volumes. It provides insight into the structure of financial markets by relating new information arrival to market prices. The price volume relationship has a direct bearing on the empirical distribution of speculative prices. Although less important to the Jamaican foreign exchange market, it also carries implications for the design of futures contracts. Numerous studies have found a strong, positive contemporaneous correlation between volumes and volatility. A theoretical explanation has been advanced for this positive relationship known as the mixture of distribution hypothesis. First advanced by Clark (1973), the theory posits that volume and volatility are both driven by a common unobservable factor, which is determined by the arrival of new information to the market. The theory predicts positive co movement of volatility and unexpected trading volumes.

Empirical studies of the futures and equities markets that have found trade volume to be significantly positively correlated with price variability includes Clark, 1973 and Epps and Epps, 1976, Frankel and Froot, 1990 and Lamoureux and Lastrappes, 1990. Frankel and Froot, 1980 using data for four currencies found evidence that the contemporaneous correlation between volume and volatility was high. [6] There are several interpretations given to this finding of a positive correlation between volume and volatility. Clark uses a random

[6] The granger causality test did not show statistically significant causation running directly from volume to volatility. However this is not surprising since any such causality would be purely contemporaneous and granger causality tests cannot detect this type of causality.

variable with a mean proportional to the mean number of daily transactions as a measure of the variance of the daily price change. He argues that since trading volume is related positively to the number of within day transactions then trading volume is positively related to the variability of the price change.

Epps and Epps assume a positive price variability volume relationship between the extent to which traders disagree when they revise their reservation prices and the absolute change in the market price. Applying this to the foreign exchange market, implies that the extent to which traders disagree is associated with a larger absolute change in the exchange rate and thus greater variability in the rate. The volatility volume relation arises then because trading volume is positively related to the extent to which traders disagree when they trade.

Like Epps and Epps, Tauchen and Pitts also posit that the correlation between volume and volatility should be positive if trading occurs because of disagreement among traders and negative when volume is determined by the number of traders. That is, volume increases because the number of traders has increased, so that there is an increase in liquidity. Tauchen and Pitts noted that the model of Epps and Epps ignored the growth in size that can occur in new financial markets over time. Trading on a new market is initially very thin. However, if the market is viable then the trading volume increases secularly as more traders become aware of the market's possibilities. Support for this theory is found if the variance is found to depend positively on volume and negatively on a time trend intended to reflect a steady growth in the number of traders.

Tauchen and Pitts (1983) have posited two theoretical explanations for the co-movement of volatility and trade volume. The first is that as the number of traders increases the volatility of the market price declines. The argument here is that as participants increase, transactors are so many that demand shocks experienced by individual traders tend to offset each other leaving the market price largely unaffected. The second explanation he posits would apply to more mature markets. In such a market where the number of traders is likely to be fixed, then an increase in volume is a reflection of greater disagreement among traders and hence will lead to higher volatility. The second link is stronger when new information is arriving in the market at a faster rate. Melvin and Yin (2000) investigated the relationship between the arrival of information, the quoting frequency and the volatility of yen/dollar and dollar/mark exchange rates using intra-day data from Reuters screens. They found a positive relationship between the amount of information arriving at a particular hour of a particular day of the week and exchange rate volatility.

Inventory control and information are the two channels highlighted by the microstructure literature through which trade volume generates price movements. The inventory control channel postulates that dealers use prices to control movements in their positions. The latter focuses on the presence of traders with private information and in light of this, dealers, because they are rational, will adjust their beliefs and prices in response to changes in order flow. One implication coming from both views is that trades initiated by buyers will drive prices upwards. Lyons (1993) using intra-daily data found strong evidence in favour of both strands of the microstructure theory.

The microstructure literature has also found a positive relationship between trading volumes volatility and spreads in foreign exchange market. Microstructure theory suggests that inventory cost is one component of the spreads in financial markets. Models that seek to explain inventory costs establish a link between spreads volatility and trading volumes. The cost of maintaining an open position in any currency is one determinant of inventory costs, which is positively related to price risk. According to this view, exchange rate volatility increases price risk and thereby pushes up spreads. Thus spreads widen when exchange rate volatility increases. Melvin and Bolerslev (1994), Bessembinder (1994) found a positive correlation between spreads and expected volatility measured by GARCH forecasts.

Trading activity, according to the literature is another determinant of inventory costs. Volumes impact spreads differently depending on whether they are expected or unexpected. Unexpected trading volumes should have a positive impact on spreads given that they should reflect the arrival of news to the market. By contrast, expected trading volumes should be negatively correlated with spreads to the extent that they reflect economies of scale associated with higher competition among market makers.

Empirical results

Until now, a few researches have been conducted that have shown that order flows explain exchange rate variations very well, better then fundamental asset (macro) approach theories.

Evans and Lyons (2002) in period of 89 working days which started in August 1996 have tested hybrid model in which they as independent variables used daily changes in domestic and foreign exchange rates (macro influence) and daily changes in order flows (micro influence). As an independent variable they used daily changes of USD/DEM and USD/JPY exchange rates. Results have shown that order flows regression coefficient for both exchange rates had expected sign (net positive order flows towards USD - purchase orders - produce its appreciation) and were statistical significant, while interest rates regression coefficient was significant only for USD/JPY exchange rate. More important is that order flow changes explain 45 per cent USD/JPY variations, and even 64 per cent of USD/DEM variations, while significance of the interest rates is irrelevant. This analysis, which is based on daily data, has also shown that order flow influence is relevant not only in the short period of time what is often an assumption in microstructure of financial market analysis because frequency of used data is very high (even to the level of seconds). In out-of-sample forecast, for one day to two weeks period (short data series allowed only this short forecast) results were 30-40 per cent better than forecast on the basis of exchange rate random walk, and that was newer case with the forecast within the assets (macro) approach.

Don, Payne and Lui (2002) used 10-month long data series for EUR/USD and EUR/GBP exchange rates and 8-month long data series for USD/GBP and USD/JPY exchange rates. Observed data frequencies were in the range from five minutes to one week. Results of this research also confirmed significant influence of order flows to the exchange rates. For most important exchange rate - EUR/USD - on average 40 per cent of its variations is explained, without any significant deviations by periods, while for USD/JPY exchange rate average is from 6 per cent of the variations (for 5-minut data frequency) to 67 per cent of the variations (for weekly data frequency). Rime (2001) uses weekly data on exchange rates of Norwegian Crown in period from 1996 till 1999 in relation to USD, DEM, GBP and SKK. Results of this research show that order flows have significant influence to the Norwegian Crown exchange rate, especially in relation to DEM (33 per cent of variations explained). For other exchange rates, the level of explained variations is above 20 per cent.

As an answer to the question what really drives order flows, first empirical researches brought out belief that private information are only driver of order flows and most important factor in exchange rate determination. However, Evans and Lyons (2003) came to the firm conclusion that direct influence of publicly announced information to the exchange rates is not so significant (about 10 per cent of total exchange rate variations), but that at the same time public information, and not only private information, move order flows and in that way indirectly have influence on exchange rates. Reason for that is in the fact that processing of publicly announced information differs among market participants[7] and so different participants give to those information different importances in exchange rate determination. Evans and Lyons (2002) have shown that of about 60 per cent of exchange rate variations explained by the order flows, 20 per cent refers to order flows that are initiated by a different perception of public macro information, and 40 per cent refers to order flows that are initiated by private information. Of remaining, before unexplained 40 per cent of exchange rate variations, 10 per cent can be connected with direct influence of publicly announced information to the exchange rate, and 30 per cent of total exchange rate variations remain unexplained.

Dealers collect private information in communication with their clients, other dealers and brokers. However, different sources of information have different influence on informing dealers and exchange rate behavior. Examinations have shown that "big players" have competitive advantage because they are better informed and hence more influence on exchange rate behavior (Cheung, Chinn and Marsh, 2000). Fan and Lyons (2001) analyzed everyday business activity of *Citibank* in five-year long period, and their conclusions confirmed that order flows have different characteristics, depending on the type of their initiator - large orders of the investment funds are more important for the exchange rate behavior in a short time period, while in the long run bigger influence have orders of nonfinancial enterprises (exporters and importers). Carpenter and Wang (2003) identified that for business activity of one bank on the Australian FX market, influence of nonfinancial corporations orders is statistical irrelevant for behavior of most exchange rates. They identified that the most important and the most permanent influence on exchange rates have orders of central bank and nonbanking financial institutions and that dealers give most importance to the orders initiated by one-quarter by total orders amount largest clients. Bjønnes, Rime and Solheim (2003) in their research for the first time use aggregated data for SKK/EUR behavior analysis. They identified that dealers like large, well informed banks, have crucial influence on exchange rate scope. All mentioned results confirm the heterogeneity of FX market participants which is manifested in different amount and quality of information they get and their different treatment by those who set exchange rates - FX dealers.

3. FX market and FX regime

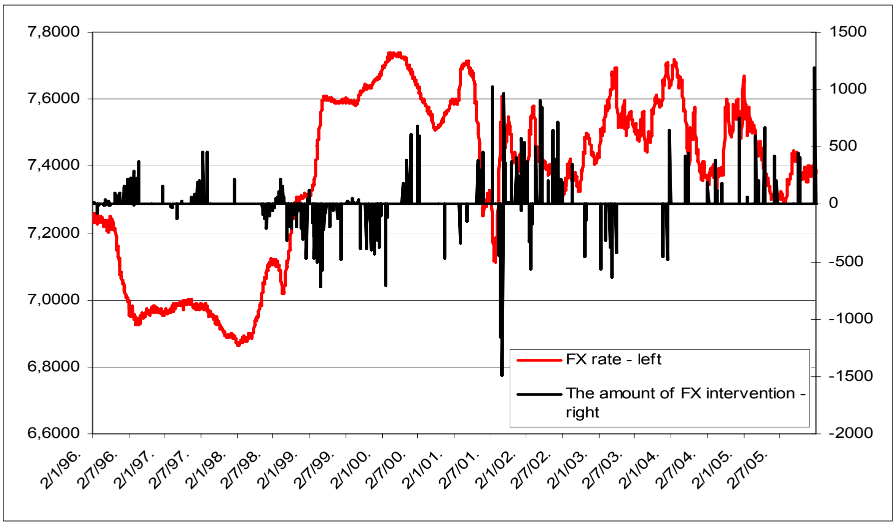
Croatian FX market is an important segment of Croatian financial market that was developed relatively early. There are couples of factors that have contributed to its development. Market supply and demand has traditionally been stimulated by significant inflow and outflow of foreign currency (based on current and capital account transactions). After 1999, because of the bigger inflow than outflow of foreign currency, Croatian currency Kuna has experienced mostly appreciative pressures. A large inflow of foreign exchange is a result of tourism, privatization of public companies, foreign public debt, foreign debt of domestic banks and arrival of foreign

[7] Different way of processing of same, publicly available information on the FX market is one of the most important facts on which criticism of asset (macro) FX teories is based.

bank-assignments of Croatian workers from abroad. On the other side, the big outflow of foreign currency is mainly a result of payment of foreign (government and banks) liabilities. The big inflow and outflow of foreign currency, together with gradual liberalization of foreign exchange Act (witch allowed no financial companies after 2001. to actively trade with foreign currency) have been main factors of development of FX market in the last few years.

Croatia uses managed float FX rate regime without announcing planned pattern of FX rate float. That way, central bank (Croatian national bank) does not determine lower or upper intervention level. It intervenes when and how much it thinks it is necessary to achieve the goals of monetary policy. Also, the management of Croatian national bank (CNB) extremely rarely announces in public the level of FX rate that they will defend. Despite the fact that a large part of public believes that CNB determines the official foreign exchange rate (called CNB middle FX rate) in accordance with the needs of monetary policy, it is actually completely determined by the FX market. CNB only determines the methodology for the calculation of the official FX rate from the FX rates from the market and FX trade and if it wants to influence the official rate movements it will do it by using FX interventions (by buying or selling foreign exchange to banks or sometimes the government). But because of the assumption that the historical effect of the FX rate volatility on domestic prices has not disappeared, central bank that guarantees price stability does not allow significant volatility of CNB middle FX rate. Therefore, CNB middle FX rate for HRK/EUR relation since the beginning of 1997 has a coefficient of variation of only 3,1% while the same coefficient for HRK/USD stands at 13,6%. It is also important to mention that two thirds of foreign reserves of Croatia are denominated in Euro which also emphasizes historical connection of Croatia with strong European currencies (in history with German Mark, since 2002. with Euro).

Figure 3.1: Croatian national bank foreign exchange interventions and middle FX HRK/EUR rate

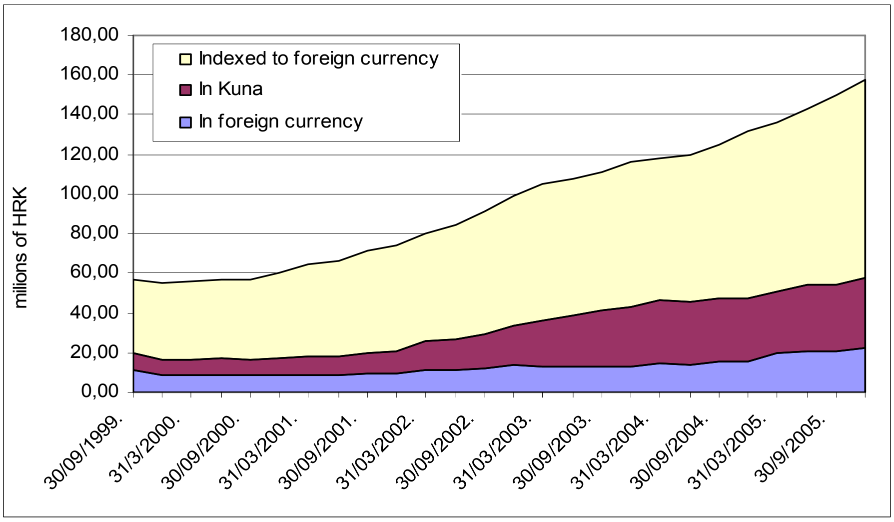


Source: HNB

Official foreign exchange rate

CNB publishes the official FX rate (CNB middle FX rate) each day. This rate is valid for the next day, or few next days if they are not working days. CNB middle FX rate has an important role in Croatian economy. Because of many reasons, Croatian currency, Kuna has never been a real measure of value. Because of that, values have always been expressed in German Marks and later in Euro. A significant part of private, corporate and even government liabilities is denominated in Euro, but the payments are actually made in Kuna indexed to CNB middle FX rate at the maturity date. Besides, CNB middle FX rate is an important entering variable in a large number of econometric models.

Figure 3.2: The structure of total bank loans in Kuna indexed to foreign currency, in Kuna and in foreign currency



Source: CNB

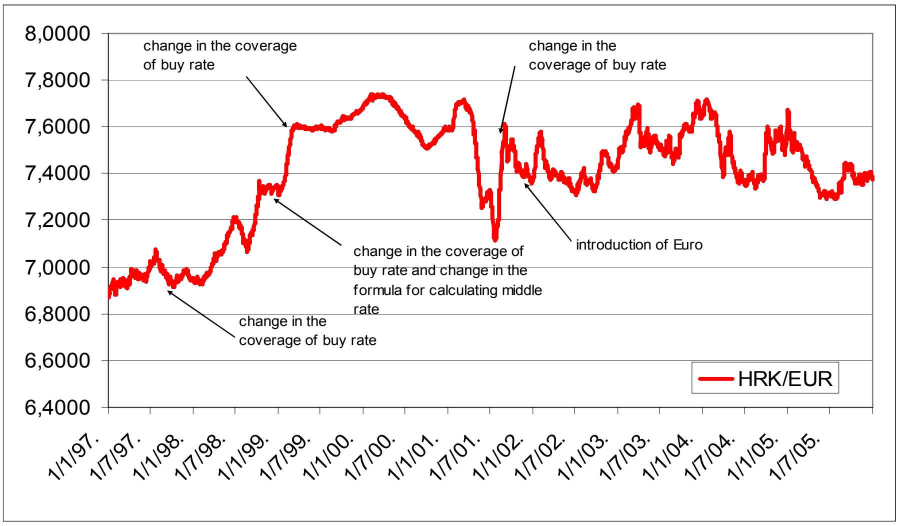
CNB middle FX rate calculation is based on FX trade and FX rates on the interbank market, and between banks on the one side and natural persons and legal persons on the other side. Commercial banks are obliged to submit standardized report to CNB regarding FX trade. FX reporting obligation refers to:

1) FX trade between banks and domestic companies,
2) FX trade between banks,
3) FX trade between domestic and foreign banks,
4) FX and foreign currency trade between banks and natural persons.

