Liquidity Provision in the Interbank Foreign Exchange Market

Frederick Van Gysegem

2013

Supervisor: Prof. Dr. Michael Frömmel

Submitted to the Faculty of Economics and Business Administration of Ghent University, in fulfilment of the requirements for the degree of Doctor in Economics

LIQUIDITY PROVISION IN THE INTERBANK FOREIGN EXCHANGE MARKET

by Frederick Van Gysegem

Doctoral Jury

Prof. Dr. Marc De Clercq	Dean, Faculty of Economics and Business Administration. Universiteit Gent
Prof. Dr. Patrick Van Kenhove	Secretary, Faculty of Economics and Business Administration Universiteit Gent
Prof. Dr. Michael Frömmel	Advisor, Universiteit Gent
Prof. Dr. William De Vijlder	Universiteit Gent
Prof. Dr. Michael J. Moore	Warwick Business School University of Warwick
Prof. Dr. Koen Schoors	Universiteit Gent
Prof. Dr. David Veredas	Solvay Brussels School of Economics and Management Université libre de Bruxelles

Acknowledgements

During my PhD, I experienced how intimidating a blank sheet of paper can be. It confronts you with questions such as ñWhere to start? The second question can be even more difficult to answer than the first. In any case, the decision to enroll for a PhD program in economics/ finance in 2008, right after my master studies, came at a time when there were many things I wanted to understand. In those days, financial markets were in the center of the attention of society. The markets were constantly in the headlines of the news, and they were apparently dictating the decisions of world leaders. Although their importance was obvious, their functioning remained to a large extent a mystery to me: it was a world of complex products, populated by actors who all claim to be rational and who follow sophisticated strategies. In those days, I met my advisor, Prof. Dr. Michael Frömmel, who was teaching a course on Investment Analysis. His course made me even more interested in the topic, and by the time the course was over, I had even more questions than before I started it (they became more advanced, though). It was Michael who took the initiative, and who offered me a platform to focus on the questions I had. Already very early, he introduced me to market microstructure. Immediately after this introduction, the working title of my PhD became ñEssays in Market Microstructureò. I that he offered me the opportunity to do a PhD in the first place, and that he directed me towards this exciting field. He gave me already from the very beginning the opportunity to develop a wide range of skills, and allowed me to broaden my horizons in many different ways. As advisor, he was willing to consider all suggestions and ideas I came up with, and we had many open discussions. Furthermore, he always had some words of encouragement (and these words were from time to time very welcome), and he ïcrucially ïalways supported me.

The members of my reading commission also made a significant contribution to this work. I greatly appreciate the time they took to read and evaluate my work, as their comments allowed me to improve my dissertation. In addition, they were all important to me in very different ways: Prof. Dr. William De Vijlder was willing to discuss my future plans, Prof. Dr. Michael J. Moore was so kind to host me at

Veredas organized an exciting and thought-provoking graduate course on market microstructure in 2010.

While recognizing the importance of my advisor and my reading commission in the making of this dissertation, I also want to acknowledge some other people that were around me in the last five years. In 1942, Joseph Schumpeter means t[1] My personal experience is that this attempt to make progress in economics also meant some form of (personal) turmoil. Having people around who are sincerely interested in what you are doing, but who can at the same time help you to put things in perspective are essential.

I want to thank every former and current member of the department of financial economics: you were all very nice colleagues. There was always somebody there to share daily joys and sorrows, and I enjoyed the interesting discussions and daily talks with you a lot. I especially want to thank my colleague and co-author Xing Han for the pleasant collaboration. Our meetings were always very stimulating, and I learned a lot from them. A special thank as well to Selien De Schryder, who became so much more than an officemate (even in times when central banks across Europe became her home base).

A very warm thank goes to my friends. Whether I got to know them over the last five years, during my graduate or undergraduate years or they are great people with whom it is nice to spend time and share experiences, such as an intensive badminton game, a good concert, a great opera, an exciting board game, the green countryside, é and a good glass of wine or some tas before I started my PhD is my family and my family in law. At very crucial points in my life, they believed in me. Many of them supported me actively and unconditionally over the years, and contributed in that way to where I stand today. I am very grateful to them.

And finally, I want to thank Vincent. He was standing by my side during the making of this dissertation, and we truly shared the ups and downs associated with it. He always believed in me. He also showed a lot of patience, and his unconditional support in so many ways was indispensable.

Frederick Van Gysegem
December 2013

[1] Schumpeter, Joseph, 1942, *Capitalism, Socialism and Democracy*, New York: Harper.

Table of Contents

List of Figures é . . . é é é é é é é é 11
List of Tables é . . . é é . 13

Overview of the Dissertation é . . . é é . 15
Samenvatting van het Proefschrift é 19

Chapter 1: Exchange Rate Policy in Central and Eastern European Countries

1. Introduction 26
2. Evolution of exchange rate regimes 27
3. De jure versus de facto exchange rate regimes 28
4. Exchange Rate Regimes and Volatility 30
5. Exchange rate regimes and monetary policy 33
   5.1 Overview of the ñde jureò monetary poli 33
   5.2. Research on the de facto monetary policy in the CE 36
6. Exchange rate regimes and interventions 40
7. Conclusion 41

Chapter 2: News, Liquidity Dynamics and Intraday Jumps: Evidence from the HUF/ EUR Market

1. Introduction 56
2. Data 60
3. Methodology 64
   3.1. Jump Detection 64
   3.2. Event study methodology 68
4. Jumps and news announcements 70
5. Jumps and liquidity dynamics 72
   5.1 Liquidity dynamics prior to the jumps 73
   5.2 Liquidity dynamics during and after the jump 74
6. Further Analysis 78
   6.1 Predictability of jumps using probit analysis 79
   6.2 Post-jump price discovery 81
   6.3 Post-jump order submission strategy 82
7. Conclusion 84

Chapter 3: Spread Components in the Hungarian Forint-Euro Market: Evidence from a Theoretical Spread Decomposition Model

1. Introduction 116

2. The foreign exchange market and data description 117
3. The analysis of spreads 118
4. Empirical model 120
5. Empirical results 122
6. Concluding remarks 127

Chapter 4: Bid-Ask Spread Components on the Foreign Exchange Market: Quantifying the Risk Component
1. Introduction 144
2. The foreign exchange market: characteristics and advantages 146
3. Cost components of the bid-ask spread 147
4. Model 148
5. Empirical results 152
   5.1 Data 152
   5.2 The bid-ask spread and its determinants 152
   5.3 Intraday patterns 153
   5.4 Results 154
6. Applications 159
   6.1 Peak vs. non-peak times 159
   6.2 Speculative attacks 160
7. Summary 163

Technical Note: The Reconstruction of the HUF/ EUR Limit Order Book using Book Data é 1 7 9

List of Figures

Chapter 1: Exchange Rate Policy in Central and Eastern European Countries

Figure 1: Exchange rate regimes in CEECô s 43
Figure 2: Filter- and smoothed probabilities for EU accession countries 44
Figure 3: ñ Monetary Policy Regimes ò in CEEC's 45
Figure 4: The band distance é . . 46
Figure 5: The derivation of the band distance element from the historical exchange rate peg values for Hungary (Forint/ Deutsche mark) é é é é é é é é é é é é é é é é é é é 4
Figure 6: The derivation of the band distance element from the historical exchange rate peg values for the Czech Republic (Czech koruna/ Deutsche mark) é é é é é é .é.é é 48

Chapter 2: News, Liquidity Dynamics and Intraday Jumps: Evidence from the HUF/ EUR Market

Figure 1: Average daily quote and total volume traded over the sample period. 87
Figure 2: Intraday distribution of ticks (CET). 87
Figure 3: Intraday distribution of jumps. 88
Figure 4: Price reversal after a jump 88
Figure 5: Bid-ask spread (SWPQS) for neg. (N)/ pos. (P) jumps during the event window. .. 89
Figure 6: Volume traded (VOL) for neg. (N)/ pos. (P) jumps during the event window. 89
Figure 7: Order imbalance (OI) for neg. (N)/ pos. (P) jumps during the event window. 90
Figure 8: Mean bid depth at best quote ($BRDTH_B$) for neg. (N)/ pos. (P) jumps during the event window. 90
Figure 9: Mean ask depth at best quote ($BRDTH_A$) for neg. (N)/ pos. (P) jumps during the event window. 91
Figure 10: Mean bid depth ($DPTH_B$) for neg. (N)/ pos. (P) jumps during the event window. 91
Figure 11: Mean ask depth ($DPTH_A$) for neg. (N)/ pos. (P) jumps during the event window. 92
Figure 12: Volume of lim. buy orders (LO_B) for neg. (N)/ pos. (P) jumps during the event window. 92
Figure 13: Volume of lim. sell orders (LO_S) for neg. (N)/ pos. (P) jumps during the event window. 93

Chapter 3: Spread Components in the Hungarian Forint-Euro Market: Evidence from a Theoretical Spread Decomposition Model

Figure 1: Decomposition by half-year. 129
Figure 2: Decomposition by trade size... 129

Chapter 4: Bid-Ask Spread Components on the Foreign Exchange Market: Quantifying the Risk Component

Figure 1: Average daily quote and total volume traded over the sample period 165
Figure 2: Number of ticks per hour (CET).. 165
Figure 3: Expected bid-ask spread (HUF/ EUR; Intraday median) 166
Figure 4: Expected quantity traded (Mill HUF; Intraday median)... 166
Figure 5: First decimal number of best bid/ best ask (HUF/EUR).. 167
Figure 6: Second decimal number of best bid/ best ask (HUF/ EUR) 167
Figure 7: First dec. bid-ask spread (HUF/ EUR) 168
Figure 8: Second dec. bid-ask spread (HUF/ EUR)... 168

Figure 9: Spread and volume traded around the speculative attack....................................... 169
Figure 10: Spread components around the speculative attack (January 2003) 169

Technical note: The Reconstruction of the HUF/ EUR Limit Order Book using Book Data

Figure 1: Detail of the reconstructed book (Feb. 13, 2003 from 15:45 till 16:15)................. 183

List of Tables

Chapter 2: News, Liquidity Dynamics and Intraday Jumps: Evidence from the HUF/ EUR Market
Table 1: Summary statistics 95
Table 2: Order descriptives. 95
Table 3: Book descriptives. 96
Table 4: Prevalence and size of jumps. 96
Table 5: Positive vs. negative jumps. 97
Table 6: Jumps and scheduled macroeconomic announcements. 98
Table 7: Share of jumps explained by news announcements. 99
Table 8: Liquidity dynamics around positive jumps 100
Table 9: Liquidity dynamics around negative jumps 101
Table 10: Probit regression of the jump probability and Tobit regression of the jump magnitude 102
Table 11: Regression of price change on order flow. 102
Table 12: Resiliency after jumps 103
Table 13: Regression of depth change on lagged transitory volatility. 103

Chapter 3: Spread Components in the Hungarian Forint-Euro Market: Evidence from a Theoretical Spread Decomposition Model
Table 1: Descriptive statistics of the dataset 131
Table 2: Two-way decomposition of the spread. 132
Table 3: Three-way decomposition of the spread. 133
Table 4a: Comparison with selected previous studies (Two-w a y   d e c o m p o s i t i o n) é é
Table 4b: Comparison with selected previous studies (Three-way d e c o m p o s i t i o n) é é é .