In this report trading data is expressed in original currencies and in Kuna value. The first step in the calculation of CNB middle FX rate is conversion of original currencies in Euro using so called cross-EUR (FX rate for Euro from Frankfurt FX market) for every currency that was valid that day at 11:45. To get the average sell rate weighted with trading volume for that day the value of the total selling transaction from all banks is divided by their value in Kuna. The same formula applies to the average buy rate weighted with trade volume. In the end, the arithmetic average of those two weighted averages is CNB middle FX rate (for Euro). CNB middle FX rate for other currencies is calculated by crossing the Kuna FX rate with cross-EUR rate that applies to the day on which the data is being used. Middle FX rates are used for calculation of liabilities in foreign currency, customs and other taxes calculation as well for statistical needs. CNB middle FX rates list is put on the CNB web site before 14:00 current day with the FX rates that refer to the next day. CNB buy and CNB sell FX rates are also published on that list but they do not reflect the real rates in buying and selling of FX. They are calculated mechanically by deducting or adding a 0,3% spread on already calculated middle FX rate.

CNB middle FX rate methodology has been changed a couple of times in history. Because of these changes there are a couple of structural breaks in the data series of CNB middle FX rate. Some changes refer to trading coverage while others refer to mathematical formula implemented on selected data. First statistical break was created in October 1997 when the trading coverage in CNB middle FX rate was changed. More precisely, the reporting method of banks FX trade was changed. Because of that change the most of statistical data with CNB FX rates start with 1.10.1997. Second statistical break happened 1.1.1999 when the interbank trade was included in the coverage for calculation of buy FX rate. In the same time, the definition of CNB middle FX rate has been changed from weighted average (weighted by trade of weighted buy rate and weighted sell rate) into arithmetic average of those two rates. The third statistical break happened 5.3.1999 when the transactions on the interbank FX market were excluded from the coverage for calculation of FX buying rate. At last, since 1.10.2001 the interbank FX trade is again included in the calculation of CNB middle FX rate in the way that it has the weight of 0,5 on buying and selling side.

Figure 3.3: CNB middle FX rate and statistical breaks in its calculation



Source: CNB

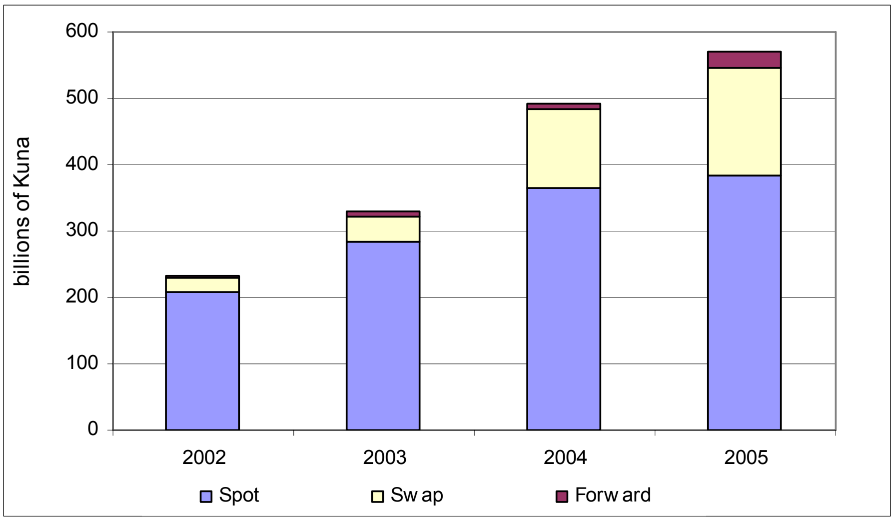
Mentioned statistical breaks are statistical fact and they make it impossible to display CNB middle FX rate as a consistent statistical time series since 1.10.1997 (see Table 1 in Appendix for more detailed chronology of changes of CNB middle FX rate calculation). Although it is a very good approximation of the market FX rate, the CNB middle FX rate is not a real market FX rate even if the statistical breaks are put aside. Because of the methodology of its calculation it always represents market FX rate from two days ago (or even more in case of non working day, or the first day after weekend or holiday). Also, because of the fact that CNB gathers only the reports in which one counterpart is bank, it does not represent the total interaction of FX market supply and demand.

Main characteristics of Croatian FX market

Market makers on Croatian FX market are commercial banks. Besides commercial banks, the government and the central bank have also important but specific roles. Croatian FX market consists of non effective segment which is mainly carried out through banks and effective segment which is carried out by exchange offices and private trade. Private FX trade is very specific and non-transparent because of the fact that it is impossible to know the exact volume of trade between natural persons.

One of the main characteristics of Croatian FX market is its shallowness. Regardless of the fact that the trading volume is growing consistently, its structure has been very uniform (monotone) in the sense that until 2004 almost all of the transactions were spot transactions. In 2004 FX swap market started to develop and in 2005 its trading volume amounted 28,6% of the total FX trading volume. On the other hand, although its trading volume doubled in 2005, forward FX market is still the smallest segment of Croatian FX market and amounts about 3,9% of total FX trading volume.

Figure 3.4: Trading volume on Croatian FX market regarding the nature of transactions



Source: CNB

The big increase in trading with the FX swap instruments can be connected with the increased volume of bank loans connected with Swiss frank. When the banks give loans in Swiss franks or indexed to Swiss franks, they are making their position in that currency longer. In order to balance their FX position, the banks have to sell Swiss frank and because of the fact that they usually don't have enough of it they have to reach for the swap instruments that enable them to sell Euro and buy Swiss frank. The credit for intensifying the use of swap instruments among banks indirectly goes to CNB or more precisely the measure called Marginal obligatory reserve. After this measure has been implemented, the FX swap instruments are the only instruments left that allow banks to get more Euros without having to extract Marginal obligatory reserve.

The role of the central bank

Croatian National Bank has an important role on Croatian FX market especially as the regulator. Besides, CNB runs the monetary policy through FX regime in the way of intervening on the FX market through asymmetric and unsterilized (or partially sterilized) FX interventions. Each domestic bank with the permission from CNB for conducting FX payments is allowed to take part in the intervention. Regardless of the public belief that CNB has an important role in daily movement of FX rate, it doesn't. It has occasional role on short term movement of FX rate because it intervenes relatively rarely on FX market but with relatively big amount. That is the reason why CNB`s role in total yearly FX trading volume is very small, but on the day (or week or even month) of intervention the FX trading volume between CNB and banks is very big.

Table 3.1: The proportion of CNB FX interventions in the total FX trading volume

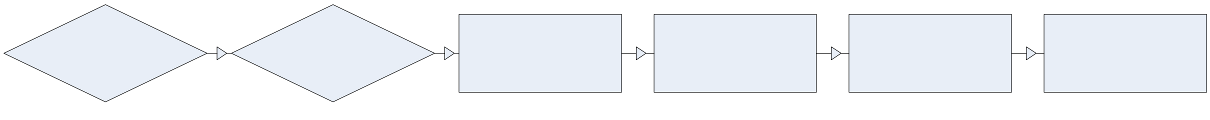
	In year						
	1999.	**2000.**	**2001.**	**2002.**	**2003.**	**2004.**	**2005.**
Foreign currency bought	12,9	2,0	3,8	2,2	2,4	0,1	0,0
Foreign currency sold	0,7	3,1	6,2	4,8	0,4	2,1	2,5
	In the month of intervention*						
	1999.	**2000.**	**2001.**	**2002.**	**2003.**	**2004.**	**2005.**
Foreign currency bought	16,4	15,7	8,5	8,9	6,5	2,5	0,0
Foreign currency sold	0,9	7,4	9,7	8,5	4,0	4,2	4,9

*Reference: This shows the average amount of foreign currency bought from or sold to CNB from commercial banks in the months in which CNB was conducting an FX intervention.

Source: CNB

Although the regulation allows CNB to use spot and swap transactions for conducting FX interventions, CNB mostly uses spot transactions. Also, CNB uses the model of differentiated rate by accepting already defined amount of offers. It doesn't use the model of universal rate that would force CNB to accept all the offers given at that rate. FX interventions are subject of quarterly projection of monetary policy accepted by the Council of CNB but it is the management of CNB who is in charge in defining time and amount of individual intervention. The intervention itself is conducted in a form of auction and usually a Dutch auction model is used.[8] For administering of that auction CNB dealing can use Reuters dealing system, telephone or telefax, but telefax is practically never used. The most frequently used type of CNB FX intervention can be described in four steps. After receiving the order to conduct the FX intervention, CNB dealers put the information about the intervention on CNB Reuters site and after that simultaneously with Reuters dealing system and telephone contact the banks that are allowed to take part in the CNB FX intervention. After the announcement the banks are given one hour of time to place their offers. Each bank is allowed to place three offers for each foreign currency that is the object of the intervention and on each side of the intervention (buy or sell position). Every offer that a bank makes is legally binding for the bank in the full amount. The minimal amount of each offer must be at least 300.000 Euro or 300.000 US Dollar. After the offers are collected CNB creates a list of banks with the results of the auction and at the very end of the auction the CNB dealers inform the banks about the results. If two banks have send their offers at the same FX rate and those offers exceed the amount the CNB is planning to accept, CNB will partially accept both offers, proportionally with the offered amount. After that the information about the conducted intervention is put on the CNB web site. This information includes bought or sold amount of foreign currency and the average rate of accepted offers.

Figure 3.5: The steps in conducting a CNB FX intervention



Source: CNB

[8] The Dutch model of auction is characterized by secrecy. This means that the bidder isn't familiar with the offers his competition makes. The opposite auction model is English type of auction where bidders publicly compete among each other and are familiar with the prices offered by their competition.

In the way it conducts FX interventions, CNB stands out as one of the most transparent among central banks. This transparency also refers to the period after the intervention because CNB puts the information about the intervention (time, amount and average FX rate) on the CNB web site. By looking at those data, one could conclude that in the period from 1993 to 2005 CNB was mainly a buyer of FX from the commercial banks. In the first couple of years of Croatian independence that was necessary because of the need for creating international reserves but later the buying of FX from banks was caused by appreciative pressures on domestic currency. Only during three years CNB was acting as net-seller of foreign currency to commercial banks. Those were the years: 1998, 1999 and 2003. In 1998 and 1999 the trust in domestic banking system was significantly reduced because of the banking crises which caused one portion of foreign savings to pour abroad or to be kept at home. That process created depreciative pressures on domestic currency which forced CNB to defend Kuna by selling foreign exchange. In 2003 Ministry of finance sold its foreign exchange (that came from abroad) only to CNB and not to the banks like it used to be common until then. In order to satisfy their foreign liquidity, the banks had to buy foreign currency from CNB in far larger amounts than they used to until then.

The role of the government

Except with commercial banks, CNB also conducts foreign exchange interventions with government. In that case, CNB buys and sells foreign currency for the account of government with the intention of decreasing unwanted influence of large direct inflow or outflow of foreign currency in the banking system. If Ministry of finance was to trade a large amount of foreign currency directly with banks, because of shallow and undeveloped market, the banks would not be able to absorb supply and demand of foreign currency and CNB would have to intervene anyway. The proportion of FX interventions that CNB makes with the Ministry of finance is relatively big (especially in the years in which privatization of public companies causes large inflow of foreign currency, or in the years in which repayment of foreign public causes large outflows of foreign currency).

Table 3.2: Sectoral distribution of CNB FX interventions

	Foreign currency bought			Foreign currency sold		
Year	2002	2003	2004	2002	2003	2004
Domestic banks	83,09%	13,67 %	74,58%	98,44%	82,5 %	11,72%
Ministry of finance	16,91%	86,33%	25,42%	1,56 %	17,5%	88,28%
Total	100%	100%	100%	100%	100%	100%

Source: CNB

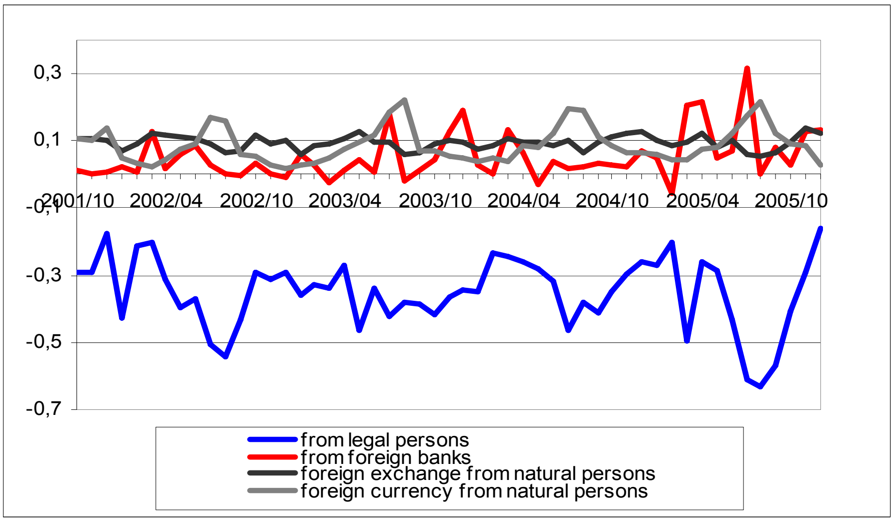
An important factor of Croatian FX market is also foreign debt policy, manifested especially through government FX bonds. Although Croatian government has started to replace foreign debt with domestic one by issuing government bonds on domestic market, there is still a substantial amount of outstanding foreign debt in form of Croatian government bonds on foreign markets. Maturity of those bonds often contributes to depreciation of Kuna because the demand for foreign currency rises. Also, the creation of new debt in foreign currency stimulates appreciation of Kuna because of the foreign currency inflow.

The role of domestic and foreign banks

The worlds FX market is an Over-the-counter market (shortly, OTC) on which the most important dealers are commercial banks. Except the trade with natural persons, this marker gradually lost its physical shape and now rest mostly on electronic transactions that enable easier access to the market as well as lower costs. In Croatia most of FX trade is also done electronically and only a proportion of FX trade (with natural persons) is done by trading effective foreign currency. The banks take part in FX trade with all sectors on Croatian financial market: legal persons, natural persons, foreign banks and domestic banks. With the exception of interbank market, banks are actually intermediaries between FX suficitary and FX deficitary segments of financial market. Although it isn't obvious, the most of the supply of foreign currency on Croatian FX market is indirectly created by foreign debt of commercial banks, that is foreign currency that is being sold from that source. In banks FX position it is being canceled with FX indexed loans so collective effect of banks foreign debt and domestic loans expansion is neutral for banks FX position.

In global relations US dollar is the most frequently used currency in FX and Euro takes second place. On Croatian FX market Euro is the most frequently used currency for trading which isn't surprising because the biggest players on the market are banks owned by mother-banks from EU. Also, one should keep in mind that the historical influence of German Mark has been very high in Croatia.

Figure 3.6: The value of monthly spot net-buy of foreign exchange through banks



Source: CNB

In their everyday FX trading banks use Reuters dealing system. If the client does not posses that platform the trading is done via the telephone and in that case all the conversations are recorded. The clients of the FX desk (a part of the banks treasury in charge of FX trading) are domestic and foreign banks as well as other financial institutions (pension funds and investment funds). Trading with legal and natural persons for larger amounts (for instance larger than 400.000 Kuna) is carried out at clients desk (a part of FX desk in charge with trading with larger clients) while trading with legal and natural persons for smaller amounts is carried out in banks facilities (or lately via electronic banking) by using the FX rates from banks regular FX rates list.

The most active segment of FX market is the interbank FX market. In that segment the FX trade is usually done in form of spot or term transactions. Spot transactions are the ones with delivery the day after tomorrow and term transactions are the ones with delivery on every other day which can include today or tomorrow. Because of the high velocity of its trade, FX market is market based on trust which means that the deals are usually struck at the moment but payments are confirmed and made later. This usually causes narrow specialization of FX dealers. They are usually in charge of striking the deals while confirmations, delivery and other administrative affairs are done in back-office. This implies that FX dealers are not responsible for defaults as long as they concluded the deal in the right manner. Each FX deal has to be confirmed by both parties and this confirmation includes all the elements from the original deal. These confirmations are sent to other party usually via SWIFT.[9] Since both parties in FX deal are buyers and sellers in the same time, FX transfer order is sent by both parties (each party for the sold currency). Although the conversation is usually done on trading monitor, telephone can also be used. The language used for these conversations is English but for the purpose of FX trading it is full of specific acronyms.

Dealers on the interbank FX market usually know each other so there is no need for introduction, they can simply ask for a quotation of bid/ask price. If dealers from a smaller bank want to make an FX transaction they will usually introduce themselves and ask for a quotation. Members of this market don't have to state their intention that is they don't have to state wheatear they are buyers or sellers of quoted currency. Bank that quotes the price quotes buy and sell price. If other party accepts the offer, offering bank is obliged to make the transaction. In the period of negotiation the FX rate can change which forces the banks to monitor this movements carefully even in the time of making deals. If the bank makes a mistake and offers an unfavorable rate that will harm their position the dealing code suggests that other party warns the offering side about their mistake of quoting non-normal prices and exposing itself to a big loss.[10]

On the interbank FX market the prices are quoted in bid/ask form. When the banks trade with commercial clients they always position themselves as market makers and quote the bid/ask price of wanted currency. Interbank FX market is specific because market makers are market users in the same time. When FX dealer from the bank is contacted by another bank or client he quotes the price as a market maker. But when he contacts another bank and asks for a quotation he is a market user. The FX rate on the interbank FX market is always quoted as a price of one currency (quoted currency) expressed in second (basic) currency.[11]

Croatian banks conduct FX trading in their treasuries. Treasury usually has front and back office, but larger banks also have a middle office. Front office usually includes money market desk, fixed income desk, FX desk, desk for corporate clients and effective money desk. FX desk is generally responsible for a couple of areas. First of all, it is responsible for internal quotation for client's desk, for creating regular FX rates list and of course for FX trading, that is FX market making as well as development of new products that could be offered to clients as part of FX trading. The process of FX trading usually has a couple of stages. First stage is usually identification of banks starting FX position. Banks FX position is the difference between the

[9] Each FX trade concluded with telephone or Reuters dealing system has to be confirmed in written form or in form of SWIFT (electronic network for conducting international payments) electronic message. Both parties are obliged to send the confirmation which has to contain all the important elements, that is: amount, date of trade, date of currency, rate, place and bank of currency delivery.
[10] The FX dealing code is not obligatory in Croatia, so in theory it is possible to earn substantial extra profit by ignoring it.
[11] In global terms the most used pair of currencies is EUR/USD, but in Croatia the most used pair of currencies is HRK/EUR.

total value of its claims and its liabilities in each currency. Because of the bank regulation that also includes FX position rules, FX position can cause a certain FX trading strategy from dealers. If a bank is to-short in a certain currency the dealers will probably be willing to buy that currency even at the higher price. Also, if a bank is to-long in a certain currency their dealers will probably be willing to sell that currency even at the lower price. That way, banks starting FX position and wanted FX position at the end of day causes the choice of FX rates at the beginning of working day.[12] After the starting strategy (based on banks FX position) is defined the FX dealers create the strategy of making profit on FX market which means that they have to find a way to buy at low and sell at high prices. The next step is determining wanted FX trade volume and market segments on which planned trade is easiest to achieve (some segments of the FX market like interbank FX market are suitable for larger trading volume while some segments like trade with natural persons for smaller trading volume). The last step in the preparation faze is the quotation of FX rates at which the dealers will be making the transactions on FX market.

All larger banks have Reuters dealing system and FX trading between banks is carried out exclusively by using this system. In Croatia there is no written rules of conduct for FX dealers but banks generally respect the International rules of conduct (business ethic) and the practices of financial markets written by ACI (International association of financial markets which ACI Croatia is a member). ACI Croatia organizes exams for ACI dealing certificate which are unofficially recognized as a certificate for FX dealers in Croatia. On Croatian FX market trading is active only during working days between 8:00 - 16:30. The trading is global which means that (in accordance with certain limits) Croatian banks can trade with any bank in the world. The trading amounts are usually expressed in millions of Euro although it is possible to trade with smaller amounts. Smaller banks on Croatian FX market usually don't trade for speculative reasons. They are usually involved in smaller transactions connected with their daily activities (or their client's daily activities) and with satisfying FX regulation.[13]

The role of natural persons

Natural persons are traditionally suficitary sector on FX market. The main characteristic of this sector is its unproportionally big proportion in effective foreign currency trade as well as impossibility to register each transaction this sector makes. Natural persons often trade with foreign currency because they use it as payment in private trade. Natural persons can trade with foreign currency in a couple of ways. First way is to trade foreign currency with commercial bank.[14] Historically, until last two years natural persons were trading with foreign currency only through banks regular FX rates list, but lately banks offer their clients direct access to interbank FX market for trading with bigger amounts. Another way is through licensed exchange office. Licensed exchange offices are legal persons or entrepreneurs registered for conducting foreign currency trade. Licensed exchange offices can trade with foreign currency after they conclude and agreement with commercial bank which settles out their relationship. Since 3.1.2005 licensed exchange offices are obliged to use one of the CNB-licensed and secured computer programs. Each exchange office concludes an agreement with bank which states the frequency of emptying their cash box that is, the number of times during a month (one time at least) that

[12] Even the largest Croatian banks don't have "on-line" FX position. Usually the middle office calculates and delivers FX position to FX dealers (if possible at the beginning of the working day, before the trading).

[13] In the case of substantial FX rate volatility smaller banks usually won't conduct risky transaction. They will rather fail to quote a price or they will quote the price very slowly or by using a very big bid/ask spread.

[14] U CNB statistics all the transactions between the banks and natural persons are considered as a spot transaction.

the exchange office will take the money to bank for repurchase. Licensed exchange office has to conclude the agreement with banks that states the conditions at which the bank will buy foreign currency by giving the exchange office a certain discount. Still, generally speaking, licensed exchange offices make their profit from trading with their clients and not from the bank that repurchases the currency from their cash box. The third way is the trade with other natural persons which causes a large part of the FX trade being left unregistered.

The role of legal persons

Legal persons usually trade with FX instruments through commercial bank with which they develop business relationships and where they have a business account. If the FX trade is in small amount legal person will have to make the transaction by using banks regular FX rates list, but in the case of larger amounts legal person can access client's desk. Legal persons are traditionally FX deficitory sector because the value of Croatian import is twice as big as Croatian export. Also, a large number of Croatian legal persons need the foreign currency to refund their foreign debts.

The biggest change for legal persons on Croatian FX market took place in April 2001. Until then legal persons were allowed to buy foreign currency only for foreign payments for goods and services. After that date they are allowed to buy foreign currency for payments abroad, capital transactions (allowed by law) and for placing their funds in FX accounts. This implies that up to 2001 Croatian legal persons couldn't control their FX instruments or their FX risk. To protect themselves from FX risk legal companies could strike business deals directly in foreign currency which was very useful in export business. Because of the FX rates volatility the legal persons in Croatia used to have loses from which they couldn't protect themselves. But after the mentioned regulation changes Croatian biggest legal persons started to form their own FX desks in their treasuries and started to protect themselves from FX risk more efficiently.

Liberalization and further development of Croatian FX market

The regulation has had a big influence on development of Croatian FX market. The key element of regulation of FX market has been the laws concerning FX business in country and with abroad. Those laws experienced a couple of changes during the last few years. In the first few years of Croatian FX market development, there wasn't a unique law to regulate FX. There were a couple of laws that regulated a segment of FX market each). Because of non-transparent system and because of the need to adjust the regulation with the EU regulation a new unique and transparent law was needed. In 2001 with Changes and amendments of the existing law a big step towards liberalization of FX market was made. Those changes made possible for legal persons to credit domestic legal persons in foreign currency for all of the abroad payments. It also made possible for legal persons to buy foreign currency for depositing on FX accounts of domestic legal persons (without stating the intention) and conversion of currencies. Besides, the steps in reconciliation of foreign liabilities and foreign claims via cessions, assignments, set-offs, etc. were also liberalized. These changes reflected immediately on trading volume on FX market (22,5% increase in November 2001). In the same year Croatia signed Stabilization and Association Agreement which demanded the liberalization of some segments of capital account during four years after the contract becomes valid. The complete liberalization of capital transactions (that is free capital flow) Croatia has to ensure before becoming a full member of EU.

During 2003 a new Foreign exchange act has been passed. The purpose of this law was accommodation with the regulation and practices of EU. It regulates three main areas: business between resident and non-resident persons in foreign currency and Kuna, business between resident persons in foreign currency, and unilateral assignment of assets from Croatia and into Croatia that doesn't have a characteristic of a business deal between a resident and non-resident. The law allows non-resident persons to hold Kuna and FX deposits in foreign banks. This means that in 2003 long-term capital flow liberalization has been almost completed. In that year gradual liberalization of short-term capital flow has been announced. Mentioned law has also canceled the possibility for commercial banks to establish an FX exchange.

Before the four years deadline stated in Stabilization and Association Agreement, in March 2005 Foreign exchange act was changed. Regarding liberalization of capital inflow, the constraints regarding the obligation of non-residents to open a custody account in banks and sign a statement which guarantees that they will not sell or pawn the security during the next year (except to another non-resident). Also, the veto for non-residents to invest in domestic short-term securities with remaining maturity up to six months has been removed. Further on, the rule that states that non-residents are not allowed to buy portions (that is shares) of investment funds whose statue requires that more of the half of its portfolio has to be in CNB bills or governments treasury bills, has also been removed.

It's important to point out that these constraints didn't refer to the countries with whom Croatia had an agreement of encouragement and mutual protection of investments (which referred to the most of the EU countries). The residents of those countries could trade with securities issued in Croatia under the same rules like the Croatian residents. Also, in case of substantial disruption in foreign payments system, Croatian national bank reserved the right to introduce temporary measures of capital movement restrictions that shouldn't last for longer than six months.

As far as the rules for residents to invest in foreign financial instruments and investment funds are concerned, the biggest change was the removal of the rule which stated in which countries residents can buy securities and shares in investment funds. This means that the issuer of securities doesn't have to be a member of OECD, international financial institution or that it doesn't have to be rated with certain rating by internationally recognized rating agency.

Regardless of substantial trading volume growth in the last couple of years which has undoubtedly stimulated its liquidity, Croatian FX market is developing relatively slowly which makes it illiquid and depended on couple of major players. The offer of FX instruments would definitely be better if the market had FX brokers, but FX brokers in global terms are slowly dying out. This isn't surprising because it's practically impossible to compete (in the means of costs) with non-physical OTC market. In that light one should observe unsuccessful attempt of Zagreb money market to organize an FX exchange as well as the failed project of Zagreb stock exchange to introduce FX term instruments and FX futures market. Also, one should keep in mind that Croatian banks in the period between 1993 and 1999 didn't exercise an option (offered by the law) to organize an FX exchange. FX market liberalization will definitely contribute to further growth of trading volume and decreasing of spreads, and in the meantime, Croatian FX market continues to develop in favorable macroeconomic situation and without substantial FX rate volatility.

4. Data

This paper employs a data set containing total daily volumes of foreign currency transactions reported by all domestic banks between October 1997 and May 2006, and sorted by: 1) type (sale, purchase), 2) instrument (spot, swap, forward), 3) currency, and 4) sector (natural person – cash, natural person – non cash, legal person, domestic bank, foreign bank). The data include the trading volume expressed in the transacting currency, in the base currency (DEM until the end of 2001, and Euro thereafter) and in the domestic currency (Kuna), so that the (weighted average daily) exchange rate can be computed separately for each reporting bank, transaction type, instrument sold, currency exchanged and the counterparty sector involved. Until the end of 2001, the dataset is based on a less extensive sectorization, so that all transactions by natural persons (cash and non-cash) are lumped together, as well as transactions with legal persons and foreign banks. Also, transactions between banks and foreign currency exchange offices are only reported by banks (within the natural persons - cash transactions sector) starting October 2, 2001. Due to the noted relevance of the above Euro-changeover and sectorization issues (to be elaborated further in this section) the econometric analysis in the next section of this paper is based on the portion of the available dataset beginning with January 1, 2002 (and ending May 31, 2006), i.e. it is based on the sample that has Euro as its base currency for the calculation of the CNB middle FX rate, and it employs the five sector classification of daily trading volumes.

Trading volume

Spot transactions have by far the highest share in the total volume traded on the Croatian foreign exchange market (Figure 4.1). The foreign exchange swap market started developing in the 2004, when the trading volume in this instrument almost doubled compared to the year 2003, but the total trading volume remained dominated by spot transactions. Except for the dominance of spot transactions, the market is also heavily dominated by the euro as the main currency of exchange (Figure 4.2). Before the introduction of the euro, the leading currency in the Croatian foreign currency market was German mark (DEM). Two other currencies with a significant share in the total volume are the US dollar (USD) and the Swiss franc (CHF).

Figure 4.1. Trading volumes by type of transaction

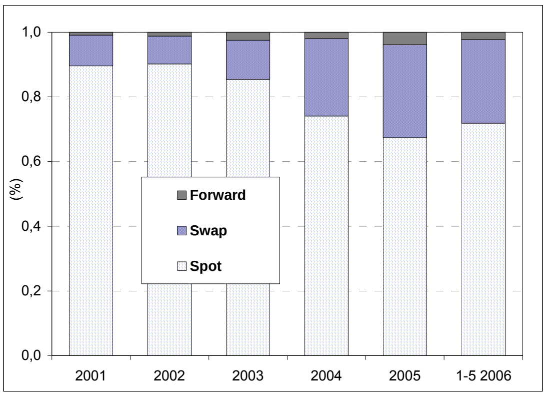
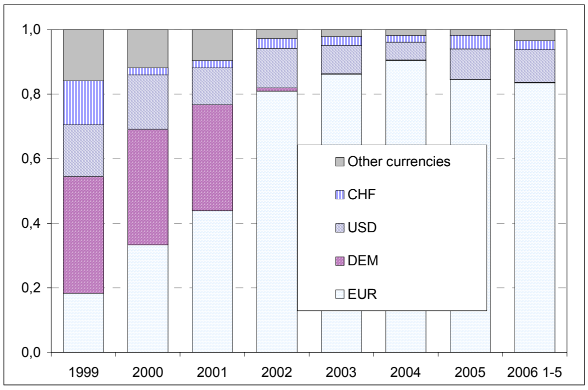


Figure 4.2. Spot transactions by currency



The most active sector in the foreign currency spot market is the legal persons sector (Figure 4.3) that comprises incorporated commercial entities as well as government units. Separate data on large government transactions in foreign currency are mostly available, but they are not extracted from the legal persons sector in this iteration of our analysis. Furthermore, legal persons are generally the net buyers of the foreign currency (from the banks) while the natural persons and the foreign banks are net sellers (Figure 4.4).

Figure 4.3. Spot transactions by sector

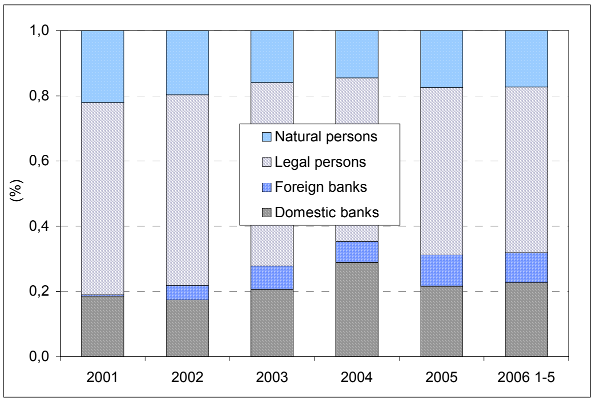
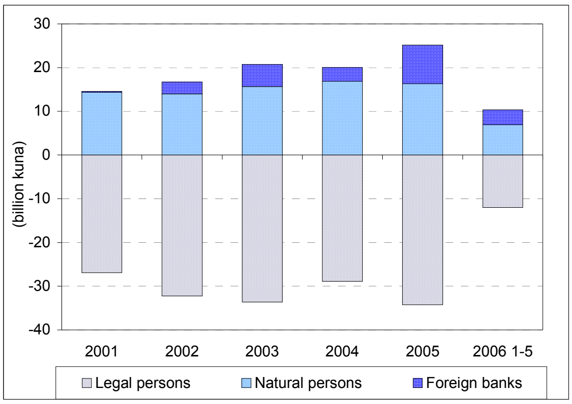


Figure 4.4. Net-spot transactions by sector



Exchange rate

Log-return

The CNB middle FX rate is calculated on a daily basis using the volumes and exchange rates at which the currencies have been traded on the market on that particular day. The methodology for the calculation of the CNB middle FX rate has changed a few times in the period from October 1997 to May 2006. There have been three major breaks in series that occurred in January 1999, March 1999 and in October 2001 (for the detailed description of the methodology see the previous section of this paper).