Chapter 4: Bid-Ask Spread Components on the Foreign Exchange Market: Quantifying the Risk Component
Table 1: Summary statistics 171
Table 2: Summary statistics of the variables used in the regression 172
Table 3: Correlation matrix 173
Table 4: Regression results and spread components. 174
Table 5: Regression with ad hoc specification 175
Table 6: Spread components during peak and non-peak times 175
Table 7: Spread components around speculative attack 176

Overview of the dissertation

Market liquidity captures how easy it is to convert an asset into cash and is a key-variable of interest when trading on financial markets and when investigating them. Moreover, liquidity also determines the speed at which information about an asset can be processed and it affects as well the assetôs expected return. From a for the stability of the global financial system. In this thesis, we study market liquidity by looking at the interaction amongst different types of participants on the Hungarian forint/ euro interbank foreign exchange market.

In the **first chapter** we start from a very general level ï in an international finance framework ï by surveying the literature on exchange rate policy in Central and Eastern European Countries (CEECôs). In 2004, a first wave of these countries all have the common long-term goal of joining European Monetary Union. Joining the monetary union is, however, conditional on the realization of the Maastricht criteria, and these criteria include stability of the exchange rate inside the European Exchange Rate Mechanism (ERM II). Despite their comm exchange rate policies. Furthermore, their exchange rate policies were subject to frequent changes and adjustments. In this chapter, we describe the official exchange rate arrangements in the CEECôs, but we also consider the diff regimes. Next, we survey the literature on exchange rate volatility and the link with exchange rate policy and monetary policy. Therefore, we consider switches between volatility regimes. A big difference between the timing of these switches and the dates of the respective policy changes may hint at a lack of credibility of the policy, including the unpeaceful exits from the pegs in the Czech Republic and Slovakia. Finally, we survey the literature on the influence of monetary authorities on the exchange rate. Here we look, amongst other things, to central bank intervention and central bank communica

From the next chapter onwards we switch on the microscope, and look at the market microstructure of the interbank foreign exchange market. Throughout these chapters we use detailed data for the Hungarian forint/ euro market ï which operates as an electronic limit order book ï in 2003 and 2004. In the **second chapter** we investigate the link between news announcements, jumps (which are basically price discontinuities) and market liquidity. In a first stage we detect the intraday jumps, and show that they are prevalent and important: there is at least one price jump on 18.20% of the trading days contained in our sample period, and 42.59% of the price variation on these jump days can be attributed to the jumps. We also find that positive and negative jumps are symmetric in terms of both frequency and size.

In a second stage, we try to link the intraday jumps with public news announcements. Here we consider both scheduled public news (e.g. GDP, PPI, trade balance unscheduled public news (e.g. central bank interventions, polls, surveys, political changes, é). They can be respectively linked which implies that more than half of the jumps cannot be explained by public information.

Hence, we would like to take a closer look at the actual genesis of jumps: are they caused by (public or private) information inflow, noise trades or insufficient liquidity? We therefore study in a third stage the dynamics of liquidity in a two-hour window around the jumps. We look at liquidity as a multi-dimensional variable and distinguish the tightness dimension (the difference between the best bid and the best ask), the immediacy dimension (the amount of euro or forint traded), resiliency (the pace at which the price reverts to former levels after it changed in response to large order flow imbalances), the overall depth (the amount of euro or forint available in the limit order book) and the depth at the best quotes. As a result, we find that jumps do not happen when liquidity is unusually low, but rather when there is an unusually high demand for immediacy concentrated on one side of the order book. Moreover, this result is independent of whether the jump can be linked to a public news announcement or not, and our findings suggest that it is information inflow that causes the jump. Moreover, a dynamic order placement process emerges after a jump: more limit sell (buy) orders are added to the book subsequent to a positive (negative) jump. We attribute this to endogenous liquidity providers on the market. Attracted by the higher reward for providing liquidity, they submit limit orders at the side where it is needed the most.

In a fourth and last stage, we provide some further analyses and apply a probit model that shows that none of the liquidity variables offers predictive power for a jump occurrence (consistent with what we find for the dynamics of liquidity around jumps) or for the magnitude of the jump. In addition, we find that more limit orders relative to market orders are submitted to the book after the jump, and that the post-jump order flow is in general less informative than in normal trading periods. Overall, our results provide insight into the origin of jumps and map the impact of endogenous liquidity provision on this market without designated market makers.

In the last two chapters, we zoom in on the process of endogenous liquidity provision. We focus in these chapters on the link between the tightness dimension/ bid-ask spread and the cost of providing liquidity. We distinguish respectively order processing costs (the operational costs of providing market making services, such as wages of traders, floor space rent, fees that have to be paid to the platforms, é), inventory holding inventory, which results from accommodating incoming orders) and adverse selection costs (the cost of engaging in a transaction with a market participant who has superior information). In the **third chapter** we provide evidence using an established, structural model that allows us to split up the spread into these different cost components. We find that over the two years, 40.09% of the bid-ask spread can be explained by inventory holding costs, 38.34% can be explained by order processing costs and 21.57% can be explained by adverse selection costs. Our results differ in some ways from previous results for the foreign exchange market where the same methodology was used, and are to some extent more intuitive. In comparison with the existing studies, the tier of the market we analyze, the completeness of the data, the size of the market and institutional differences between markets seem to play an important role. Furthermore, we find that the estimated spread on large trades is over the whole dataset 32.35% higher than the spread on small trades. We show that this higher spread is caused by a higher combined inventory holding and adverse selection cost.

In the **fourth chapter**, we follow a novel direction. Here we study the bid-ask spreads using an empirical spread decomposition model and specify the individual spread components explicitly. The combined inventory holding and adverse selection cost is here modeled as an option premium. This is very intuitive, and has the advantage that the risk can be quantified using option valuation techniques. We provide the first complete forex results for this type of model, and show that the combined component accounts for 52.52% of the bid-ask spread. Furthermore, we provide evidence for an endogenous tick size of 0.05 HUF/ EUR and we also estimate the number of liquidity providers based on the results for the risk component.

In addition, the empirical approach we follow in this chapter allows us to examine two interesting spread patterns: the stylized difference in spreads between peak-times and non-peak times and the spread pattern around a speculative attack against the Hungarian forint in the beginning of 2003. First, we confirm the stylized difference in spreads between peak-times and non-peak times. As a matter of fact, during non-peak times the spread is more than double as high as during peak-times. We find that this is caused by an increase in the risk component, and if we elaborate on the origin of it we show that it is not only the calculated option premium that increases but also the sensitivity to this option premium. Clearly, the increase in the premium still underestimates the actual increase in risk for the liquidity provider. We explain this by the increased probability that the liquidity provider will have to keep his position overnight.

Second, we map the spread pattern around the speculative attack. Prior to the attack, the spread decreases until it reaches a level below the endogenous tick size. This decrease is caused by a strong decrease in the risk component. During the speculative attack, the spread increases massively, as a result of the rising risk component. The order processing component, on the other hand, decreases at the same time. This pattern is consistent with increased competition amongst liquidity providers who are well aware of the increased risk that their activity during this period of high speculation involves. After the attack, both the order processing component and risk component increase. Consequently, the tightness of this market is much lower than before the attack. Overall, this chapter demonstrates the relevance of an option based decomposition approach for understanding how liquidity is provided on the interbank foreign exchange market.

Samenvatting van het proefschrift

Marktliquiditeit omvat hoe makkelijk het is om een investering in een financieel actief om te zetten in contanten en is van essentieel belang wanneer men handelt op financiële markten of wanneer men deze markten onderzoekt. Overigens bepaalt de liquiditeit van een actief eveneens de snelheid waarmee informatie kan worden geïncorporeerd in de prijs, en beïnvloedt zij ook de verwachtte opbrengst van het actief. Vanuit het standpunt van een beleidsmaker is liquiditeit belangrijk voor de stabiliteit van het globale financiële systeem. In dit proefschrift bestuderen wij marktliquiditeit door de interactie tussen verschillende types actoren in de handel op de Hongaarse forint/ euro wisselmarkt voor banken in kaart te brengen.

In het **eerste hoofdstuk** vertrekken we heel algemeen vanuit het denkkader van de internationale financiën. We geven een overzicht van de bestaande wetenschappelijke literatuur over wisselkoersbeleid in de landen uit Centraal- en Oost-Europa (hierna C
genoemd). In 2004 is een eerste groep CEECô
hebben al deze landen het gemeenschappelijke doel om finaal toe te treden tot de Europese Monetaire Unie (EMU). Toetreden tot de EMU is echter slechts mogelijk mits naleving van de Maastricht criteria, die onder andere stabiliteit van de wisselkoers binnen het Europese Wisselkoersmechanisme (ERM II) omvatten. Niettegenstaande hun gemeenschappelijke doel, hebben de CEECôs geopteerd voor verschillende type
wisselkoersbeleid regelmatig gewijzigd. In dit hoofdstuk beschrijven we in eerste instantie het
offici±le wisselkoersbeleid van de verschill eing
met het verschil tussen ñde jureò en ñde fa
overzicht van de wetenschappelijke literatuur omtrent de volatiliteit van de wisselkoers, en het verband met wisselkoersbeleid en monetair beleid. We focussen hierbij vooral op veranderingen tussen volatiliteitsregimes. Zij kunnen ons ï in combinatie met gegevens over het beleid ï een indicatie geven van de geloofwaardigheid van het beleid: indien veranderingen in de volatiliteitsregimes en veranderingen in het beleid op verschillende momenten plaatsvinden, duidt dit op een gebrek aan geloofwaardigheid van het beleid. Dit was bijvoorbeeld het geval toen Tsjechië en Slovakije hun vaste wisselkoers ongepland verlieten. We sluiten dit hoofdstuk af met een overzicht van de wetenschappelijke literatuur over de invloed van monetaire beleidsmakers op de wisselkoers. Hier beschouwen we, onder

andere, interventies van centrale banken en communicatie door centrale banken in de CEECôs.

In de rest van het proefschrift zetten we de microscoop aan, en concentreren we ons op de microstructuur van de handel op de wisselmarkt voor banken. Over de verschillende hoofdstukken heen gebruiken we hier gedetailleerde data van de Hongaarse forint/ euro markt ï die functioneert aan de hand van een limiet orderboek ï in 2003 en 2004. In het **tweede hoofdstuk** onderzoeken we het verband tussen aankondigingen van nieuws, jumps (die in essentie discontinuïteiten zijn in de prijs) en marktliquiditeit. In eerste instantie sporen we daartoe jumps gedurende de dag op, en tonen we aan dat zij vaak voorkomen en belangrijk zijn: er is ten minste één jump gedurende de dag op 18,20% van de handelsdagen die onze dataset bevat, en 42,59% van de prijsvariatie op deze dagen kan toegewezen worden aan de jumps. We vinden verder ook dat positieve en negatieve jumps symmetrisch zijn in termen van frequentie en grootte.