Figure 4.5. Monthly pattern

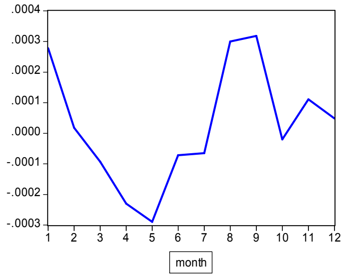


Figure 4.6. Intra-month pattern

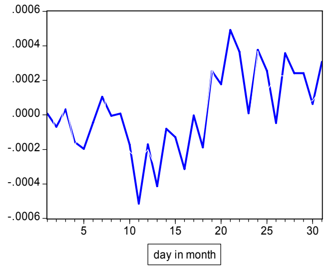
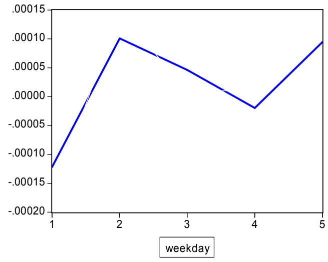


Figure 4.7. Intra-week pattern



For the purpose of this analysis the original CNB middle FX rate series has been transformed into the logarithm of the daily return series (further: log-return). The monthly average of such transformed series seems to show monthly seasonality (Figure 4.5): the log-return is, on average, declining from March to May and increasing from July to September. Also, the average daily log-return seems higher (and notably, positive) in the last third of the month than in the first two thirds of the month(Figure 4.6). Finally, it seems that the log return is lower (and negative) on Mondays, while it is higher (and positive) on Fridays (Figure 4.7).

<u>Bid-ask spread</u>

Bid-ask spreads are proxied by a simple difference between the weighted average bid rate and the weighted average and ask rate realized in the transactions between banks and their counterparties in the FX market, excluding the inter-bank transactions, as the available data do not contain the information on the initiator of the inter-bank trade that could be used to separate "purchases" from "sales" in this trading segment.

Figure 4.8. Natural persons, non-cash

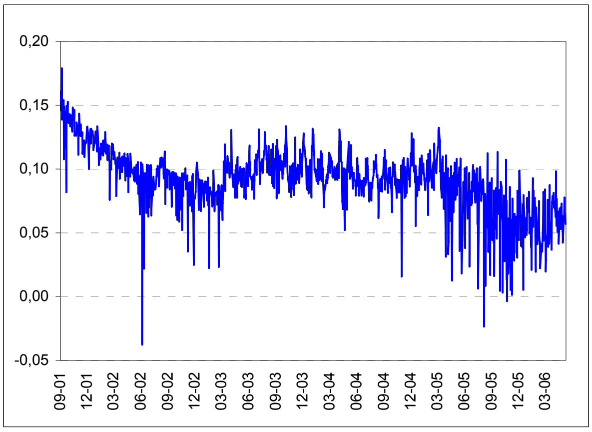


Figure 4.9. Natural persons, cash

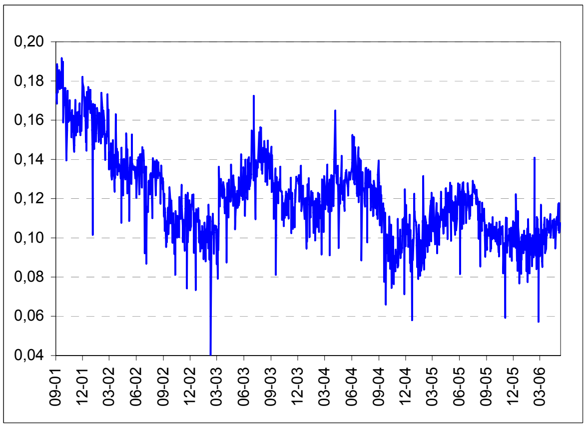


Figure 4.10. Legal persons

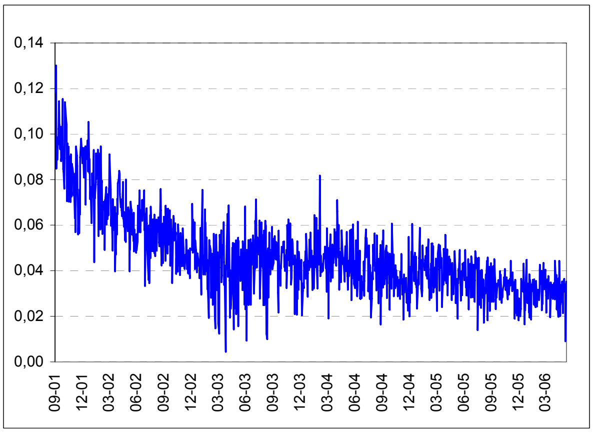
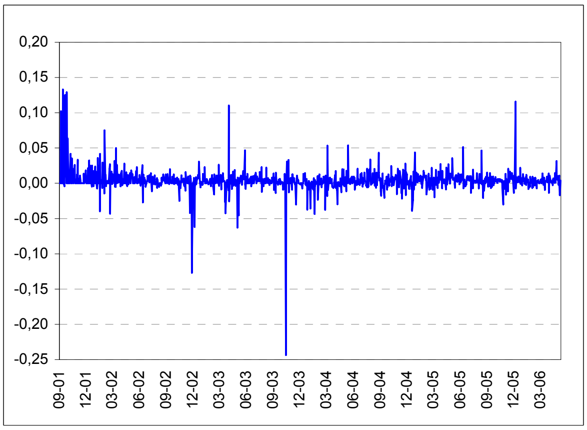


Figure 4.11. Foreign banks



Overall, it seems that the bid-ask spread has been declining over the past 5 years. A monthly seasonality appears strong in the segment of natural persons' cash transactions. Also, higher spreads for the transactions with the natural persons (especially cash transactions) than for the transactions with the legal persons probably reflect the higher costs of the cash transactions and smaller trading volumes in trading with natural persons.

Volatility

The CNB middle FX rate volatility is represented in three different ways. Figure 4.12 shows the daily movements of the log-return of the exchange rate in the past nine years. From that graph it seems evident that the volatility has increased in the first quarter of 2001, most likely as a consequence of the first phase of the capital account liberalization that occurred in the beginning of the year 2001. The square of the daily log-return and the absolute daily log-return series also show an apparent rise in the volatility level in 2001, but perhaps they also indicate a drop in the beginning of 2005 (Figures 4.13 and 4.14). If this is really so, it is very difficult to pinpoint a specific cause of this volatility shift, unlike with the 2001 shift.

Figure 4.12. Log returns

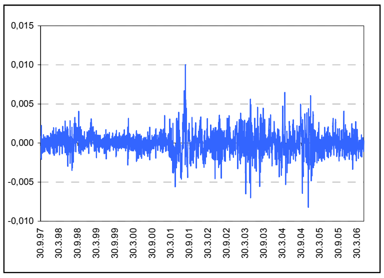


Figure 4.13. Abs. log-returns

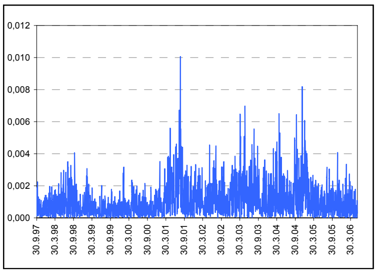
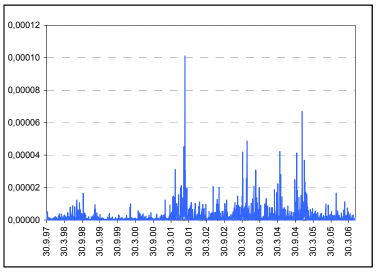


Figure 4.14. Sq. log-returns



Correlation matrices

The tables below represent the correlation matrices for the three main sectors in the foreign exchange market as well as for the market as a whole. The matrices show the relationship between the trading volumes (net and total), volatility of the exchange rate and the bid-ask spread.

It can be noted that there is a high negative correlation between the bid-ask spread and the total volume traded in the segment of natural persons' non cash-transactions and the legal persons' transactions. In the segment of cash transactions, there is no such correlation. That is most likely due to the fact that even in the case of a large transaction, high administrative costs of the cash transaction offset the potential decrease in the margin. There is also some negative correlation between the bid-ask spread and the two measures of volatility, as well as some positive correlation between the total volume and these measures, for all sectors combined. However, the latter relationship is much weaker for natural and legal persons, so it must reflect a specific characteristic of trading with domestic banks.

Natural persons - cash transactions

	Net volume[1]	Total volume[2]	Squared daily change[3]	Absolute daily change[4]	Bid-ask spread[5]
Net volume[1]	1,00	0,50	-0,02	-0,05	0,22
Total volume[2]	0,50	1,00	0,04	0,02	-0,04
Squared daily change[3]	-0,02	0,04	1,00	0,92	0,03
Absolute daily change[4]	-0,05	0,02	0,92	1,00	0,03
Spread[5]	0,22	-0,04	0,03	0,03	1,00

Natural persons - non-cash transactions

	Net volume[1]	Total volume[2]	Squared daily change[3]	Absolute daily change[4]	Bid-ask spread[5]
Net volume[1]	1,00	0,10	-0,03	-0,03	-0,02
Total volume[2]	0,10	1,00	0,06	0,07	-0,67
Squared daily change[3]	-0,03	0,06	1,00	0,91	-0,11
Absolute daily change[4]	-0,03	0,07	0,91	1,00	-0,12
Spread[5]	-0,02	-0,67	-0,11	-0,12	1,00

Legal persons

	Net volume[1]	Total volume[2]	Squared daily change[3]	Absolute daily change[4]	Bid-ask spread[5]
Net volume[1]	1,00	0,03	-0,07	-0,05	0,01
Total volume[2]	0,03	1,00	0,05	0,02	-0,62
Squared daily change[3]	-0,07	0,05	1,00	0,90	-0,03
Absolute daily change[4]	-0,05	0,02	0,90	1,00	0,02
Spread[5]	0,01	-0,62	-0,03	0,02	1,00

All transactions

Total	Total volume[2]	Squared daily change[3]	Absolute daily change[4]	Bid-ask spread[5]
Total volume[2]	1,00	0,18	0,14	-0,69
Squared daily change[3]	0,18	1,00	0,90	-0,11
Absolute daily change[4]	0,14	0,90	1,00	-0,09
Spread[5]	-0,69	-0,11	-0,09	1,00

[1] Net volume - the difference between the total purchases and sales,
[2] Total volume - sum of all the purchases and sales,
[3] Squared daily change of euro mid exchange rate,
[4] Absolute daily change of euro mid exchange rate,
[5] Bid-ask spread - kuna difference between the bid and ask exchange rate.

5. Results

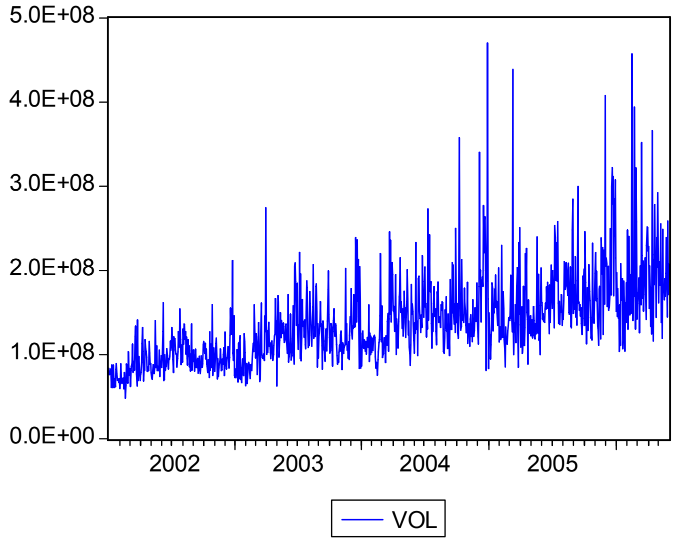
Before testing the proposed theoretical relationships betweeen unexpected trading volume and unexpected exchange rate volatility, and between expected exchange rate volatility and the bid-ask spread in the market for Croatian kuna, it is informative to glance at the raw daily data on trading volumes, exchange rate returns, and bid-ask spreads. The sample period convenient for the econometric analysis is shorter than the one described in the previous sections of the paper, and it covers daily data reported to the CNB for trading days between Jan 1, 2002 and May 31, 2006. The data set is also more aggregated and it covers only total daily spot transaction volumes between commercial banks and their customers, with all banks and all currencies lumped together, expressed in the base currency, euro, and in the domestic currency, kuna, broken down between buy and sell volume, and by the customer type: natural persons (broken down further as cash and non-cash transactions), legal persons (including government), domestic banks (i.e. inter-bank trading) and foreign banks. The weighted average daily kuna/euro exchange rates are then computed from these volumes, broken down in the same way as the volumes. Thus, possible effects of trading swaps and forwards on the volatility and the spread in the spot market are not analyzed in this study. Also, possible differential effect of trading volumes in different currencies on the volatility and the spread are not assessed at this time.

Table 5.1. Main variables – descriptive statistics

Descriptives	DLOG_CNBmr_ABS	DLOG_CNBmr_SQR	VOL	SPR
Mean	0.001230	2.66E-06	1.39E+08	0.050394
Median	0.000945	8.94E-07	1.30E+08	0.049193
Maximum	0.008217	6.75E-05	4.70E+08	0.107623
Minimum	1.63E-06	2.66E-12	48368312	0.013073
Std. Dev.	0.001071	5.15E-06	51853596	0.015101
Skewness	1.761.434	5.319.353	1.660.975	0.663541
Kurtosis	7.800.409	4.506.388	8.437.992	3.854.039
Jarque-Bera	1.638.295	86989.60	1.876.387	1.150.832
Probability	0.000000	0.000000	0.000000	0.000000

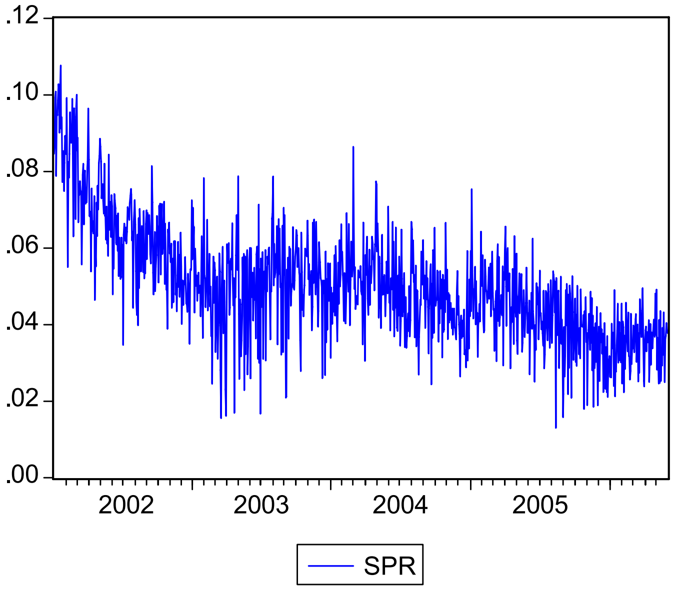
The total trading volume is measured as the sum of buy and sell orders, expressed in kuna, between commercial banks and their counterparties, not including the central bank, and counting the inter-bank volume only once. Other measures of volume have been examined as well, and the results of the econometric analysis did not change significantly, so they are not reported here. In the analyzed period, both the total trading volume and its volatility show a steady increase. The picture is different however, when the trading volume is disaggregated by the trading sector. While the cash trades with natural persons do not show a trend, but exhibit a strong seasonal pattern, non-cash trades with this sector show an almost exponential increase in size and especially in volatility during 2005, both of unknown origin (a rise in e-banking and open investment funds are possible, but yet untested explanations of this phenomenon). On the other hand, trading with legal persons shows a much steadier increase in size and volatility, and trading with foreign banks exhibits a much larger increase in volatility than in size. None of these trading segments follows a clear seasonal pattern.