In tweede instantie gaan we jumps gedurende de dag in verband brengen met aankondigingen van nieuws. We beschouwen hier zowel geplande publieke aankondigingen (zoals bijvoorbeeld BBP, index van de producente
ongeplande publieke aankondigingen (zoals bijvoorbeeld interventies door de centrale bank, bevragingen, politieke veranderingen, é). Zi ijk in verband worden
gebracht met 16% van de jumps en 30,4% van de jumps, wat impliceert dat meer dan de helft van de jumps niet kunnen worden verklaard door publieke informatie.

We zouden dan ook meer inzicht willen verkrijgen in de genese van jumps: worden zij veroorzaakt door een instroom van publiek of privaat nieuws, noise handel of onvoldoende liquiditeit? Om hierop een antwoord te krijgen, gaan we in derde instantie de liquiditeitsdynamiek bestuderen in de twee uren rond jumps. We beschouwen liquiditeit hier als een variabele die meerdere dimensies heeft, en onderscheiden de strakheid (het verschil tussen de beste biedprijs en de beste laatprijs), de directheid (de hoeveelheid euro of forint die verhandeld wordt), veerkracht (de snelheid waarmee een prijs zich terug herstelt naar een eerder niveau, nadat hij gewijzigd is door een groot onevenwicht in de orderstroom), de diepte van het orderboek (de hoeveelheid euro of forint die beschikbaar is in het orderboek) en de diepte tegen de beste prijs. Onze analyse toont dat jumps niet gebeuren op een moment dat de liquiditeit ongewoon laag is, maar eerder wanneer er een ongewoon hoge vraag naar directheid is die geconcentreerd is op één zijde van het limiet orderboek. Dit resultaat geldt overigens zowel voor jumps die in verband kunnen worden gebracht met de aankondiging van nieuws, als voor jumps voor dewelke dit niet het geval is, en onze resultaten suggereren dat het een instroom van informatie is die de jump veroorzaakt. Verder zien we dat door de jump een dynamisch proces ontstaat waarbij limiet verkooporders worden geplaatst na een positieve jump en limiet kooporders na een negatieve jump. We schrijven dit toe aan endogene liquiditeitsvoorzieners op deze markt. Aangetrokken door de hogere compensatie voor het voorzien van liquiditeit op de markt, voegen zij limiet orders toe aan de zijde van het orderboek waar dit het meest nodig is.

In vierde instantie voeren we enkele verdere analyses uit en passen we een probit model toe dat aantoont dat geen enkele van de dimensies van liquiditeit in staat is om een nakende jump te voorspellen (in overeenstemming met wat we vonden in de sectie over de liquiditeitsdynamiek rond jumps) of de grootte ervan. Verder vinden we ook dat het relatief aandeel van limietorders ten opzichte van marktorders toeneemt na een jump, en dat de orderstroom na de jump minder informatie bevat dan onder normale omstandigheden. Globaal genomen verschaffen onze resultaten inzicht in de oorsprong van jumps, en brengen zij de impact van endogene liquiditeitsverschaffers in kaart op deze markt waar geen speciale marktmakers zijn aangesteld.

In de laatste twee hoofdstukken wordt er ingezoomd op het proces waarbij liquiditeit op een endogene manier wordt aangeboden. We focussen hierbij op de link tussen de strakheid van de markt/ het verschil tussen de bied- en laatprijs (hierna de spread genoemd) en de kostprijs van het aanbieden van liquiditeit. We onderscheiden respectievelijk order verwerkingskosten (hierna OPC genoemd, de operationele kosten van het aanbieden van liquiditeit, zoals de lonen van handelaren, de huur van de kantor voorraadkosten (hierna IHC genoemd, de kostprijs van het aanhouden van een ongewenste voorraad) en averechtse selectiekosten (hierna ASC genoemd, de kostprijs van het handelen met partijen die over meer en/ of betere informatie beschikken dan de aanbieder van liquiditeit). In het **derde hoofdstuk** leveren we resultaten met behulp van een gevestigd structureel model dat ons toelaat de spread op te splitsen in de verschillende kostencategorieën die we hierboven introduceerden. We tonen aan dat over de periode van twee jaar, 40,09% van de spread verklaard kan worden door IHC, 38,34% kan verklaard worden door OPC en 21,57% kan verklaard worden door ASC. Onze resultaten verschillen op sommige vlakken van bestaande resultaten voor de wisselmarkt voor dewelke dezelfde methodologie werd gebruikt. Ze zijn tot op zekere hoogte ook meer intuïtief. In vergelijking met bestaande studies spelen de aard van de markt die wij beschouwen, de volledigheid van onze data, de grootte van de markt en institutionele verschillen een belangrijke rol. Verder vinden we dat de geschatte spread die aangerekend wordt bij grotere verhandelde volumes

32,35% hoger ligt dan de spread die aangerekend wordt bij kleinere verhandelde volumes. We tonen dat de hogere spread in dat geval wordt veroorzaakt door een hogere gecombineerde IHC en ASC.

In het **vierde hoofdstuk** volgen we een nieuwe richting binnen het onderzoek naar de microstructuur van financiële markten. Dit houdt in dat we de spreads bestuderen aan de hand van een empirisch model dat ons toelaat de spread op te splitsen in de verschillende kostencategorieën. Daarbij wordt elke kost expliciet gespecifieerd en gekwantificeerd, en hier wordt de som van de IHC en de ASC gemodelleerd als een optiepremie. Dit is heel intuïtief, en heeft als voordeel dat het risico kan worden gekwantificeerd aan de hand van technieken voor optiewaardering. We leveren de eerste volledige resultaten voor de wisselmarkt voor dit type model, en we tonen dat de gecombineerde risicocomponent instaat voor 52,52% van de spread. Verder vinden we bewijs voor een endogene minimale prijsverandering van 0,05 HUF/ EUR en schatten we het aantal verschaffers van liquiditeit op basis van de resultaten voor de risicocomponent.

Aansluitend laat het empirische model dat we in dit hoofdstuk hanteren toe om twee interessante patronen in de spread te bestuderen: het vaste verschil in spread tussen piekuren en daluren, en het patroon van de spread rond een speculatieve aanval tegen de forint in het begin van 2003. We tonen eerst aan dat de spread tijdens de daluren meer dan dubbel zo hoog is als tijdens piekuren. Dit is te wijten aan een toename van de risicocomponent, en als we verder ingaan op de oorzaak van deze toename zien we dat niet enkel de optiepremie toeneemt, maar ook de gevoeligheid voor deze optiepremie. We leiden hieruit af dat de berekende optiepremie het risico voor de verschaffer van liquiditeit nog onderschat. Dit is het gevolg van het risico dat hij zijn positie zal moeten aanhouden gedurende de nacht.

Daarna brengen we het patroon van de spread rond de speculatieve aanval in kaart. Vóór de aanval daalt de spread tot hij een niveau bereikt dat onder de endogene minimale prijsverandering ligt. Deze daling wordt veroorzaakt door een sterke daling in de risicocomponent. Tijdens de aanval neemt de totale spread toe door een sterke stijging van de risicocomponent. De OPC dalen tijdens de aanval. Dit patroon kan verklaard worden door hogere competitiviteit tussen verschaffers van liquiditeit, die zich tegelijkertijd heel bewust zijn van het risico dat zij nemen door liquiditeit te verschaffen in een periode van hoge speculatie. Na de aanval nemen zowel de OPC als de risicocomponent toe. Bijgevolg is de strakheid van de markt veel lager dan voor de aanval. Globaal genomen toont dit hoofdstuk de relevantie aan van een model om de spread op te splitsen aan de hand van opties om te begrijpen hoe liquiditeit wordt verschaft op de wisselmarkt voor banken.

Chapter 1

Exchange Rate Policy in Central and Eastern European Countries

Exchange Rate Policy in Central and Eastern European Countries*

Michael Frömmel, Ghent University, BELGIUM[a]
Frederick Van Gysegem, Ghent University, BELGIUM[a]

Published as Frömmel, M. and F. Van Gysegem (2011). Exchange rate policy in Central and Eastern European Countries. In N. Perkins (Ed.), *Exchange Rates: Policies, Effects and Fluctuations* (pp. 25-46). New York, NY: Nova Science Publishers
This version: December 1, 2013

Abstract

The Central and Eastern European Countries (CEEC ô) s which joined the European Union between 2004 and 2007 show an interesting evolution of their exchange rate regimes. Although they all started from a comparable situation and have the common long-term goal of joining European Monetary Union, they opted for different exchange rate policies. Furthermore, the exchange rate policies were subject to frequent changes and adjustments. We first describe the evolution of exchange rate arrangements in CEEC ô, s and survey in this paper various aspects of their exchange rate policy.
We start with the discussion of differences between de facto and de jure exchange rate regimes. Second, we analyze the impact of exchange rate policy on exchange rate volatility, focusing on structural breaks or volatility regimes. While the level of volatility shows the external dimension of monetary stability, the break points may help to understand the processes that lead to changes in exchange rate arrangements. Third, we highlight the role of CEEC's exchange rates in monetary policy rules. Finally we review the literature on central bank interventions in CEEC ô. s

JEL: E58, F3

Keywords: European Union, Central and Eastern European Countries, transition economies, exchange rate policy

[a] Department of Financial Economics, Ghent University, St. Pietersplein 5, 9000 Ghent, Belgium
* The authors gratefully acknowledge Franziska Schobert (Deutsche Bundesbank) for reviewing the manuscript and Nora Srzentic for helpful suggestions.

Chapter 1

Exchange Rate Policy in Central- and Eastern European Countries

1. Introduction

The European Union has grown substantially in the 21st century. The first wave of Central and Eastern European Countries (CEEC ô)s joined in 2004, namely the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovenia and Slovakia (plus Cyprus and Malta), while Bulgaria and Romania followed in 2007. All countries have the obligation to join European Monetary Union. This is, however, conditional on the realization of the Maastricht criteria. Since these criteria include stability of the exchange rate inside the European Exchange Rate Mechanism (ERM II) for two years, the exchange rate policy of the CEEC ô is of major importance and the question arises CEEC ô s. The CEEC ô s show an interesting evolution of their exchange rate regimes. Although they all started from a comparable situation and have the common long-term goal of joining European Monetary Union, they opted for different exchange rate policies. Furthermore, the exchange rate policies were subject to frequent changes and adjustments. We first describe the evolution of exchange rate arrangements in CEEC ô s, and survey in this paper various aspects of their exchange rate policy. Since there has been a plethora of works on exchange rates in CEEC ô s, the survey has to be both, subjective and selective. We are aware of the fact that this approach is incomplete and the survey is not intended to be exhaustive.

A natural starting point is the description of the evolution of (official) exchange rate arrangements in the CEEC ô s in section 2. However, it is known that what countries announce to be their exchange rate regime and what they de facto implement often differs. For this reason we review the literature on differences between de facto and de jure exchange rate regimes.

In section 3 we analyze the relation of exchange rate policy and exchange rate volatility. Since the CEEC ô s frequently modified their exchange rate arrangements, there has been a strong focus on structural breaks or volatility regimes. Since the level of volatility is often understood as external dimension of monetary stability, one should expect a close relation between monetary policy regimes and exchange rate volatility. At the same time, switches between volatility regimes that deviate from the dates of the respective policy changes may hint at a lack of credibility of policy, including the unpeaceful exits from the pegs in the Czech Republic and Slovakia.