Figure 5.1. Trading volume



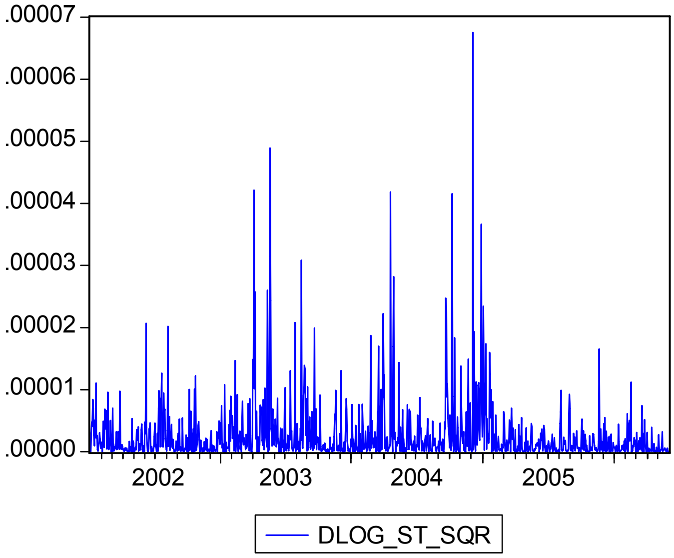
The overall bid-ask spread is measured as the volume weighted average of the spread in trading with legal persons and the spread in non-cash trading with natural persons. The omission of the foreign bank sector is intentional, because in many instances the spread for this sector cannot be computed (there are either no sales or no purchases on certain trading days). The spread in cash-trades with natural persons carries also the cost of foreign currency cash transactions, so that it is much higher than the spread in other trading segments, and it exhibits a seasonal pattern, two elements of the spread that are not of interest, so it too is left out from the calculation of the total spread. The spread in the inter-bank market is not available in our data-set. In the period analyzed, the overall bid-ask spread in the market for Croatian kuna exhibits a falling trend with steady volatility.

Figure 5.2. Bid-ask spread



The kuna exchange rate volatility is based on the official CNB mid-rate and measured two ways, as the average square change and as the average absolute change of the log of daily returns. Both measures are expectedly leptokurtic (both peaked and fat-tailed), and the square measure puts more emphasis on large returns, so it is more leptokurtic than the absolute measure. In the period observed, both measures of exchange rate volatility show signs of possible conditional heteroscedasticity of daily log returns of the CNB mid-rate. However, it is difficult to say from such a short sample whether volatility clustering in this case could perhaps be attributed due to a seasonal pattern, at least prior to 2005.

Figure 5.3. Volatility



The correlations between the observed volume, volatilities and the spread, reveal a strong negative relationship between the volume and the spread, and a much weaker positive relationship between the volume and both measures of volatility, while the relationship between the volatility and the spread is indeterminate. The second of these relationships gives an early indication that in the market for Croatian kuna the Mixture of distributions hypothesis may hold, that is that higher volumes are associated with more heterogeneous beliefs among market participants, and not with the increase in market liquidity. The first relationship, on the other hand, indicates that the spread in the Croatian kuna market is possibly much more affected by the competition among trading banks than by their inventory costs, which would then probably indicate that the market liquidity is affected by (at least some component of) the trading volume.

Table 5.2. Main variables – correlations

Correlations	DLOG_CNBmr_ABS	DLOG_CNBmr_SQR	VOL	SPR
DLOG_ST_ABS	1.000.000	0.903764	0.133930	0.031109
DLOG_ST_SQR		1.000.000	0.175642	-0.005888
VOL			1.000.000	-0.613546
SPR				1.000.000

To test the presumed relationships between the three microstructural variables in more detail, the trading volume and the exchange rate volatility are decomposed into their expected and unexpected components. For the decomposition of the total trading volume, that coud not be rejected as stationary in the observed period, an AR(5)-GARCH(2,1) model was found to be appropriate. The model reasonably accounted for central bank intervention volume, intra-week pattern, intra-month pattern, and some standard annual seasonality of the trading volume, as well as well for its autocorrelation and conditional heteroscedasticity. Actually, an AR(1) model found in similar studies would almost be appropriate for the mean equation, if it wasn't for an apparent multiplicative weekly pattern that could only be captured with an AR(5) term, and not by the weekday dummies. As usual, the fitted volume from this model is taken as expected volume, while the residuals of the mean equation are treated as the unexpected volume in the further analysis. The decomposition of the exchange rate volatility was performed much more mechanically, using a GARCH(2,1) model in conjunction with the mean regression of daily log returns of the CNB mid-rate on a constant term, and taking the residuals from the variance equation to be the unexpected component of the exchange rate volatility for a later use in the spread analysis.

Table 5.3. Decomposition of trading volume

Method: ML - ARCH
Date: 14/06/06 Time: 10:07
Sample (adjusted): 9/01/2002 31/05/2006
Included observations: 1105 after adjustments
Convergence achieved after 162 iterations
Variance backcast: ON
GARCH = C(12) + C(13)*RESID(-1)^2 + C(14)*RESID(-2)^2 + C(15)
*GARCH(-1)

	Coefficient	Std. Error	z-Statistic	Prob.
C	56877084	5295552.	10.74054	0.0000
VOL(-1)	0.221082	0.035729	6.187779	0.0000
VOL(-5)	0.120567	0.021540	5.597388	0.0000

DAY_W=5	-6637902.	2574144.	-2.578684	0.0099
VOL_CNB(-1)	0.040390	0.004971	8.125508	0.0000
TIME	48924.49	14730.18	3.321378	0.0009
TIME_SQ	25.90821	11.29050	2.294691	0.0218
DAY_MO<12	-6201577	1943061.	-3.191654	0.0014
(MO>=7 AND MO<=8)	8725724	2957855.	2.950017	0.0032
MO=12	11574770	2884201.	4.013163	0.0001
MO=1	-1,3E+07	4642008.	-2.707786	0.0068
	Variance Equation			
C	9.44E+14	1.07E+14	8.816728	0.0000
RESID(-1)^2	0.550581	0.054133	10.17092	0.0000
RESID(-2)^2	0.199438	0.031174	6.397515	0.0000
GARCH(-1)	-0.149099	0.069037	-2.159712	0.0308

R-squared	0.468405	Mean dependent var	1.39E+08
Adjusted R-squared	0.461577	S.D. dependent var	51822166
S.E. of regression	38025721	Akaike info criterion	37.65
Sum squared resid	1.58E+18	Schwarz criterion	37.71
Log likelihood	-20787.68	F-statistic	68.60
Durbin-Watson stat	2.151	Prob(F-statistic)	0.0000

With the total volume and the exchange rate volatility decomposed into their expected and unexpected components, the first of the two theoretical relationships could be tested. The regression of the unexpected volatility on the unexpected volume was performed using the GARCH-M(1,1) model for each of the two measures of volatility. The eur/usd exchange rate and the three-month ZIBOR/EURIBOR spread were added as macroeconomic variables to the mean equations. The two models yielded similar results (so, only one model output is reported in the table bellow), with the three-month spread highly insignificant, so it was dropped in the model selection process. The models confirm the positive relationship between the unexpected volume and the unexpected volatility in the Croatian kuna spot market as predicted by the Mixture of distributions hypothesis.

Table 5.4. Modeling volatility

Dependent Variable: DLOG_ST_ABS
Method: ML - ARCH
Date: 14/06/06 Time: 09:49
Sample: 9/01/2002 31/05/2006
Included observations: 1105
Convergence achieved after 42 iterations
Bollerslev-Wooldrige robust standard errors & covariance
Variance backcast: OFF
GARCH = C(4) + C(5)*RESID(-1)^2 + C(6)*GARCH(-1)

	Coefficient	Std. Error	z-Statistic	Prob.
SQRT(GARCH)	1.112.011	0.091065	12.21123	0.0000

VOL_UNEXP	4.48E-12	8.46E-18	528982.2	0.0000
EUR_USD_ABS	0.023674	0.007706	3.072350	0.0021

Variance Equation

C	3.29E-08	1.28E-08	2.580244	0.0099
RESID(-1)^2	0.078159	0.018101	4.317946	0.0000
GARCH(-1)	0.890597	0.024042	3.704352	0.0000

R-squared	0.150194	Mean dependent var	0.001229
Adjusted R-squared	0.146328	S.D. dependent var	0.001071
S.E. of regression	0.000990	Akaike info criterion	-11.07
Sum squared resid	0.001077	Schwarz criterion	-11.04
Log likelihood	6123.557	Durbin-Watson stat	1.755

The regression of the spread on the expected volatility presented a challenge, even though the series passed the standard stationarity check. However, the best univariate model for the Croatian kuna spread is ARMA(1,1) process that yields near unit root for the AR term with the near MA root near -1. Following the literature, we had to treat the spread as non-stationary in the further analysis. Then, we regressed the expected volatility on the spread in differences rather than in levels. The model was designed by augmenting the ARMA(2,1) model that gave a reasonable univariate fit to the spread-change variable by the explanatory variable in the form of change of the expected volatility. The resulting model confirmed the positive relationship between expected volatility and the spread in the Croatian kuna market, as predicted by the spread microstructure theory.

Table 5.5. Modeling bid-ask spread

Dependent Variable: D_SPR
Method: Least Squares
Date: 14/06/06 Time: 14:17
Sample (adjusted): 8/01/2002 31/05/2006
Included observations: 1106 after adjustments
Convergence achieved after 13 iterations
Backcast: 1/01/2002

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.77E-05	1.98E-05	-2.409222	0.0161
D(TEC_EXP)	484.6768	206.8859	2.342726	0.0193
AR(1)	0.094297	0.032269	2.922263	0.0035
AR(2)	0.099772	0.032000	3.117930	0.0019
MA(1)	-0.944937	0.011029	-85.67631	0.0000

R-squared	0.424993	Mean dependent var	-5.70E-05
Adjusted R-squared	0.422904	S.D. dependent var	0.012490
S.E. of regression	0.009488	Akaike info criterion	-6.472
Sum squared resid	0.099123	Schwarz criterion	-6.450

Log likelihood	3584.559	F-statistic	203.4
Durbin-Watson stat	1.985	Prob(F-statistic)	0.0000

6. Directions for further research

The preliminary results of the CNB research on the microstructure of the Croatian foreign exchange market presented in this paper indicate that some of the expected theoretical relationships between volumes, spreads and the volatilities in this market can be confirmed by the data. However, the descriptive analyses imply that further improvements can be expected by extending this research to the less aggregated data. Particularly, breaking down the trading volume by the sector of the transactor, and introducing order-flows in the analysis should have some effect on the results, considering strong descriptive evidence of widely different behavior of volumes and order-flows (proxied by net-volumes) for different sectors. Also, the data available to the CNB allows breaking down the variables by type of transaction (spot, swap, forward), and by the currency, and that also may shed more light on the behavior of the kuna exchange rate. Finally, bank-by-bank analysis of the trading behavior, may reveal individual trading strategies of market-makers, which may show extremely useful in modeling daily exchange rate behavior in a small foreign currency market such as Croatian. Some research in the direction of studying the individual bank behavior in the spot market for just the euro currency is currently under way in the CNB (see Appendix 2).

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Appendix 1:

Table 1: Formula for CNB buy, sell and middle FX rate from 1.10.1997

from 1.10.1997 to 31.12.1998	$BR = \frac{(b\_lpfb * br\_lpfb) + (b\_np * br\_np)}{b\_lpfb + b\_np}$ $SR = \frac{(s\_lpfb * sr\_lpfb) + (s\_np * sr\_np) + (s\_db * sr\_db)}{s\_lpfb + s\_np + s\_db}$ $\mathrm{MR} = \frac{(\mathrm{b\_lpfb + b\_np}) * \mathrm{BR} + (\mathrm{s\_lpfb + s\_np + s\_db}) * \mathrm{SR}}{\mathrm{b\_lpfb + b\_np + s\_lpfb + s\_np + s\_db}}$
from 1.1.1999 to 5.3.1999	$BR = \frac{(b\_lpfb * br\_lpfb) + (b\_np * br\_np) + (b\_db * br\_db)}{b\_lpfb + b\_np + b\_db}$ $SR = \frac{(s\_lpfb * sr\_lpfb) + (s\_np * sr\_np) + (s\_db * sr\_db)}{s\_lpfb + s\_np + s\_db}$ $MR = \frac{BR + SR}{2}$
from 8.3.1999 to 1.10.2001	$BR = \frac{(b\_lpfb * br\_lpfb) + (b\_np * br\_np)}{b\_lpfb + b\_np}$ $SR = \frac{(s\_lpfb * sr\_lpfb) + (s\_np * sr\_np) + (s\_db * sr\_db)}{s\_lpfb + s\_np + s\_db}$ $MR = \frac{BR + SR}{2}$
from 2.10.2001	$BR = \frac{(b\_lpfb * br\_lpfb) + (b\_fxnp * br\_fxnp) + (b\_fcnb * br\_fcnb) + (0{,}5 * b\_db * br\_db)}{b\_lpfb + b\_np + 0{,}5 * b\_db}$ $SR = \frac{(s\_lpfb * sr\_lpfb) + (s\_fxnp * sr\_fxnp) + (s\_fcnp * sr\_fcnp) + (0{,}5 * s\_db * sr\_db)}{s\_lpfb + s\_np + 0{,}5 * s\_db}$ $MR = \frac{BR + SR}{2}$

Key word	Description	Key word	Description
b_lp	legal persons purchase in Euro	s_lp	legal persons sale in Euro
b_db	domestic banks purchase in Euro	s_db	domestic banks sale in Euro
b_fb	foreign banks purchase in Euro	s_fb	foreign banks sale in Euro
b_fxnp	natural persons foreign exchange purchase in Euro	s_fxnp	natural persons foreign exchange sale in Euro
b_fcnp	natural persons foreign currency purchase in Euro	s_fcnp	natural persons foreign currency sale in Euro
b_lpfb	b_lp+b_fb	s_lpfb	s_lp+s_fb
b_np	b_fxnp+b_fcnp	s_np	s_fxnp+s_fcnp
br_lp	buy FX rate for 1 Euro in Kuna reached with legal persons on Croatian FX market	sr_lp	sell FX rate for 1 Euro in Kuna reached with legal persons on Croatian FX market
br_db	buy FX rate for 1 Euro in Kuna reached with domestic banks on Croatian FX market	sr_db	sell FX rate for 1 Euro in Kuna reached with domestic banks on Croatian FX market
br_fb	buy FX rate for 1 Euro in Kuna reached with foreign banks on Croatian FX market	sr_fb	sell FX rate for 1 Euro in Kuna reached with foreign banks on Croatian FX market
br_fxnp	buy FX rate for 1 Euro in Kuna reached with natural persons - foreign exchange on Croatian FX market	sr_fxnp	sell FX rate for 1 Euro in Kuna reached with natural persons - foreign exchange on Croatian FX market
br_fcnp	buy FX rate for 1 Euro in Kuna reached with natural persons - foreign currency on Croatian FX market	sr_fcnb	sell FX rate for 1 Euro in Kuna reached with natural persons - foreign currency on Croatian FX market
br_lpfb	weighted average br_lp and br_fb	sr_lpfb	weighted average sr_lp and sr_fb
br_np	weighted average br_fxnp and by_fcnp	sr_np	weighted average sr_fxnp and sr_fcnp
mr	CNB middle FX rate - accepted method		

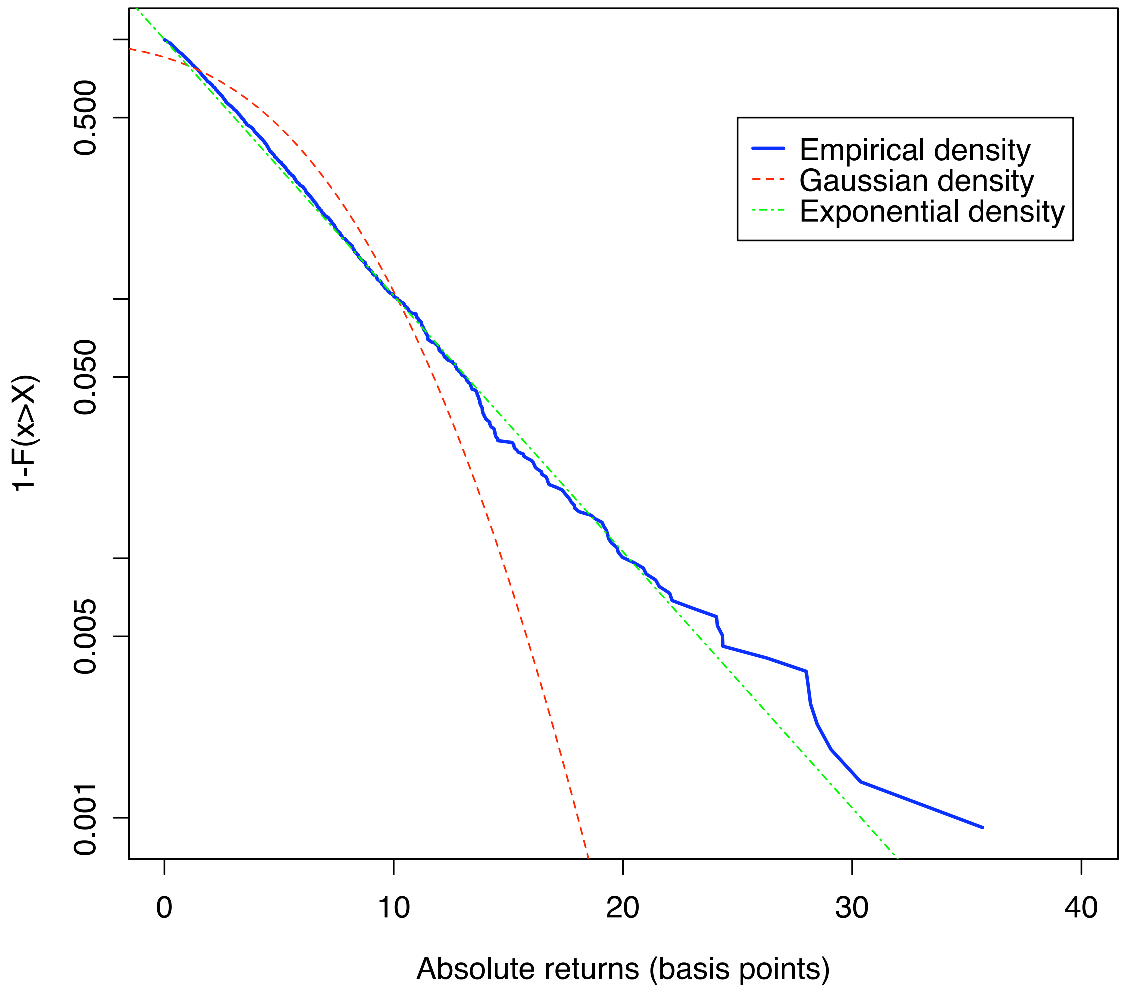
Source: CNB

Central bank FX rate returns

Of central importance in any analysis are the CNB FX rate returns. In particular, if one is interested in risk estimation, modeling the tails of the return distribution should receive a lot of attention. The tails of the distribution describe the relative probabilities of large FX rate changes. In capital markets one is typically concerned only with the negative tail, corresponding to a large fall in price. But in the operations of the central bank, currency stability depends on both positive and negative tails. In our early data analysis, fluctuations seem to be symmetric around zero and we choose to examine only the absolute returns. We define the returns as log differences.