The last sections deal with the influence of monetary authorities on the exchange rate. We start in section 4 with the role of the exchange rate in monetary policy rules. In contrast, section 5 reviews the literature on central bank interventions in CEEC ô s, including central bank communication.

2. Evolution of exchange rate regimes

The exchange rate regimes in Central and Eastern European countries underwent a remarkable evolution in the past two decades. This evolution is illustrated in Figure 1. We see that most CEEC ô s chose a fixed exchange rate[1] as a tool in their stabilization strategy after the dissolution of the Soviet Union in December 1991. The standard arguments behind the fixed exchange rate are the reduction of transaction costs for external trade and macroeconomic stabilization (Halpern & Wyplosz 1997). Additionally, at least two major reasons can be given for why countries may not let their currency float freely.[2] First, small open economies are highly susceptible to exchange rate movements; therefore, the exchange rate must be considered by monetary authorities even if it is not the primary goal of monetary policy (Ball 1999). Most of the EU accession countries in Central and Eastern Europe belong to this class of countries. Second, in many emerging and transition countries, financial markets are less developed and do not allow domestic firms to borrow in their home currency. This is considered to be the original sin (Eichengreen & Hausmann 1999). Because their debt is nominated in foreign currency they will have incentives to peg their exchange rates because their debt is nominated in foreign currency, as (Hausmann *et al.* 2001) argue.

Even after considering the above mentioned arguments, a country may still not find it convenient to commit to an official peg. The political support for the necessary but unpopular measures to defend the peg may be very low in emerging and transition countries (Obstfeld & Rogoff 1995). Furthermore, under an officially floating regime, adjustments of the exchange rate are less visible to the public and less costly politically than devaluations under an official peg (Obstfeld 1997).

[Insert here: Figure 1: Exchange rate regimes in CEEC ô] s

[1] A fixed exchange rate is sometimes referred to as a pegged exchange rate.
[2] The literature on optimum currency areas surveyed by (De Grauwe 2003) suggests that the choice of a pegged exchange rate is feasible only for a limited number of countries.

We see in Figure 1 that in the late 1990s, many countries moved to more flexible arrangements (Sachs 1996). The Visegrád Group, i.e., the Czech Republic, Hungary, Poland and Slovakia followed entirely this path (Kocenda 2002). The combined strategy of a fixed exchange rate directly after the transition and a more flexible regime later on adds the benefits from pegging to the anchor currency to the ability to cope better with volatile capital movements in the later period (Corker *et al.* 2000).

The Czech Republic and Slovakia opted initially for narrow horizontal bands. Subsequently, these fixed exchange rate regimes became more flexible and, after widening the bands, the Czech Republic (1997) and Slovakia (1998) declared managed floating or freely floating exchange rates.

Poland and Hungary chose narrow crawling bands that served the dual objectives of maintaining competitiveness and moderating inflation (Szapáry & Jakab 1998). In 2000 the Polish zloty was declared freely floating. In Hungary the band was widened in 2001 to 15% and changed from a crawling to a horizontal band to mirror the exchange rate regime envisaged in the Exchange Rate Mechanism (ERM-2). Hungary kept a fixed exchange rate until early 2008. Early in the transition, other countries opted either for completely fixed exchange rates, e.g., the Baltic States and Bulgaria, or rather flexible regimes, e.g., Romania and Slovenia.[3] The Baltic States all stepped in the ERM system. Still, they chose to keep their currencies de facto fixed. The reported bandwidth of 15% remains thus purely theoretical. Estonia is announced to join the Eurozone on the first of January 2011.

The development described above follows the so called bipolar view.4 The bipolar view is based on the idea that, in a world of high capital mobility, adjustable pegs may be costly and difficult to defend so that they will be replaced by either hard pegs, i.e. currency boards and currency unions, or absolutely flexible exchange rate systems. The bipolar view is currently a mainstream conclusion in exchange rate policy. According to the official classification by the International Monetary Fund (IMF), the share of intermediate exchange rate regimes has declined during the last decade, as (Fischer 2001) discusses. This confirms the bipolar view.

3. De jure versus de facto exchange rate regimes

In the previous paragraph we gave an overview of the ñde ju
the CEECôs, or in other words ñwhat countrie

[3] Exchange rate arrangements chosen by transition countries are discussed in (Mussa *et al.* 2000)
[4] The bipolar view is also named as the hollowing out hypothesis or the two-corner hypothesis

countries are actually doing. In practice fear of floating and de facto pegging is very common (Calvo & Reinhart 2002).[5] Hence, the IMF acknowledges since 1999 de facto exchange rate regimes. The IMF classification remains a hybrid system: it combines data on actual flexibility with information on the official policy framework (IMF, 2004). According to the hybrid classification, the Slovenian and Romanian exchange rate regimes are crawling pegs, whereas these two countries announced to be managed floats. Relying solely on the official announcements could be misleading, especially for economies in transition. Knowing whether countries follow their officially announced exchange rate is crucial for assessing economic performance in terms of growth, volatility, inflation, and sensitivity to crises, as (Reinhart & Rogoff 2004) discuss. In the literature most studies are based on de jure classifications until the late 1990s. Recent literature, e.g. (Flood & Rose 2005), tries to classify exchange rate arrangements in a more realistic manner.

In general, two main approaches can be followed to identify de facto exchange rate regimes. One approach analyzes the development of exchange rates and policy variables that are indicative of exchange rate management by the central bank. (Popper & Lowell 1994) take this approach for Pacific Basin countries; (Hausmann *et al.* 2001) and (Levy-Yeyati & Sturzenegger 2005) use it on a broad sample of countries. (Schnabl 2004) applies this technique to the CEECôs. The second approach considers the outcomes of implicit exchange rate targeting, i.e., the time series of exchange rates. This can be done by comparing exchange rate developments with those of some possible anchor currencies. Exemplary for this approach is the work of (Haldane & Hall 1991). They analyze the transition of the British Pound from a dollar peg to a Deutsche mark peg. Other examples include (Frankel & Wei 1992), who investigate the influence of the yen on the exchange rate policies of some Asian countries and (Frankel *et al.* 2001), who consider its impact on other emerging market economies. Some CEECôs are included in the work of (Bénassy-Quéré 1996), who investigates de facto pegs during their early period of transition. (Reinhart & Rogoff 2004) stress the importance of market-determined exchange rates and also consider the behavior of parallel exchange rates to construct a natural classification algorithm.

(Frömmel & Schobert 2006) use the approach by (Frankel & Wei 1992) to analyze the de facto exchange rate regimes of six CEECôs, namely the Czech Republic, Hungary, Poland,

[5] (Fischer 2001), (Reinhart & Rogoff 2004), (Levy-Yeyati & Sturzenegger 2005), and (McKinnon & Schnabl 2004) also support this view. (Rogoff *et al.* 2004) state that, from an ex post perspective, the de facto exchange rate regime differs from the announced one about 50% of time.

Romania, Slovakia and Slovenia. They use daily data from 1994 to 2004, when most of the countries under consideration joined the European Union and estimate the regression:

$$\Delta s_t = d + \sum_{i=1}^{N} w_i \left(\Delta s_{i,t}\right) + \varepsilon_t \tag{3.1}$$

where s_t is the currency under observation expressed in special drawing rights that are used here as a numeraire, d is the rate of crawl, t the time parameter and $s_{i,t}$ are currencies to which s_t is pegged.

The currencies $s_{i,t}$ are expressed in the same numeraire as s_t and weighted in the basket with some weights w_i, which are nonnegative real numbers. The specification of equation (1) nests several relevant alternative regimes. A simple peg implies d=0 and N=1, while a crawling peg indicates d>0 and N=1. A basket peg results in d=0 and N>1, while and a crawling basket implies d>0 and N>1.

The setting of eq. (3.1) allows testing the de facto exchange rate regime. First one may test whether the rate of crawl (d) or the estimated weights (w_i) are different from zero. Second it is possible to test whether the estimated weights significantly differ from the officially announced ones.

Their findings imply that the Polish zloty and the Hungarian forint have most likely behaved according to their officially announced regime during their periods of higher exchange rate flexibility, while the results for the Czech Republic and Slovakia suggest a somewhat higher importance of the euro (and Deutsche mark) than officially announced. The Slovenian regime before 2004 matches rather peg than its official announcement of a managed float. Although (Frömmel & Schobert 2006) cannot clearly confirm the Romanian regime as a de facto crawling peg, it occasionally seemed like a crawling peg to a basket of euro and US dollar.

4. Exchange rate regimes and volatility

As pointed out above, we observe an increasing degree of exchange rate flexibility for the CEECôs between 1994 and 2004.[6] This increased flexibility of the exchange rate, however,

[6] This movement towards more flexible exchange rate arrangements stopped in recent years after several of the CEECôs joined the exchange rate mechanism (ERM2) of t exchange rate to the euro within a band of ±15 percent. This is the case in particular for Slovakia and Slovenia, which had officially announced managed floats prior to their entry to ERM2. Slovenia and Slovakia joined EMU in 2007 and 2009, respectively.

may not necessarily lead to higher volatility. In support of this, (Krugman 1991) argues that widening the fluctuation band will make it more credible, because it gets less likely that the fluctuation margins will be reached. Consequently volatility decreases. In contrast, (Flood & Rose 1999) conclude that fixed exchange rate regimes are in general less volatile than floats. This was also found by (Hughes-Hallett & Anthony 1997) and (Frömmel & Menkhoff 2001) for the European Monetary System. (Stancík 2007) corroborates this result for the Visegrád countries and Slovenia, but also stresses the importance of trade openness. (Frömmel & Menkhoff 2003) additionally show that changes in monetary policy settings determine volatility switches for exchange rates of major industrial countries.

Some empirical results suggest that the effect on volatility of the type of exchange rate regime is conditional on the appropriateness of the exchange rate regime. The work of (Berger *et al.* 2000) confirms that the type of exchange rate regime affects volatility, but that the ñwrongò peg (that is, the choice of a peg by a country for which a flexible exchange rate would be more appropriate) induces higher exchange rate volatility than a peg which is in line with the macroeconomic conditions. Accordingly, volatility can here be seen as a measure of credibility of an exchange rate arrangement and visible measure of the governmentôs success in macroeconomi (Dattagupta *et al.* 2004). (Fidrmuc & Horváth 2008) apply various GARCH-type models to five new member states of the EU and find an inverse relation between credibility of the exchange rate regime and exchange rate volatility.

There are only few works which investigate structural breaks in the exchange rate volatility of Central and Eastern European transition economies. (Kocenda 1998) compares GARCH estimates for the Czech koruna before and after the exchange rate band was widened in 1996 and finds significantly differing volatility patterns. (Kóbor & Székely 2004) apply a simple Markov switching model to the exchange rates of the so called Visegrád Group (the Czech Republic, Hungary, Poland, and Slovakia) between 2001 and 2003 and find frequent regime switches. Their sample period however does not include any change of the officially announced exchange rate system. (Kocenda 2005) argues that a lack of coincidence between policy changes and structural breaks in exchange rate behavior may hint at policy settings which are not consistent with the opinion of market participants and, accordingly, low credibility of the system. This is in line with the observation that if the costs of changing an exchange rate regime are high, a country may uphold an exchange rate regime even though it is not the optimal choice or even sustainable in the long run (Eichengreen & Masson 1998), (Juhn & Mauro 2002).

(Frömmel 2010) picks up the relation between credibility and volatility and applies a Markov switching GARCH model to exchange rates of the Visegrád countries between 1994 and their entry to the European Union in 2004. Romania joins the sample as a country that never announced an official peg.

The model allows the coefficients in a GARCH volatility equation (see (Bollerslev 1986)) to switch between two states:[7]

$$\sigma_{t,s_t}^{2} = \omega_{s_t} + \alpha_{s_t}\varepsilon_{t-1}^{2} + \beta_{s_t}\sigma_{t-1}^{2} \qquad (4.1)$$

Where the state process s_t follows a time-discrete Markov process with two possible states.[8] The process is characterized by the transition matrix P and the probability distribution in t = 1:

$$P = \begin{bmatrix} p_{11} & p_{21} \\ p_{12} & p_{22} \end{bmatrix}, \qquad (4.2)$$

with $p_{ij}=P(s_t=j|\, s_{t-1}=i)$, and $\Omega_t = \{r_t, r_{t-1}, .., r_1; \vartheta\}$ is the set of available information at time t, i.e. the set of all realisations of the returns process up to time t and the vector ϑ of parameters.

The model allows then to distinguish a high and a low volatility state, with the switches between high and low volatility being of particular interest. As pointed out by (Kocenda 2005) a coincidence of switches between volatility states and changes of the officially announced regimes hint at high credibility and primacy of the policy. Figure 2 shows the probabilities of being in the high volatility regime for the five countries. Volatility regimes and policy regimes clearly coincide in the cases of Hungary and Poland. The control by policy was comparatively high, providing some evidence for the success of gradually increasing exchange rate flexibility for exiting a peg (Eichengreen 1999). This is in particular the case when countries have liberalized financial markets, as it is typical for the CEEC — They need to manage their exposure to international capital accounts and are more vulnerable to being forced off their currency pegs. This high vulnerability of intermediate exchange rate arrangements is also stressed by the results for the Czech Republic and Slovakia, which had to follow the pressure by markets and leave their pegs during currency crises. Accordingly we

[7] See (Hamilton 1994), p. 237. For details of the model see (Frömmel 2010).

[8] The model can be easily generalised to k states, as well as the mean process can be modified. This will, however, not lead to substantial changes in the model, so we rely on the simple model as described in the main text.

can observe a switch to the high volatility regime before policy reacted in the course of the crisis. In these cases the markets rather than policy drove the evolution of exchange rate policy.

As a conclusion, the results are strongly in favour of gradually and early widening the bandwidth of currency pegs. Furthermore crawling pegs instead of horizontal ones seem to be advantageous, giving a certain degree of flexibility to react to an evolving environment. The credibility of an exchange rate arrangement is a crucial condition for its success and it is hardly possible to exit smoothly from a peg when markets expect it.

[Insert here: Figure 2: Filter- and smoothed probabilities for EU accession countries]

5. Exchange rate regimes and monetary policy

Exchange rate policy and monetary policy are interdependent. For this reason we will discuss here the monetary policy in the CEE different perspective: to the policy "de jure" and th

5.1 Overview of the policy "de jure" in the CEEC's since

In the Czech Republic, the monetary policy initially followed a strategy of jointly targeting the exchange rate and monetary aggregates. Although this policy worked well in the early 1990s, increasing capital inflows made the system unsustainable. After widening the exchange rate band in March 1996, the Czech National Bank (CNB) switched to a managed float in May 1997. Later on, in 1998, monetary policy changed to a strategy of inflation targeting because the CNB considered the demand for money to be too unstable to use a monetary aggregate as an intermediate target (CNB 1998).[9] However, during the period of inflation targeting, the CNB kept on intervening in the foreign exchange market. (Holub 2004) argues that these interventions in early 1998 and in 1999/2000 are not consistent with inflation targeting. These claims are supported by regular discussions in the central bank's council about the equilibrium exchange rate.[10] An in-depth survey of Czech monetary policy can be found in (Böhm & Zdarsky 2005).

[9] From 1998 to 2001, the CNB pursued a net inflation target, i.e. headline inflation minus regulated prices and changes in indirect taxes. In 2002 the CNB switched to headline inflation targeting with a continuous and declining target band.

[10] The minutes of the CNB board meeting of December 21, 1999 report that a considerable amount of time was spent discussing exchange rate developments. Board members agreed on the importance of guarding against inadequate appreciation of the koruna's exchange rate. From the minutes of October 26, 2000 meeting: "A large-volume transaction ... was responsible for the kor

In Hungary the monetary policy concentrated until 2001 on managing the nominal exchange rate within a fairly narrow crawling band (Kiss 2005). During 2001, the National Bank of Hungary (NBH) widened the band substantially. The following transition from a crawling band to a horizontal band coincided with the adoption of inflation targeting. The inflation target is surrounded by a one percent tolerance band, which was achieved until 2002. According to (Dibooglu & Kutan 2001) and (Barlow 2005), the Hungarian policy mix was successful in gaining internal and external stability of the economy.

Until 1998, the National Bank of Poland (NBP) attempted to combine money and exchange rate targets by pursuing a crawling devaluation of the zloty vis-à-vis a basket of currencies. This strategy did not result in both intermediate targets being met in full, but it did facilitate the reduction of inflation initially. Beginning in 1995, Poland experimented with targeting money growth, the interest rate, and the monetary base. However, the NBP did not wait for a crisis to widen the exchange rate band substantially. Due to increased financial market integration, direct inflation targeting was introduced in the last quarter of 1998, although not announced formally until January 1, 1999.
play a major role in monetary policy as the
market. In April 2010 the NBP did intervene, because the strong zloty was considered to be a threat for the economic growth in Poland. The intervention was preceded by more than a month of efforts of the NBP to talk the zloty down. The central bank declared after this
intervent iôotn etxhcaltu diet iñnctaenr vening againò.

Although no official commitment is made to any specific exchange rate or inflation path, statements of officials from the National Bank of Romania openly express that monetary policy has aimed at a certain exchange rate path to maintain external competitiveness. The 2001 Annual Report states that the central bank is
was mainly aimed at enlarging the monetary policy's room for maneuvers through abolishing intensive reliance on the exchange rate as an instrument providing an underpinning to external competi(NBR 2001). In discussions with the IMF, Romanian authorities have mentioned that they pursue twin objectives of gradual disinflation and maintaining a sustainable external position by using the exchange rate as an implicit nominal anchor (IMF 2003). The Romanian authorities also mentioned the use of an informal euro/ dollar basket,

few days. However, attention was drawn to the fact that, in the present phase of completing state share privatization, this distinct type of divergence could occur again, and even possibly lead to new exchange rate levels. The CNB would carefully monitor and analyze any developments in this direction.ò which should be replaced gradually by only the euro as the reference exchange rate on the path to EU accession.

Slovakia focused from the beginning on exchange rate stability, combined with tracking a broad money aggregate, namely M2. Following policies in the Czech Republic, the National Bank of Slovakia (NBS) widened its exchange rate band in January 1997 and changed to a managed float in October 1998. The NBS has used inflation bands as an informal guide for monetary policy since 1999 but the authorities do not consider this strategy to be formal inflation targeting. According to (Beblavy 2002), current monetary policy in Slovakia can be characterized as implicit inflation targeting with a significant amount of discretion. Furthermore, the exchange rate still plays an important role, even though it is officially floating. For example, the stated monetary appreciation pressures. It is ready to inte stabilize the foreign exchange rate approximately at the c (NBS 1999).

Slovenia's official policy was monetary targeting until switching to a two-pillar strategy similar to that of the European Central Bank in 2001. Within this official framework, the Bank of Slovenia states that it ñpursues t stability, by simultaneously modifying the quantity of money in circulation and the exchange rate. In order to maintain control over the money supply in the face of the free flow of capital, the Bank must adjust interest rates and th (BOS 2002). However, if the Bank pursues only price stability as its primary objective in a managed floating exchange rate regime, it would not need to adjust exchange rate developments in reaction to capital flows. Rather, the statement reveals implicit dual objectives, namely internal price stability and an exchange rate target.

The Bulgarian policy was over the whole period characterized by a firm focus on a fixed exchange rate. There was one break in the monetary policy in mid-1997, together with the launch of the currency board. The stabilization of inflation and inflation expectations then became also important objectives of the Bulgarian National Bank. Some authors argue that after the introduction of these objectives Bulgaria reached the lowest and most stable inflation rates combined with the highest and most stable output growth since the beginning of the transition process (Hristov & Zaimov 2003). One should however not neglect that Bulgaria was in a period of hyperinflation before the introduction of the above mentioned objectives, which makes a comparison difficult.

In the Baltic States the monetary policy was, because of the currency board arrangements in these countries, characterized by exchange rate targeting. For Estonia there was a strong focus on the exchange rate since the early nineties (Hartsenko 2002). Latvia and Lithuania were in exactly the same situation (Repse 1999; BOL 2007).

The ñde jureò exchange rate policies are

histories, we conclude that, despite the fact that countries announce fairly flexible exchange rate regimes officially, central banks in transition economies pay considerable attention to the exchange rate in monetary policy, which is often embedded in broader macroeconomic programs. In the next section we focus on the research on de facto monetary policy.

[Insert here: Figure 3 : ñDe Jureò Monetary Policy Re

5.2. Research on the de facto monetary polic

An important tool to analyze the de facto exchange rate regime is the Taylor rule, which was first proposed in 1993. The Taylor rule suggests that interest rates would be changed according to the deviation of inflation from a target and an output gap (Taylor 1993). Other studies often focus on the comparison of the actual setting of policy rates by central banks with what would have been predicted by the Taylor rule as a benchmark. However, as (Peersman & Smets 1999) among others emphasize, the Taylor rule should be perceived as a descriptive instrument to understand the interest rate setting behavior of central banks rather than as a normative guide for monetary authorities. The empirical literature on such interest rate rules for industrial countries has grown significantly during the past decades and has proven the ability of interest rate rules to describe the interest rate setting behaviour of central banks[11].

In contrast, research in the context of emerging market economies and particularly transition economies is of more recent origin and relatively scarce. An important finding is that central banks in emerging market economies tend to look beyond inflation and focus on other objectives as well, most prominently on exchange rate changes. (Mohanty & Klau 2004) find that many central banks in their sample of emerging market economies change interest rates systematically in response to exchange rate changes. For some countries the response is even found to be stronger than that to the inflation rate or the output gap.