Figure 1 presents the probability distribution (or the cumulative distribution) of the absolute returns. More precisely, the function shown is one minus the distribution in order to emphasize the tails. Furthermore, when examining the tails of a distribution it is better to plot the distribution than the probability density: In addition to being less sensitive to noise, the distribution is easier to construct as one does not need to choose the bin width. One can construct the cumulative through a rank plot.[1]

Figure 1



[1] Rank plot is a plot of the ordered values against their rank number. It is in a simple manner related to the cumulative probability.

In order to investigate the functional form of the cumulative, the scale of the y-axis is natural logarithm so that exponentials appear as straight lines. It is clear that the functional form of the empirical distribution is not Gaussian which is plotted on the graph as the dashed parabola. It would not have been unreasonable to expect a Gaussian as the unconditional distribution of the returns. Typically, the central bank mid rate is calculated as a weighted average of commercial transactions on the FX market. As such the central bank rate is an ideal candidate for the central limit theorem (CLT) to assure normality for the returns. However, the CLT holds only for non-correlated variables with finite second moments. As we will see, both of these two assumptions are violated in the FX market. Additionally, this may not be the entire story behind FX rate fluctuations. Transaction volume fluctuations also play a role in the central bank returns (transaction volumes are the weights in the central bank rate). The influence of volumes is not taken up here and is left for future work.

As said previously, in order for the CLT to hold, the variables in the summation must be independent and of finite variance. As is well known, relaxing the variance assumption leads to a CLT in the Lévy stable basin of attraction producing fat tailed limiting distributions. It is however not known what happens when one relaxes the independence assumption. Numerical simulations[2] and early theoretical work[3] seem to indicate existence of yet another CLT. Said CLT holds for sums of long range correlated variables and also produces fat-tailed distributions. Long range correlations may be found in many physical systems but their real significance is in social systems as long range correlated variables are ubiquitous in economics and finance. For example, in equity trading, all traders look at the same or similar signal such as index futures when trading. As a relevant example for the problem at hand, commercial banks all set their FX rate in part by taking into account the published central bank rate. Such a common signal that all agents in a market observe and take into account when making economic decisions provides a clear and simple mechanism for correlating their behavior regardless of physical or other constraints.

Q-exponentials

As said in the previous section, it is clear from figure 1 that the empirical returns distribution is not even close to a Gaussian. From the figure it is suggestive that an exponential function may be a good model for the distribution. Only for fluctuations of 20 and more basis points is there indication that the empirical distribution diverges from an exponential. However, for stability and risk analyses, these are the most important fluctuations and there is evidence that the exponential may also underestimate their relative prevalence. In addition, as far as the authors are aware there exists no theoretical foundation to expect a distribution to be described by a simple exponential function. There is however another class of functions, of which the exponential is a member, that does have theoretical foundations related to the theory of non-extensive statistics and long range correlated variables.

In essence, systems with long range interactions between their components behave statistically fundamentally different than systems with short range interactions. The appropri-

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[2] L.G. Moyano, C. Tsallis and M. Gell-Mann, *Numerical indications of a q-generalised central limit theorem*, Europhys. Lett. 73, 813 (2006)

[3] Umarov, Tsallis and Steinberg, *A generalization of the central limit theorem consistent with nonextensive statistical mechanics*, arXiv:cond-mat/0603593, http://lanl.arxiv.org/

ate statistical treatment of short range systems consists of maximizing the Shannon entropy

$$S(p) = -\sum_i p_i \log(p_i)$$

which under appropriate constraints leads to the ubiquitous exponential function for the distributions of various quantities as manifested by the Boltzmann-Gibbs law. For systems with long range interactions, the appropriate entropy is not the Shannon one, but arguably rather the Tsallis one

$$S_q(p) = \frac{1}{q-1}\left(1 - \sum_i p_i^q\right).$$

This functional form reduces to the log form found in the Shannon entropy for q=1. Defining the q-logarithm as

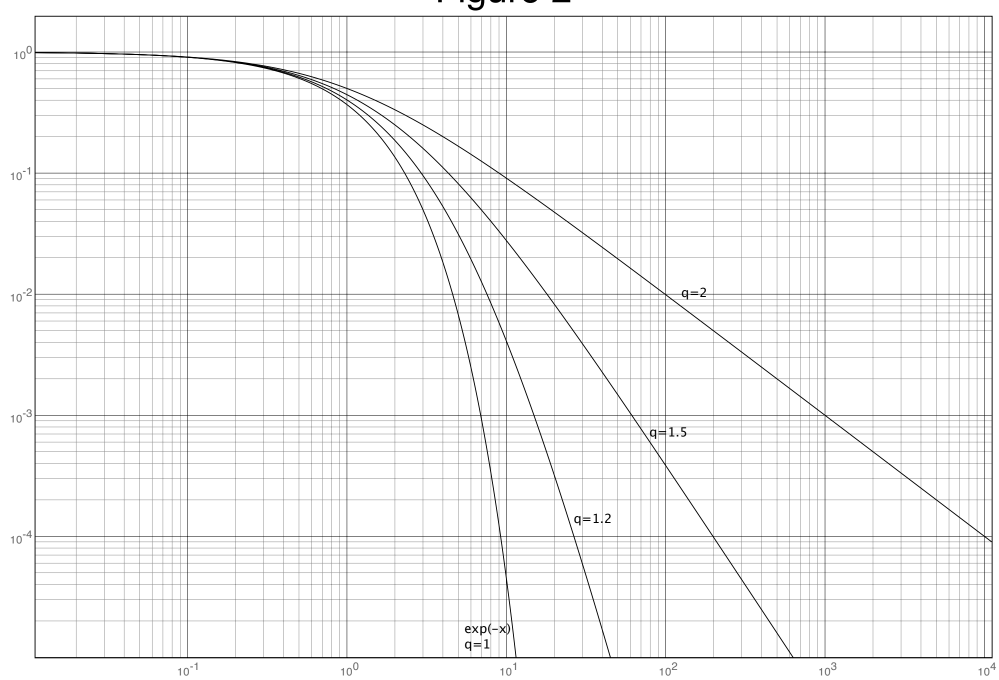
$$\log_q(x) = \frac{1}{1-q}(x^{1-q} - 1)$$

the Tsallis entropy form can be written to resemble the Shannon one as

$$S_q(p) = -\sum_i p_i^q \log_q(p_i).$$

The q-logarithm has the same algebraic properties as the standard logarithm and in the limit q=1 actually becomes identical to the standard logarithm. Intuitively the q parameter serves to distort the weight probabilities receive in the entropy sum. By changing q one changes the importance of rare and common events in the entropy sum.

Figure 2



Appendix 2

Maximizing the Tsallis entropy gives rise to q-exponentials in place of the exponentials for the Shannon case. Therefore, expecting a q-exponential distribution from a system with long range interactions is basically very similar to expecting an exponential distribution from a system with short range interactions. The main difference between the two functions is that a q-exponential has a power law decaying tail described by the parameter q. For q=1 the q-exponential becomes the exponential function. Figure 2 shows several q-exponentials for the values of q={1, 1.2, 1.5, 2}. The curve for q=1 is identical to the exponential function.

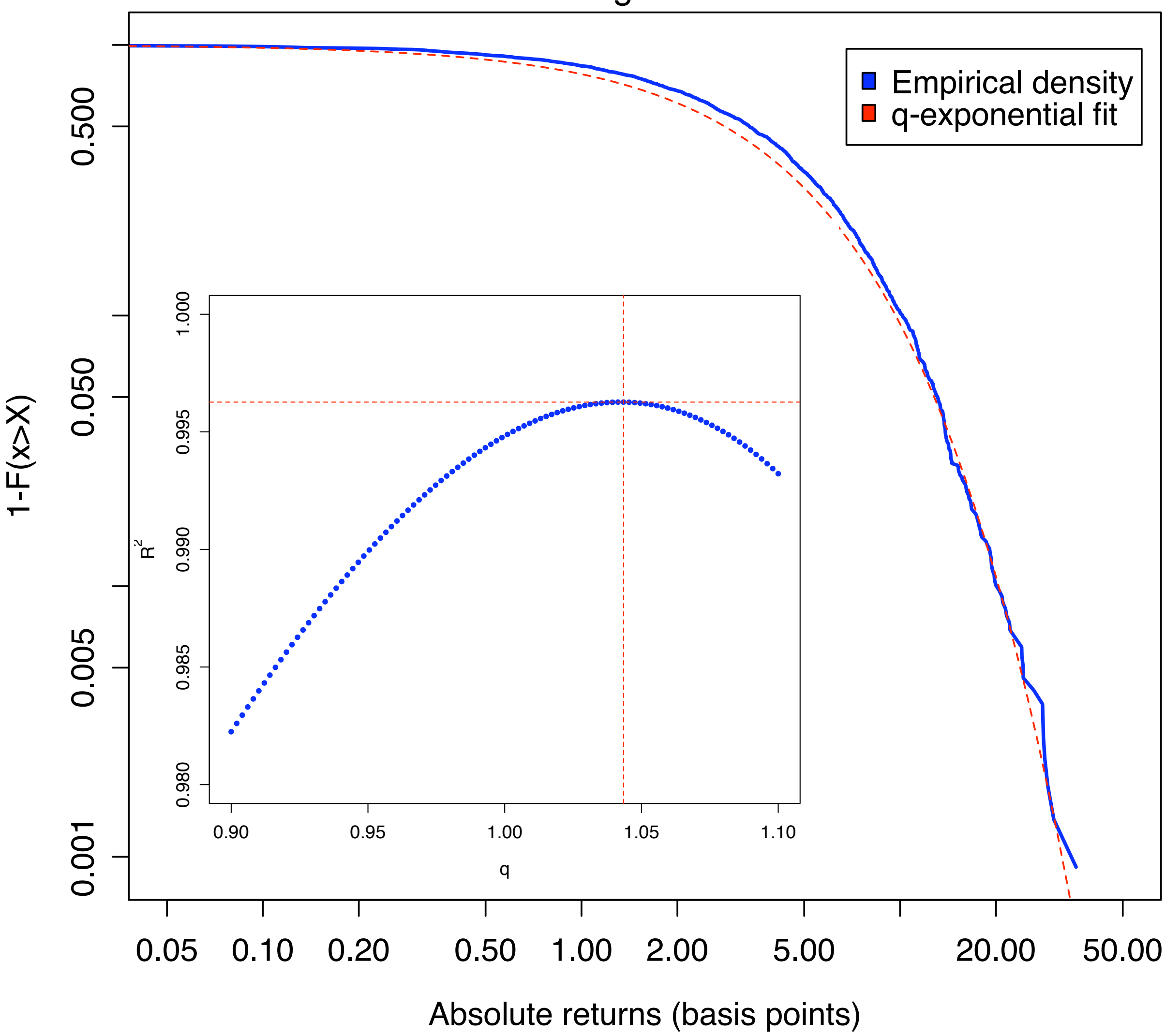
Q-exponential fit to the empirical distribution

We therefore fit a q-exponential for the distribution of absolute returns. In addition to the parameter q we must also fit a scale parameter a

$$\exp_q(x) = [1 + (1-q)x/a]^{\frac{1}{1-q}}.$$

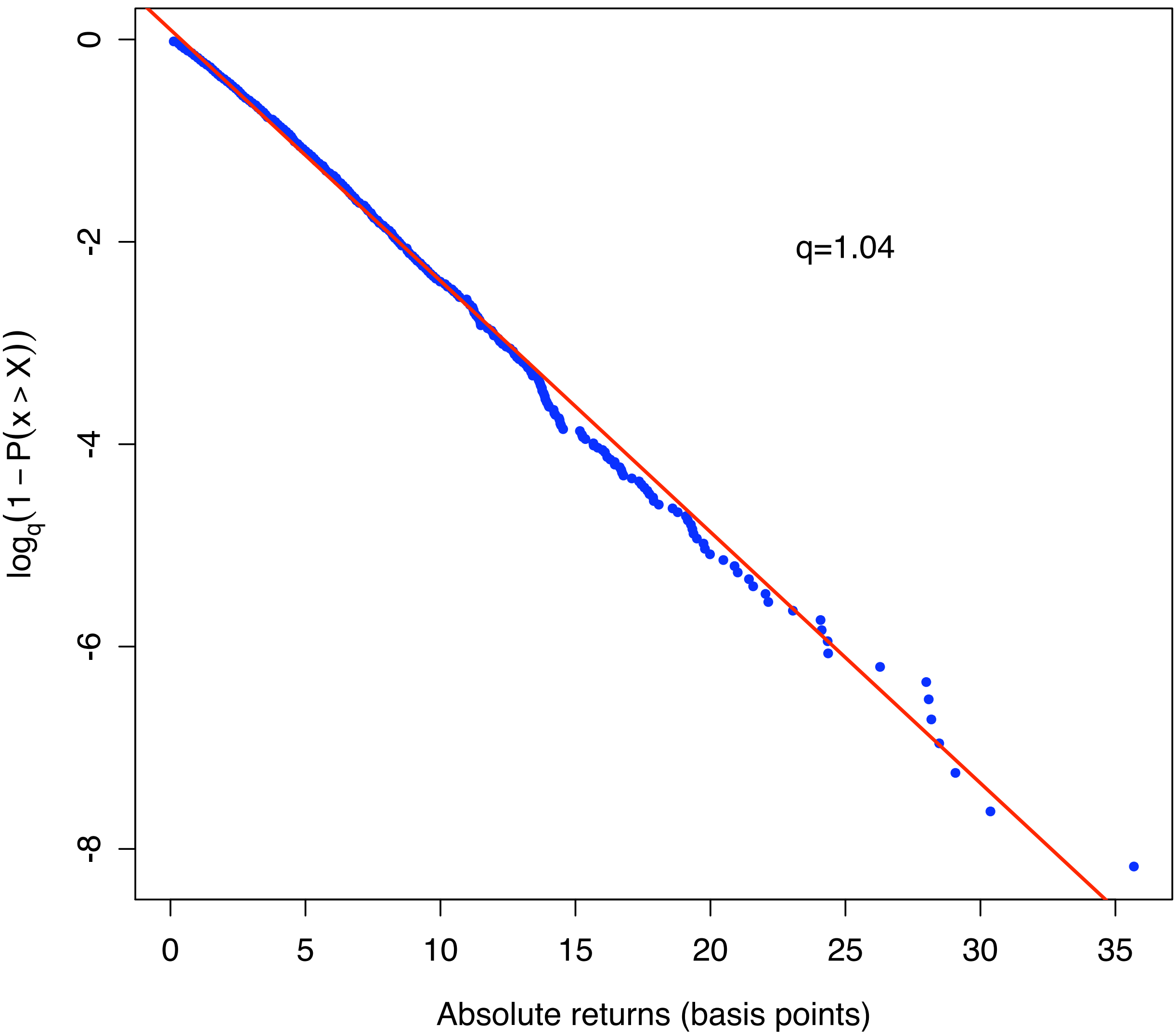
The procedure for fitting q is analogous to plotting data on log-linear paper. When plotting an exponential function on log-linear paper, it becomes a straight line. Similarly, when

Figure 3



plotting a q-exponential function on an appropriate log-linear paper, the q-exponential becomes a straight line. The appropriate function analogous to the log is the already mentioned q-logarithm. When transforming the y values by a q-logarithm with the correct value of q, the q-exponential becomes a straight line. We can than choose the value of q that produces the most straight line. Figure 4 shows the distribution function plotted on q-log-linear paper with q=1.04. The criteria for straightness can be done by a simple R^2 of a linear fit. The inset in figure 3 shows the variation of R^2 as a function of q. The value maximizing R^2 is close to 1, confirming that the distribution is indeed close to an exponential, but is slightly larger. A larger q means more probability to large fluctuations. The final fit of the scale parameter is done using a simple nonlinear least squares. Figure 3 shows the fit of a q-exponential with parameters q=1.04 and a=4 to the data. We see that the fit is pretty good and better than the exponential for large returns.