There are few papers on monetary policy rules in CEEC ô s. This is due to several reasons. First, the time series available are comparatively short. They usually start in the middle of the 1990s. Second, most CEEC ô s have not followed one single strategy of monetary policy and

[11] For monetary policy rules in the context of inflation targeting see Neumann and von Hagen (2002) and the references therein.

also gradually made their exchange rates more flexible (See Figure 1 and Figure 3). Third, it is not quite clear which target values for inflation the CEEC ô s followed, as most countries introduced inflation targeting and explicit inflation goals only between 1997 and 2001. The unstable and dynamic economic situation in the CEEC ô s makes this task even more demanding.

However, there have been recently some attempts to describe the monetary policy in selected CEEC ô s using interest rate rules: (Maria-Dolores 2005) estimates Taylor rules for the Visegrad countries Czech Republic, Hungary, Poland and Slovakia between 1998 and 2003 and comes to the conclusion that the Taylor rule describes the interest rates well for all countries but Slovakia. Similarly to the original Taylor rule, the rules used by (Maria-Dolores 2005) do not consider exchange rate movements. The lagged interest rate, however, is included. The same set of countries is considered by (Paez-Farell 2007), whereas the sample periods differ from country to country. He compares different versions of interest rate rules and finds that there is a reaction to exchange rate movements. (Angeloni *et al.* 2007) estimate interest rate rules for the Czech Republic, Hungary and Poland from 1995-2004. They introduce the US dollar interest rate as a proxy for inflationary pressures of global origin and dummies for the years preceding the adoption of inflation targeting. (Yilmazkuday 2008) applies Taylor rules to the Czech Republic, Hungary and Poland for the period 1994-2007. He includes the exchange rate in the interest rate rule, but also considers structural breaks. (Moons & Van Poeck 2008) focus on the period 1999-2003 and find that the accession countries do not differ substantially from the current EMU members with respect to the interest rate setting behavior. Furthermore it seems that the potential new entrants have witnessed a notable tendency for increased convergence during the last years. Finally, (Horváth 2009) analyzes the policy neutral rate in the Czech Republic from 2001 to 2006 using a time-varying parameter model with endogenous regressors. The results indicate that the policy neutral rate decreases gradually over the course of the sample period showing a substantial interest rate convergence to levels comparable to the euro area.

All of these studies conclude that a Taylor-like rule is helpful in understanding monetary policy of the CEEC ô s. However, in most cases inflation coefficients are found to be far below unity, thus violating the so-called Taylor principle. If the Taylor principle holds, the policy rate should move more than one-for-one with increases in the inflation rate and thereby raise the real interest rate. If the monetary policy rule violates the Taylor principle, it will mean that the central bank does not react adequately on bringing down inflation.[12] This result is counterintuitive as the CEEC ôs have experienced a remarkable degree of disinflation during the last 15 years. The literature suggests mainly two explanations: (Angeloni *et al.* 2007) argue that part of the reaction on inflation is captured by the coefficient on the US interest rate included in their equation. An increase in global inflation would then lead to a composed reaction, which is partly due to domestic inflation via the conventional inflation coefficient and partly due to foreign inflation via the coefficient on the foreign interest rate. One might similarly argue that the exchange rate included in the interest rate rule partially takes the reaction on inflation, as it anchors expectations on future monetary policy. Another argument, proposed by (Golinelli & Rovelli 2005) is that the reaction to an increase in inflation may be modest, if the initial interest rate compared to inflation was set high enough. Thus a smaller coefficient means that in the course of the disinflation process monetary policy is getting even more aggressive. The scenario seems to be well applicable to the CEEC ôs. However, one would at least expect the inflation coefficient to be close to unity during periods of autonomous monetary policy.

Besides the above mentioned empirical research, the treatment of exchange rate changes in monetary policy rules is also discussed in the theoretical literature. (Svensson 2000) compares strict inflation targeting (when stabilizing inflation around the inflation target is the only objective for monetary policy) with flexible inflation targeting (when there are additional objectives for monetary policy). His results also indicate that strict inflation targeting implies a vigorous use of the direct exchange rate channel for stabilizing (CPI-) inflation at a short horizon. In contrast, flexible inflation targeting ends up stabilizing inflation at a longer horizon, and thereby also stabilizes real exchange rates and other variables to a significant extent. In comparison with the Taylor rule, the reaction function under inflation targeting in an open economy respond to more information, in particular to foreign disturbances. The particular importance of the exchange rate for monetary policy rules in the case of emerging economies is also stressed by (Amato & Gerlach 2002).

(Taylor 2001) argues that a monetary policy rule that reacts directly to the exchange rate, as well as to inflation and output, sometimes works worse than policy rules that do not react directly to the exchange rate and thereby avoid more erratic fluctuations in the interest rate. In (Taylor 2002), however, he points out that monetary policy in open economies is different from that in closed economies. Open-economy policymakers seem reluctant to considerable

[12] For a more detailed discussion of the Taylor principle see Woodford (2001).

variability in exchange rate. In his view they should target a measure of inflation that filters out the transitory effects of exchange rate fluctuations and they should also include the exchange rate in their policy reaction functions. He leaves open to further research, whether the exchange rate should appear on the left- or the right-hand side of the rule ï that is, whether the policy instrument should be an interest rate or rather a monetary condition index.

(Frömmel *et al.* 2009) extend the existing work on monetary policy rules in CEEC ô by splitting up the exchange rate into two components, one of them (b_t) capturing the ī reaction to deviations from the central parity in a peg, and the other one (Δs_t) measuring trends in the exchange rate:

$$i_t = r^* + \pi_t + \alpha \pi_t^* + \beta y_t^* + \delta \Delta s_t + \gamma b_t \qquad (5.1)$$

With r* being a long run real exchange rate, π_t the in inflation rate, π_t* the inflation gap, and y_t* the output gap. b_t is a nonlinear function of the exchange influence rate's distance to the edges of the band of a currency peg (if there is one at that time), as shown in Figure 4.

The band distance reflects pressure on the exchange rate, as every time the market rate tends to or actually does exceed one of the borders, the central bank is obliged to react by interventions and/or interest rate changes. This implies that there should be a strong influence of the band distance on the interest rate stance of the monetary policy. The closer the exchange rate comes to the intervention margins the stronger the central bank should react, and the values of b_t increase dramatically during times of crises, when boundaries are reached or exceeded.

[Insert here: Figure 4: The band distance]

[Insert here: Figure 5: The Derivation of the band distance element from the historical exchange rate peg values for Hungary (forint/ Deutsche mark)]

[Insert here: Figure 6: The Derivation of the band distance element from the historical exchange rate peg values for the Czech Republic (Czech Koruna/ Deutsche Mark)]

Figure 5 and Figure 6 show the evolution of the band distance element as an example for Hungary (crawling peg) and the Czech Republic (horizontal peg) respectively. Obviously the band distance takes in general higher values if the exchange rate pegs are narrow (i.e., during the first parts of the respective sample periods). Furthermore the violation of the band during the Czech exchange rate crisis 1997 substantially increased the pressure on the Czech interest rate policy.

(Frömmel *et al.* 2009) estimate equation (5.1) in a cointegration approach and let the coefficients vary depending on whether the ñfloatingò regime. They find that the, Taylor during principle is violated, but the band distance explains most of the interest rate variation. This is in line with the argument by (Angeloni *et al.* 2007), see above. In contra exchange rate regimeò for all countries but Slovakia approach therefore leads to a substantial improvement of empirical results.

Two interesting features stand out. First, the exchange rates of Central and Eastern European countries often had appreciating pressure during fixed regimes and therefore, were close to the strong edge of the narrow bands (see Figure 5 and Figure 6). Second, the values increase dramatically during times of crises, when boundaries are reached or exceeded (see Figure 6).

6. Exchange rate regimes and interventions

Monetary policy influences the exchange rate. In this section we review how central bank interventions and central bank communication can influence the exchange rate. A basic insight of the research on central bank interventions (for surveys see e.g. (Sarno & Taylor 2001; Vitale 2007)) is that interventions are able to move the exchange rate. They affect the first two moments of the exchange rate (Scalia 2008) and the impact is usually stronger in emerging than in developed countries (Canales-Kriljenko 2003). This may be due to less sterilization, the market's size and organization.

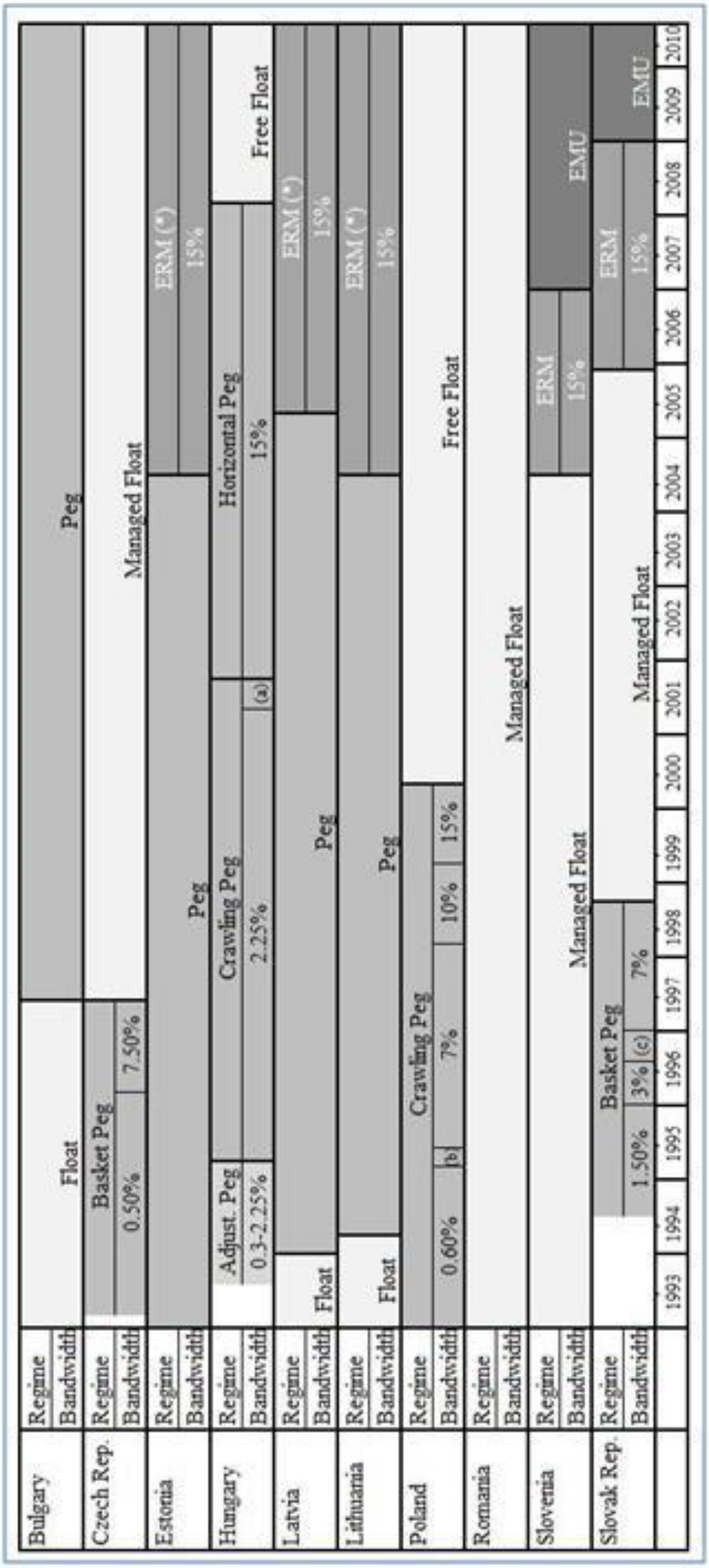
Besides direct interventions central bank communication may also be seen as a form of intervention, that is ï although less obvious at first sight ï able to affect the exchange rate as well (Ehrmann & Fratzscher 2007). There is a huge amount of research providing some ambiguous empirical evidence on an exchange rate impact of central bank communication (see the survey in (Blinder et al. 2008)). The impact of verbal interventions or communication stems from their role in anchoring expectations on future monetary policy, i.e. the signaling or expectation channel of monetary policy (Sarno & Taylor 2001), but also by functioning as a coordination advice for market participants (Reitz & Taylor 2008). Thus, communication may complement intervention or substitute it (Fratzscher 2008).

Due to the more dynamic economic environment in a transition economy verbal interventions may be more effective than in developed markets. However, again most of the work deals with developed markets, mostly for the FOMC, the ECB, the Bank of England and the Bank of Japan, and there are only few papers that focus on transition economies: (Rozkrut et al. 2007) find for the Czech Republic, Hungary and Poland, that speeches about monetary policy affect the exchange rate. (Égert 2007) finds influence of central bank communication for Hungary, but not for other CEEC ô. s He also concludes that the Hungarian National Bank (MNB) used actual interventions very rarely, but mainly relies on verbal interventions. The latter is also analyzed by (Frömmel *et al.* 2010) who estimate the impact of communication by central bankers and politicians on high-frequency exchange rates. They find that central bank communication mainly affects the exchange rate indirectly via order flow, i.e., signed transaction volume.

7. Conclusion

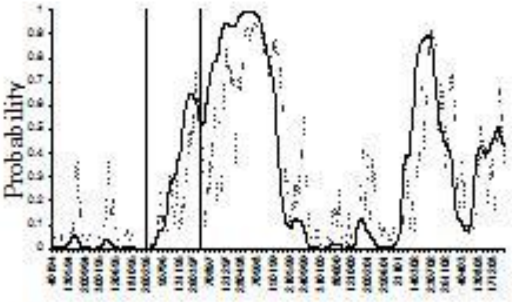
The exchange rates of CEEC ô. s have been subject of numerous studies. In this selective survey we have described the evolution of exchange rate arrangements of CEEC ô. s and reviewed four aspects of their exchange rate policy: the deviation of de facto from de jure exchange rate regimes, the relation between exchange rate volatility and exchange rate arrangements, the inclusion of exchange rates in monetary policy rules and the intervention policy of CEEC ô. s

FIGURES

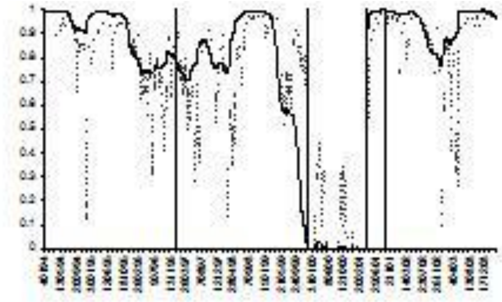


(a) 15%, (b) 2%, (c) 5%
(*) Note that this is only the official exchange rate regime. After joining the ERM, the Baltic States decided to hold on to their fixed exchange regimes.

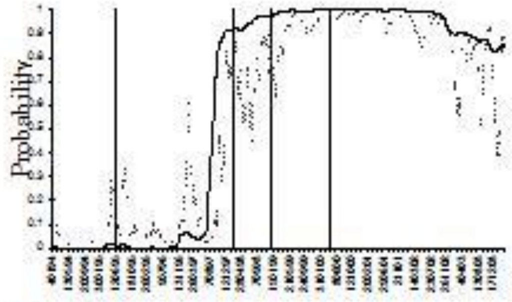
Figure 1: Exchange rate regimes in CEEC's



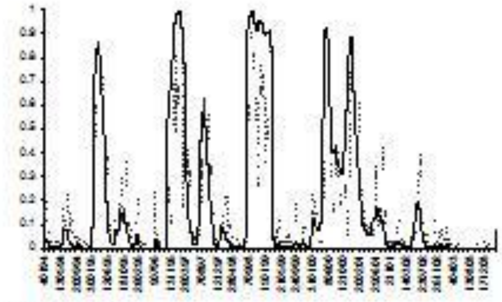
CZK/DEM



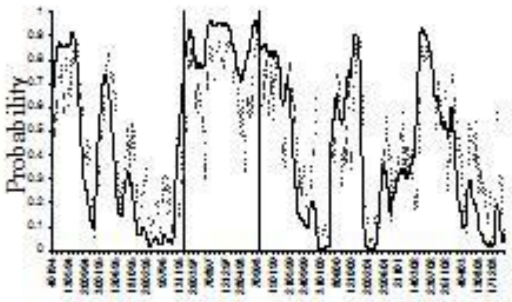
HUF/DEM



PLZ/DEM



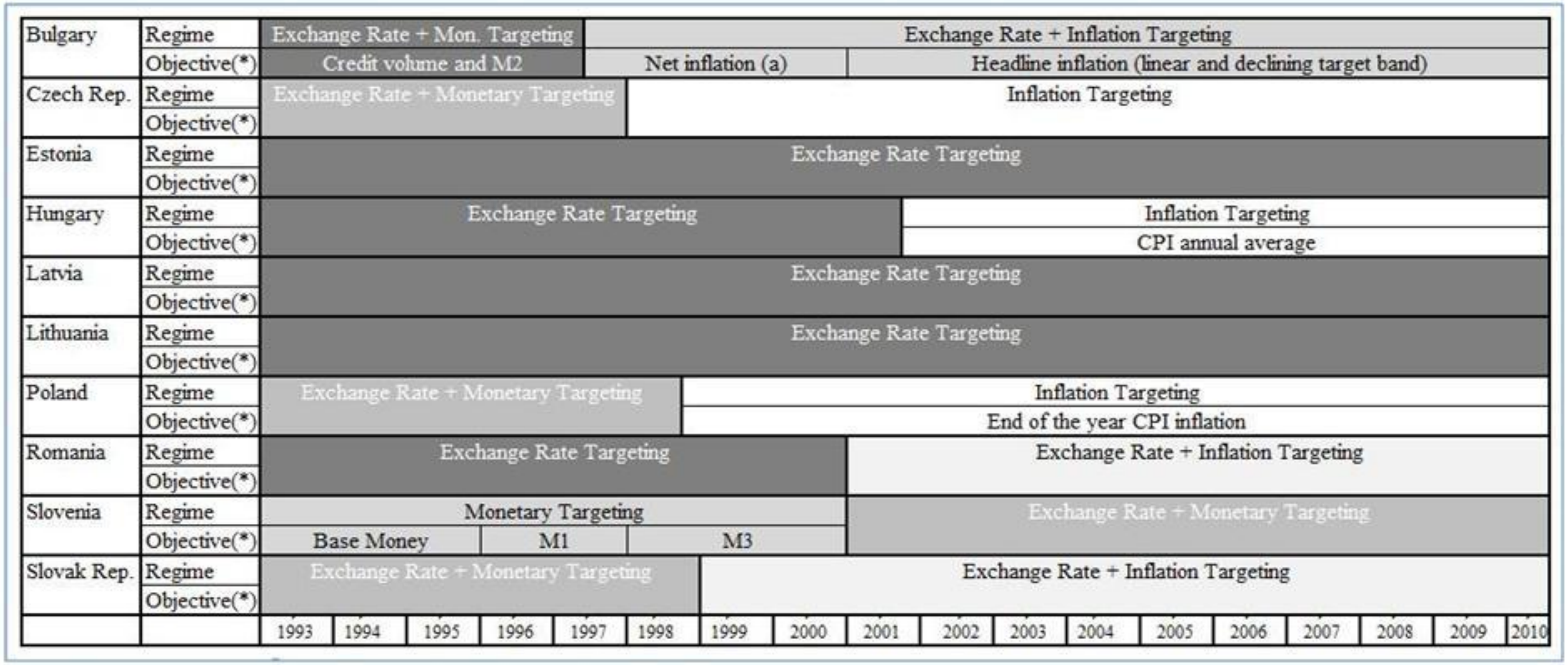
ROL/DEM



SKK/DEM

Figure 2: Filter- and smoothed probabilities for EU accession countries

The bold lines are the smoothed probabilities $P(s_t=1 \mid \Phi_T)$ of being in the high volatility regime, the dotted lines reflect the filter probabilities $P(s_t=1 \mid \Phi_t)$ of being in the high volatility regime 1. The smoothed probabilities correspond with an ex post analysis, whereas the filter probabilities are the probabilities as observed on the respective day. The vertical lines represent changes in the exchange rate system of the respective country.Source: (Frömmel 2010)



(*) If available we included the inflation or monetary target variable
(a) Net Inflation = Headline Inflation minus regulated prices and changes in indirect taxes