Figure 4

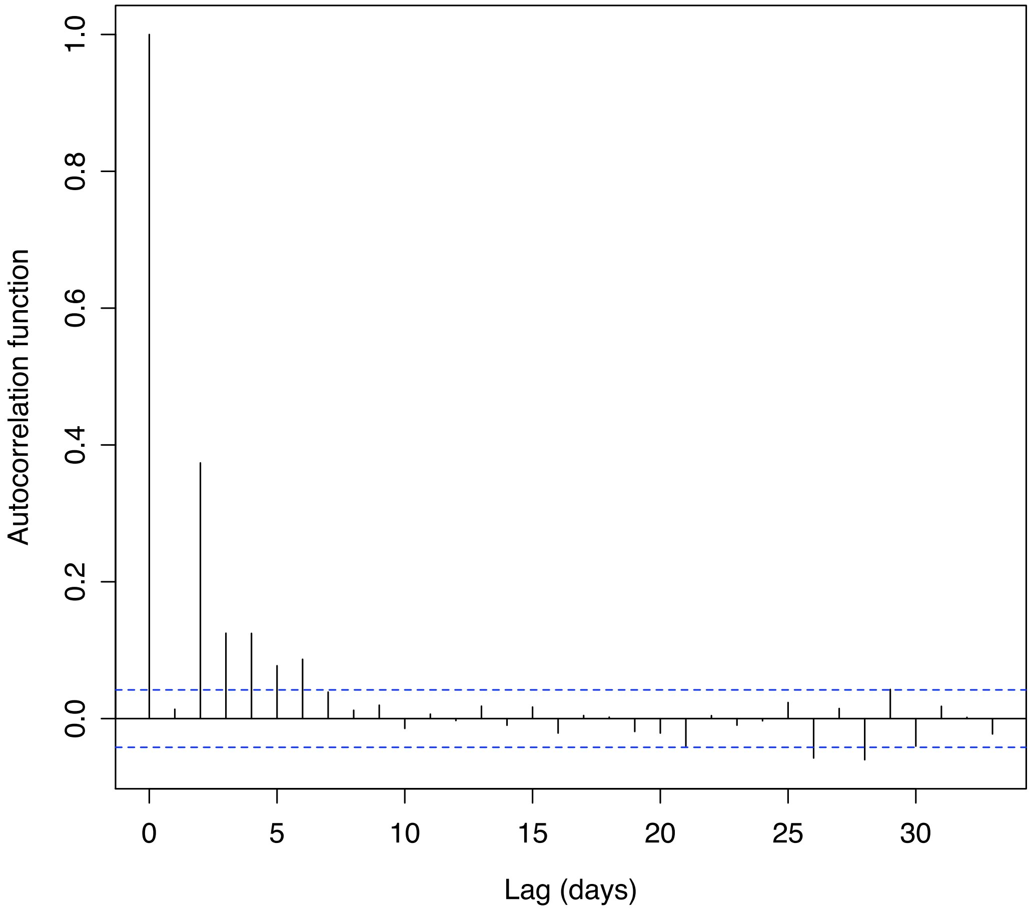


Appendix 2

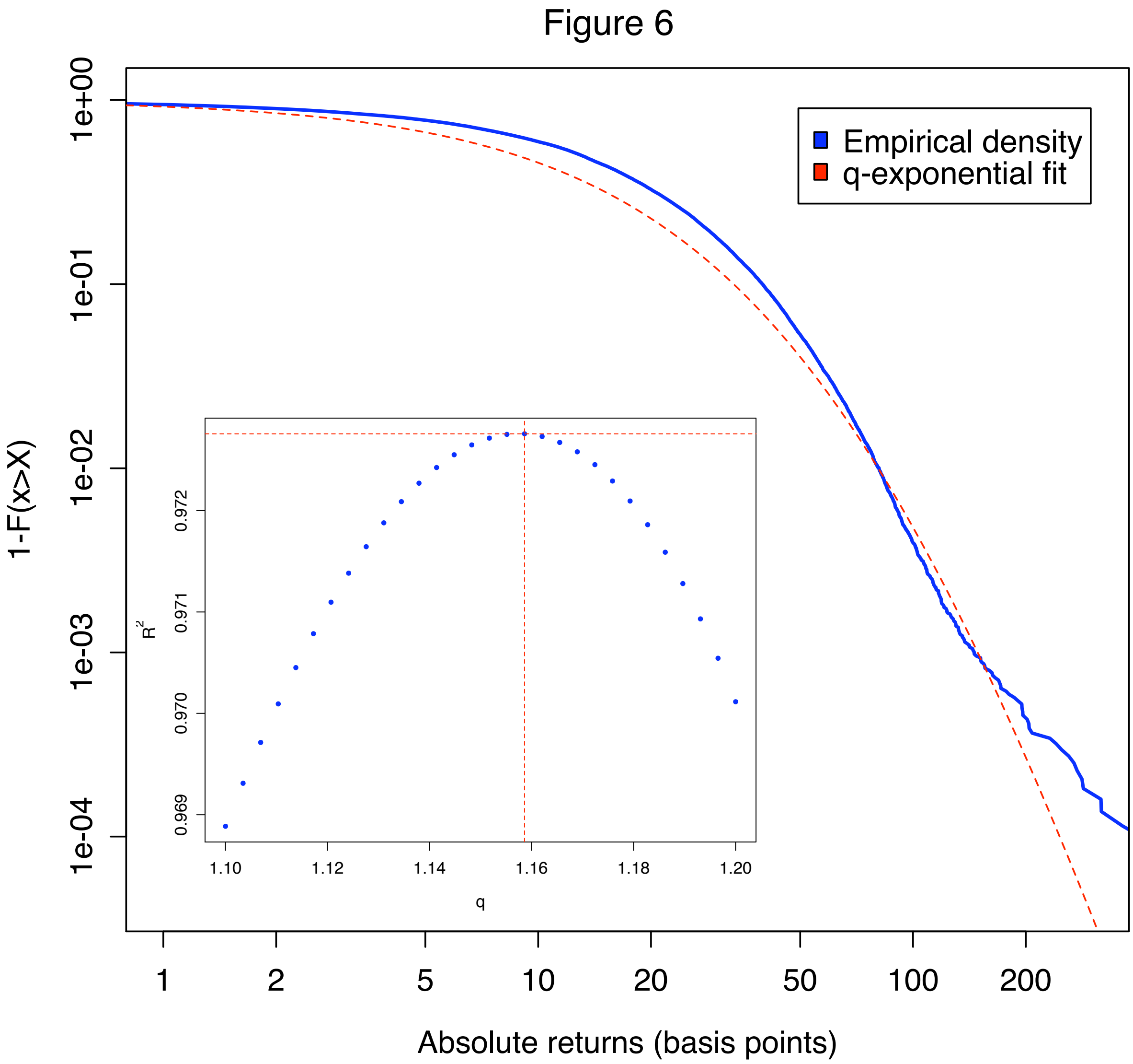
Time series properties of returns

Given the mechanism of the calculation of the central bank FX rate, it is not surprising that there are strong autocorrelations present in the rate, see figure 5. The central bank publishes rate with a two day delay and the large value of the autocorrelation function at lag 2 is expected. Larger lags are also significantly positive but smaller. This is mostly due to the propagation of the correlation through banks' behaviour. One should take note that it is not possible to exploit the predictability of the central bank rate directly. One may only try to predict the behavior of individual banks through their use of the central bank rate in setting their own rate for trading.

Figure 5



FX rate of commercial banks



The central bank FX rate is calculated from the FX trading of commercial banks. It typically is a weighted average of commercial banks' trading on a particular day. It is therefore natural to analyse the fluctuations of the individual banks' rate as they enter the sum. The fluctuations in trading volumes also enter the sum as weights but in the present analysis we do not analyse that.

The distribution of the banks' FX rate returns is shown in log-log scale in figure 6. It is a fat tailed distribution with large fluctuations much more probable than for the central bank rate. We again fit a q-exponential distribution with parameters q=1.16 and a=16. The value of q is larger than for the central bank fluctuations reflecting larger probability of extreme changes. The ACF for the banks seems to be similar to the one for the central bank rate, however it is much more noisy.

Information content of trading in sectors
As said in some of the previous sections, FX trading of banks can be divided among several sectors: trading with private persons (people trading FX primarily for consumption purposes), legal persons (firms and companies), domestic banks (banks operating in

Croatia) and foreign banks. The information content of trades in the different sectors varies. A trade with a private person who presumably trades only for consumption purposes, probably does not carry the same information as a trade with a bank. Therefore, FX rate fluctuations may be correlated with trade volume only in some sectors. Since the trading volumes in sectors greatly differ between each other,[4] one must equalize the influences of total trade volume by defining an information proxy of a trade. One could proxy the amount of information in a trade of a bank in a specific sector as the volume of the trade divided by the average volume that bank makes in that particular sector. An informative trade for a bank would than be a larger than average trade for that bank in that sector.

We construct variables representing information in a trade V_t^{DB}, V_t^{FB}, V_t^{LP}, and V_t^{PP}. V_t^{DB} is the volume a bank made on day t with domestic banks (hence superscript DB) divided by the average volume that bank makes with domestic banks. Analogously for other variables representing information content of trades in other sectors. All these variables are relatively well behaved but are substantially autocorrelated. This, in addition to the problematic properties of the returns themselves will require some nonstandard estimation techniques. More about this later.

Model estimation

For each bank and each day we calculate the mid FX rate. The buy and sell rates are weighted averages of the buy and sell volume respectively. The mid FX rate is then a simple average of the buy and sell rates. In the calculation of the daily mid rate for a bank, we make no distinction between trading in different sectors. Even though the FX rate is different for trading with, for example, banks and trading with private persons, the mid rate, we believe, reflects a basic FX rate around which then the sector varying spreads are applied. The returns r_t are then daily log differences of the mid FX for a particular bank.

The model we choose to estimate is given by

$$\mathrm{Abs}(r_t) = \alpha \cdot V_t^{DB} + \beta \cdot V_t^{FB} + \gamma \cdot V_t^{LP} + \delta \cdot V_t^{PP} + \varepsilon_t$$

The disturbances can not be assumed to be Normal or uncorrelated. As we have seen the distribution of absolute returns is fat-tailed and close to exponential. We have noted that there is some autocorrelation in the returns of individual banks as well. The absolute returns are related to volatility which is known to have long-memory (volatility clustering). Given these facts it is quite difficult to properly perform inference based on asymptotic results built on strict assumptions. Instead we attack the problem using surrogate data methods and bootstrap. Such methods, in-spite of sometimes not being theoretically or rigorously proven, are valuable for their robustness in real-world statistics. Conceptually they are simple and straight forward to implement. They are computationally intensive but that is becoming less and less of a problem given modern computers.

Bootstrap and surrogate data methods

Traditional bootstrap calls for drawing samples from the data under the null hypothesis and building the distribution of the test statistic. The null hypothesis of no correlation between the sector volumes and absolute returns is simply realized by shuffling the bank returns. In this way, the unconditional distribution of the returns is preserved and the correlation with

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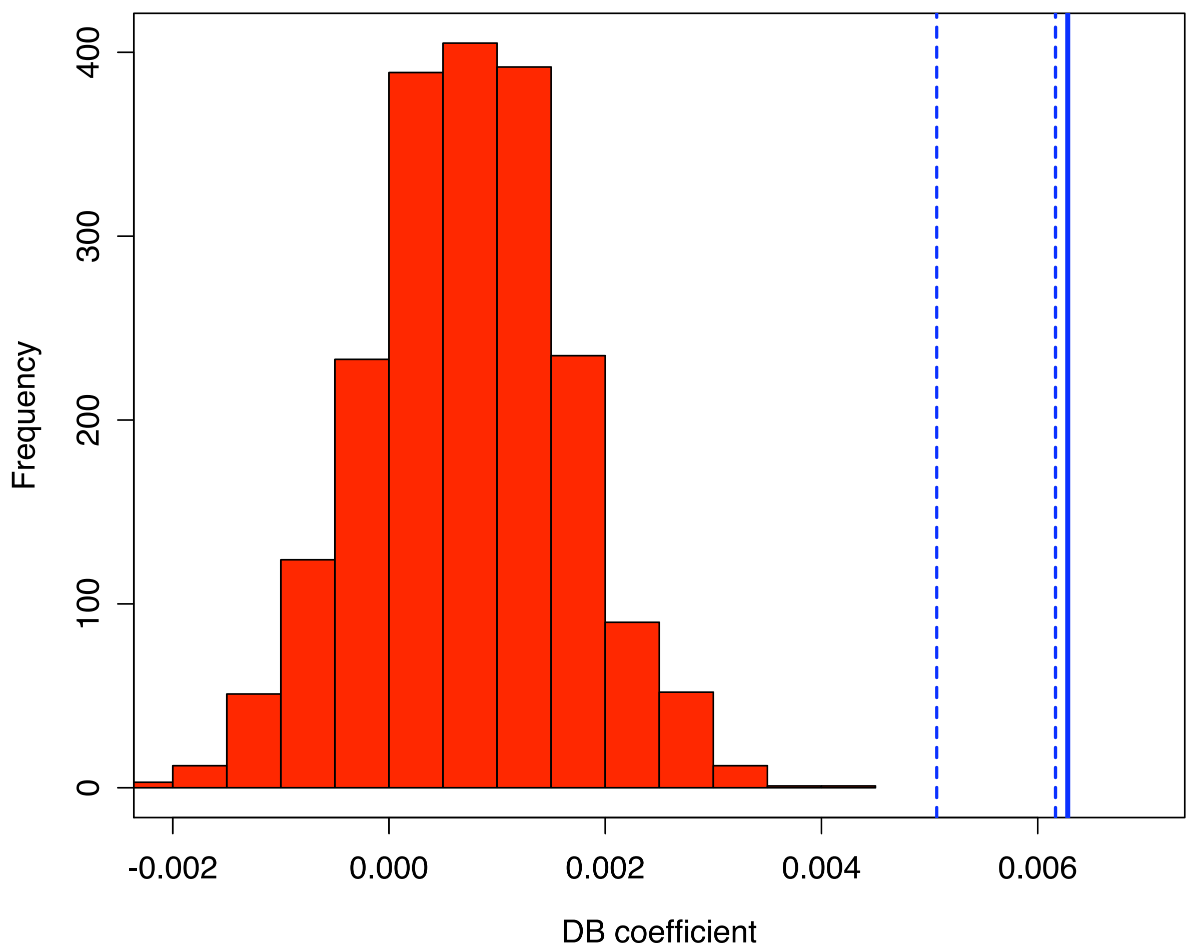
[4] Trading with legal persons is the largest volume, followed by domestic banks, private persons, and finally foreign banks.

the volumes removed. However, it also removes the autocorrelation structure of the returns which is not part of the hypothesis. Preserving all the unconditional distributions, the null hypothesis is only that there are no correlations between the absolute returns and the volumes. Not that there are no autocorrelations in the returns. We therefore resort to a surrogate data method to produce the null hypothesis. This method preserves both the unconditional distribution and the autocorrelation structure[5].

For each bank we compute the discrete Fourier transform of the absolute return time series. We then randomly permute the phases of the series satisfying some symmetry conditions. Finally, the inverse Fourier transform creates a surrogate sample that has the same unconditional distribution as the absolute returns and the same autocorrelation function. The only difference with the original returns is that they are not correlated with volumes. By performing this procedure for all banks we get a surrogate dataset that is the same as the original data in distributions and time correlations, the only difference is that the returns are uncorrelated with volumes, exactly the null hypothesis we want to test.

Figure 7



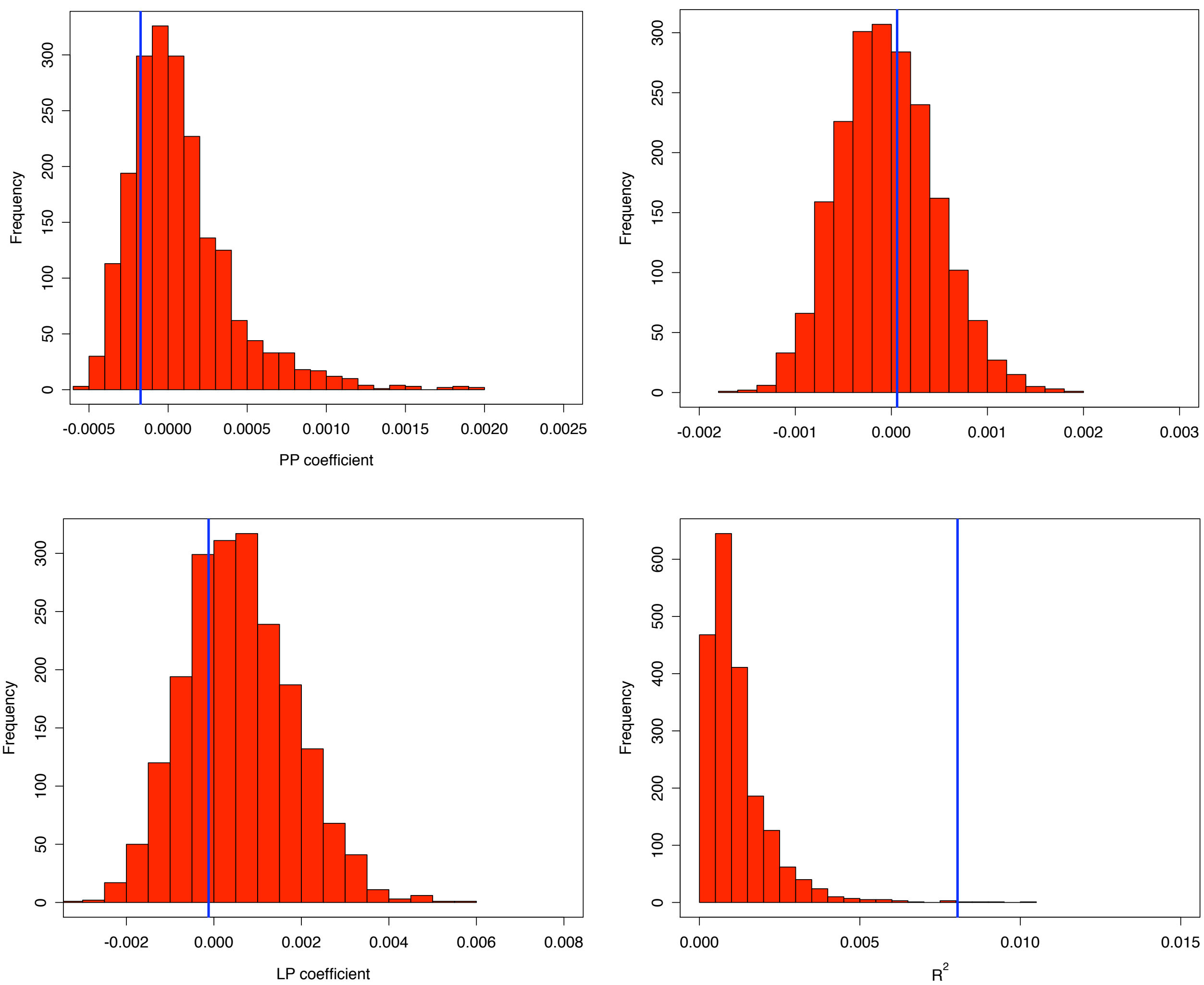
[5] J. Theiler, B. Galdrikian, A. Longtin, S. Eubank, and J. Farmer, *Detecting nonlinear structure in time series*, *Physica 58D*, pages 77–94, 1992.

Appendix 2

We create 2000 surrogate data samples and perform the regression for each sample. The distribution of the parameter α, the domestic bank (DB) coefficient, from these 2000 samples is given in figure 7. This is the distribution of the regression parameter under the null hypothesis of no correlation. In comparison, the blue line is the estimated coefficient from the original data. We clearly see that the coefficient is significantly different from zero. Trading with domestic banks is informative in the sense that banks' FX rate responds to high volumes in this sector. The two dashed lines are estimates of the model for the data divided in roughly two parts, time period of 2002-2004 and of 2004-2006. The estimates are similar and both are significant, but one must keep in mind that the null was constructed for the full dataset, not the two halves.

Parameters corresponding to trading in other sectors are not significant as seen in figure 7. As a test of the overall significance of the regression, bottom right figure is the value of R^2. The regression is clearly significant, however overall economic significance is quite low. Excess trading volume with domestic banks can not be taken as a predictor of absolute returns, but there is a correlation.

Figure 8



Clustering analysis of bank behavior

As a hint at understanding the dynamics of bank FX behaviour and a direction for further research we analyse the correlations in commercial banks' FX rates. The results and directions we outline here, may in the future turn out to be valuable as signals of the state of the FX market in Croatia. For example, changes in the correlation structure that we find in this section may point to some developments in the FX market that would need extra attention or monitoring. This is analogous to the "Early warning system" developed by the Financial stability department of the HNB as a monitor of individual banks' stability, but on an aggregate level of the FX market.

We select 15 most active banks on the Croatian FX market and analyse the correlations between their rate returns. Denoting by p^i_t the FX rate of bank *i* on day *t*, we define the return r^i_t of bank *i* on day *t* standardly as the log difference of the rates

$$r^i_t = \log\left(\frac{p^i_t}{p^i_{t-1}}\right)$$

We then calculate the correlation matrix C (of dimension 15x15, which is the number of analysed banks) whose elements are the correlation coefficients between the individual banks' returns

$$C_{i,k} = \mathrm{Cor}(r^i_t, r^k_t)$$

Two banks *i* and *k* which change their rates in a perfectly correlated manner will have the element $C_{i,k} = 1$. Banks which behave uncorrelated will have $C_{i,k} = 0$; anti-correlated banks will have $C_{i,k} = -1$. Therefore, if there are correlations in the FX rate setting behavior of banks, some of the elements of the correlation matrix will be significantly different from zero. Furthermore, if, for example, there is one "leader" bank, which all other banks copy, all correlation coefficients between that bank and other banks will be significant. It is interesting to investigate the existence of such correlations.

Eigenvalues of the correlation matrix

In order to test such hypotheses, one could construct joint tests for the significance of correlation coefficients. However, a relatively simpler way is to perform the test via eigenvalue analysis since eigenvalues of a matrix are related to products of matrix elements, in our case the correlation coefficients.

To perform the test, the 13 empirical eigenvalues one compares with a distribution of eigenvalues under the null of no correlation among the original variables, in our case the FX rate returns. A result from random matrix theory provides us with the functional form for the distribution of the eigenvalues for a random correlation matrix.[6]

Upon performing this analysis, we find that the data supports two statistically significant eigenvalues. The first one corresponding to the movement of the market as a whole, described by the Central bank's FX rate. All banks' rates are correlated though the Central bank rate. The second significant eigenvalue possibly hints at some non-trivial dynamics.

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[6] L. Laloux, et al, *Random Matrix Theory and Financial Correlations*, International Journal of Theoretical and Applied Finance, 2000, vol 3, part 3, pages 391-398, and
L. Laloux, et al, *Noise Dressing of Financial Correlation Matrices*, Phys. Rev. Lett. 83, 1467–1470 (1999)

As we will see, the second largest eigenvalue seems to be due to a distinct classification of banks as FX setting and FX following.

Clustering analysis based on the correlation matrix

In order to gain insight to the origin of this second eigenvalue we perform a clustering analysis based on the correlation matrix. We construct the distance metric from the correlation coefficients $C_{i,k}$ as

$$d_{i,k} = \sqrt{2 * (1 - C_{i,k})}$$

which can be proven to construct a metric space. Basically, for perfectly correlated banks for which $C_{i,k}=1$, the distance is zero, $d_{i,k}=0$. For non-correlated banks, distance is square root of 2. For anti-correlated banks, distance is 2. We use this distance measure to run a relatively standard clustering algorithm.[7] The clustering results are presented in figure 8 below.

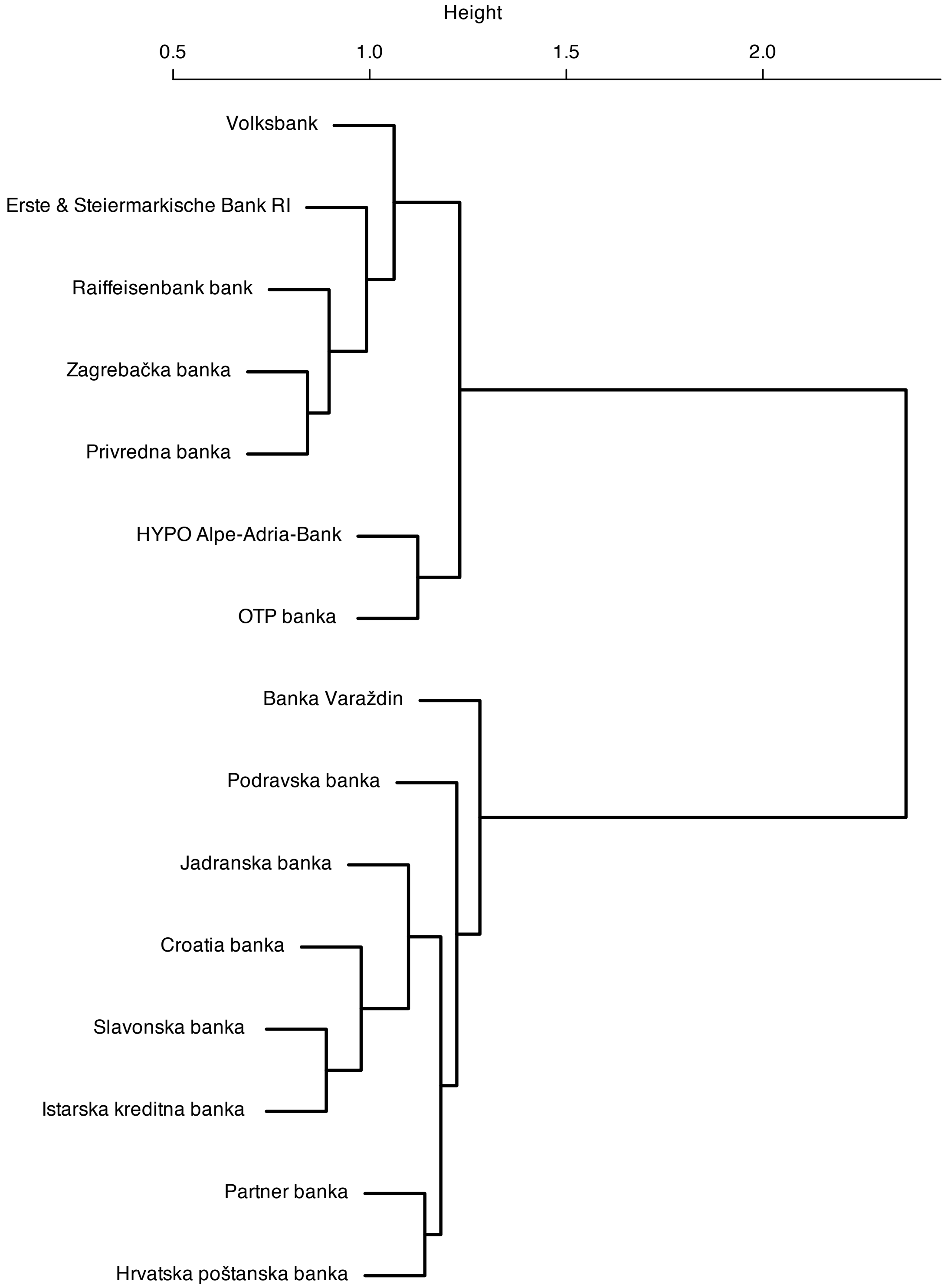
Interestingly, large banks all tend to cluster with each other, while smaller banks clustered separately. Note that the “height”, which is a measure of the metric distance between the two main clusters, is relatively large compared to the heights between members of the cluster. This means that the banks within the two main clusters are “close” to each other while the two main clusters are “far apart”.

We have tested this observation thoroughly. Scrambling the bank order in the algorithm showing that the clustering is not due to the mechanics of the algorithm. Testing several time sub-periods shows very similar structure. Large banks in one cluster, small in another. Finally and most striking is that we have repeated the analysis with only the sign of the FX rate change. That is, if on a particular day a bank increased its rate, we assign a +1 in that period to it, if it decreased its rate, a -1 is assigned. Still we obtain the same clustering of large banks and small banks. For comparison, figures 9 and 10 in the paper show two examples how clusterings would look if the banks FX returns were random. We scrambled the days and produced the dendograms. The randomized figures look very different then the one coming from the data. Note that there is absolutely no information on bank size in the information we give to the algorithm. There is only the indirect effect through the central bank FX rate. Large banks tend transact larger volumes and indirectly more influence the central bank rate. But the mechanism through which banks set their FX rates, perhaps partly by incorporating the lagged central bank rate is precisely the kind of topics that we are interested in.

[7] We performed a number of reality tests on the clustering algorithm, such as modifying to an extent the distance metric and using different, but suitable, agglomeration methods, without affecting the results significantly.

Appendix 2

Figure 8



Appendix 2

Figure 9

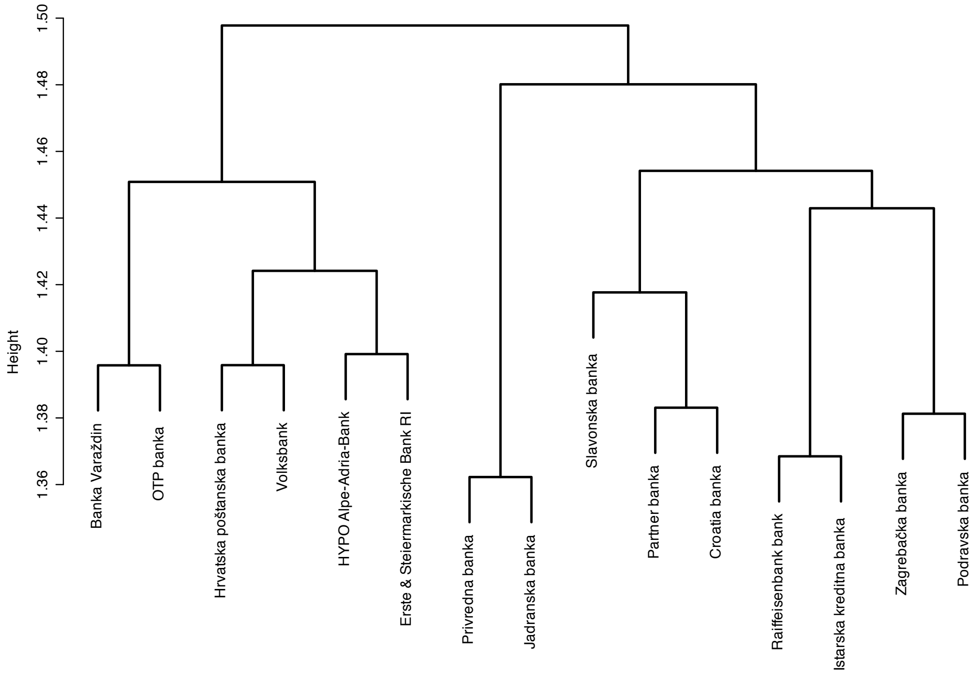


Figure 10