Figure 3: "De Jure" Monetary Policy Regimes in CEEC's

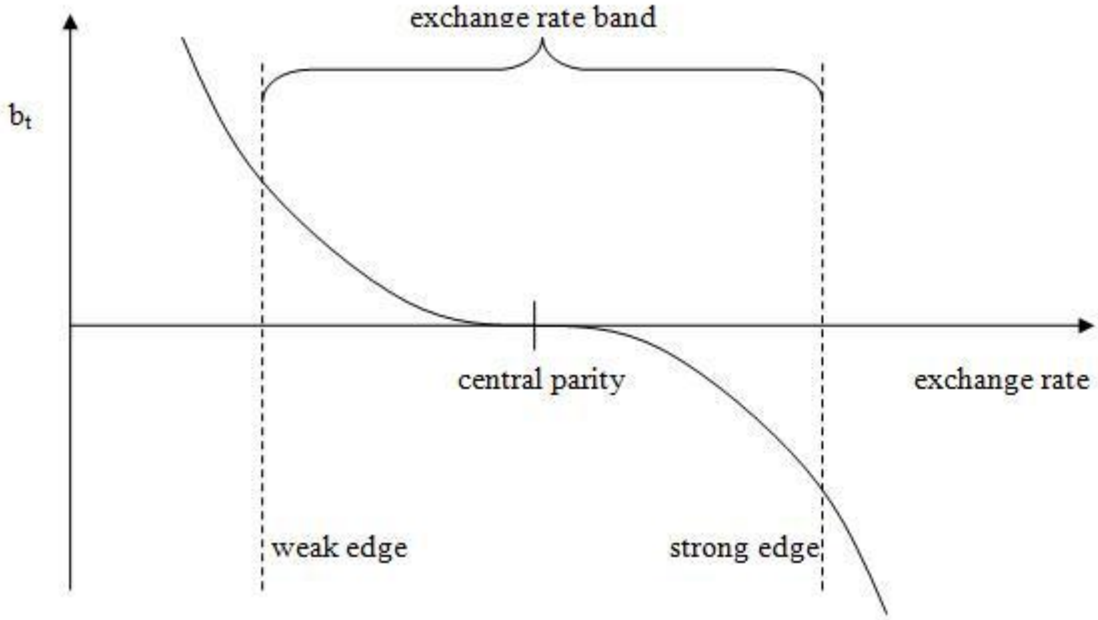


Figure 4: The band distance

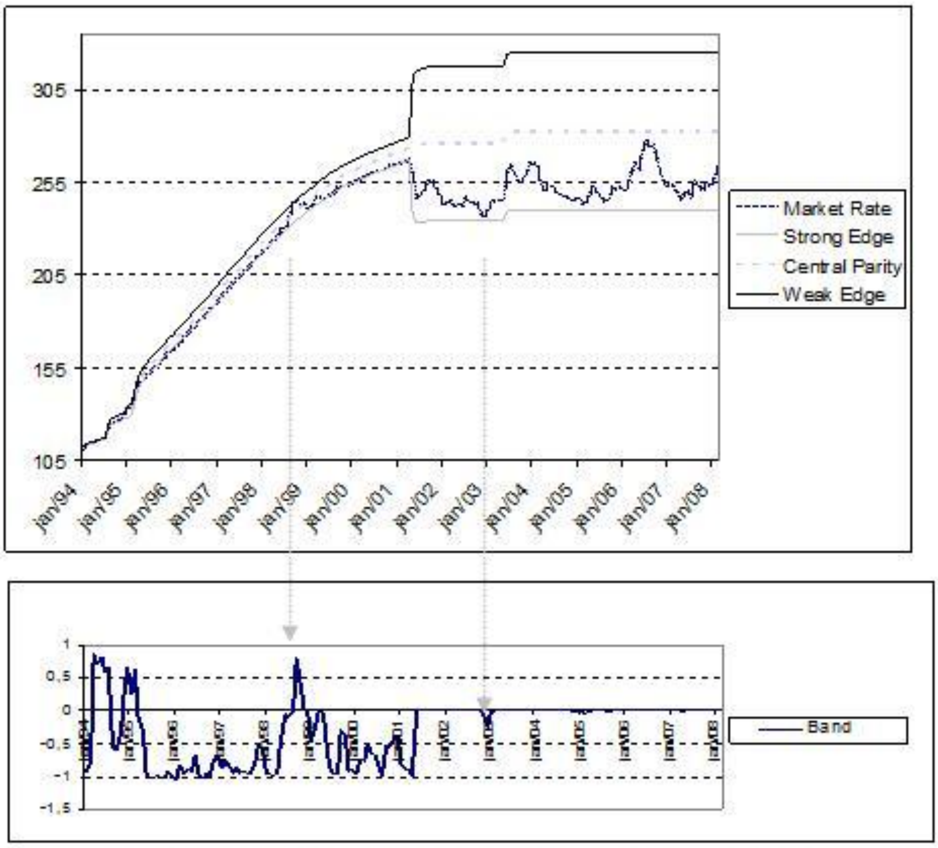


Figure 5: The Derivation of the band distance element from the historical exchange rate peg values for Hungary (Forint/ Deutsche Mark)

Source: (Frömmel *et al.* 2009)

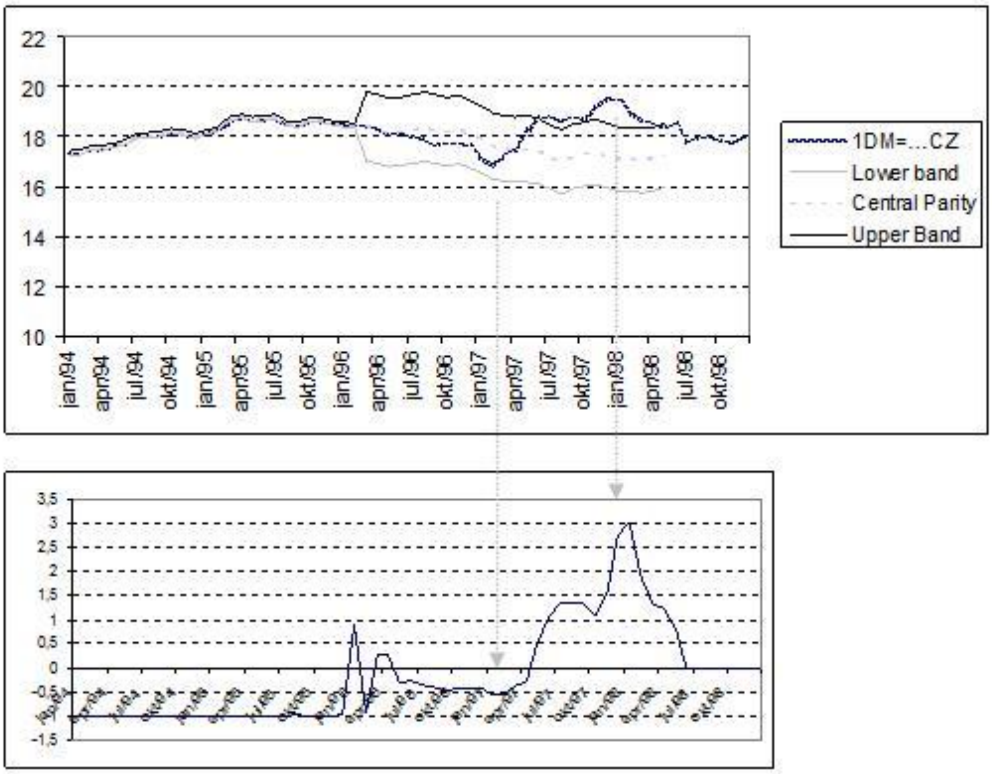


Figure 6: The Derivation of the band distance element from the historical exchange rate peg values for the Czech Republic (Czech Koruna/ Deutsche Mark)

Source: (Frömmel *et al.* 2009)

LIST OF REFERENCES

Amato, J.A., Gerlach, S., 2002. Inflation Targeting in Emerging Market and Transition Economies: Lessons after a Decade. European Economic Review 46, 781-790

Angeloni, I., Flad, M., Mongelli, F.P., 2007. Monetary Integration of the New EU Member States: What Sets the Pace of Euro Adoption? Journal of Common Market Studies 45, 367-409

Ball, L., 1999. Policy rules for open economies. University of Chicago Press, Chicago.

Barlow, D., 2005. The Hungarian Exchange Rate and Inflation over the Transition. Economic Systems, 87-97

Beblavy, M., 2002. Exchange Rate and Exchange Rate Regime in Slovakia: Recent Developments. European Center Working Paper on Macroeconomic Studies

Bénassy-Quéré, A., 1996. Potentialities and opportunities of the euro as an international currency. CEPII Report for the European Commission

Berger, H., Sturm, J.-E., De Haan, J., 2000. An empirical investigation into exchange rate regime choice and exchange rate volatility. CESifo Working Paper Series

Blinder, A.S., Ehrmann, M., de Haan, J., Frzatzscher, M., Jansen, D.-J., 2008. Central Bank Communication and Monetary Policy: A Survey of Theory and Evidence. ECB Working Paper Series

Böhm, J., Zdarsky, V., 2005. Conducting Monetary Policy in a Small Open Economy under Globalized Capital Markets: The Experience of the Czech Republic. BIS Papers, 141-149

BOL, 2007. Annual Report 2007 of the BOL (Bank of Lithuania). Annual Reports, 25-29

Bollerslev, T., 1986. Generalized Autoregressive Conditional Heteroskedasticity. Journal of Econometrics 31, 302-327

BOS, 2002. BOS (Bank of Slovenia) Annual Report 2002.

Calvo, G.A., Reinhart, C.M., 2002. Fear of floating. Quarterly Journal of Economics 117, 379-408

Canales-Kriljenko, J.I., 2003. Foreign Exchange Intervention in Developing and Transition Economies: Results of a Survey. IMF Working Paper Series

CNB, 1998. CNB (Czech National Bank) Annual Report.

Corker, R., Beaumont, C., van Elkan, R., Iakova, D.M., 2000. Exchange rate regimes in selected advanced transition economies - Coping with transition, capital inflows and EU accession. . IMF Policy Discussion Papers PDP/00/03

De Grauwe, P., 2003. The economics of monetary union. Oxford University Press, Oxford.

Dibooglu, S., Kutan, A., 2001. Sources of Real Exchange Rate Fluctuations in Transition Economies: The Case of Hungary and Poland. Journal of Comparative Economics, 257-275

Duttagupta, R., Fernandez, G., Karacadag, C., 2004. From fixed to float: Operational aspects of moving towards exchange rate flexibility. IMF Working Paper Series

Égert, B., 2007. Central Bank Interventions, Communication and Interest Rate Policy in Emerging European Economies. Journal of Comparative Economics 35, 387-413

Ehrmann, M., Fratzscher, M., 2007. Communication by Central Bank Committee Members: Different Strategies, Same Effectiveness? Journal of Money, Credit and Banking 39, 509-541

Eichengreen, B., 1999. Kicking the Habit: Moving from Pegged Rates to Greater Exchange Rate Flexibility. Economic Journal, C1-C14

Eichengreen, B., Hausmann, R., 1999. Exchange rates and financial fragility. NBER Working Papers 7418

Eichengreen, B., Masson, P., 1998. Exit strategies: Policy options for countries seeking greater exchange rate flexibility. IMF Occasional Papers 168

Fidrmuc, J., Horváth, R., 2008. Volatility of exchange rates in selected new EU members: Evidence from daily data. Economic Systems 32, 103-118
Fischer, S., 2001. Exchange Rate Regimes: Is the bipolar view correct? Journal of Economic Perspectives 15, 3-24
Flood, R.P., Rose, A.K., 1999. Understanding exchange rate volatility without the contrivance of macroeconomics. Economic Journal 109, 660-672
Flood, R.P., Rose, A.K., 2005. A new approach to asset integration: methodology and mystery. Pacific Economic Review
Frankel, J.A., Fajnzylber, E., Schmukler, S.L., Servén, L., 2001. Verifying exchange rate regimes. Journal of Development Economics 66, 351-386
Frankel, J.A., Wei, S.-J., 1992. Yen bloc or dollar bloc? Exchange rate policies in the East Asian economies. In: Takatoshi I & Krueger A (eds.) Macroeconomic linkages: Savings, Exchange ratres and Capital Flows. University Press of Chicago, Chicago.
Fratzscher, M., 2008. Oral Interventions versus Actual Interventions in FX Markets - An Event Study Approach. Economic Journal 118, 1079-1106
Frömmel, M., 2010. Volatility Regimes in Central and Eastern European Countries' Exchange Rates. Czech Journal of Economics and Finance
Frömmel, M., Garabedian, G., Schobert, F., 2009. Monetary Policy Rules in Central and Eastern European Countries: Does the Exchange Rate Matter? Ghent University Working Paper Series
Frömmel, M., Kiss, M., Pintér, K., 2010. Central Bank Communication, Macroeconomic Announcements, and Order Flow: An Analysis of the Hungarian Foreign Exchange Market. International Journal of Finance & Economics
Frömmel, M., Menkhoff, L., 2001. Risk reduction in the EMS: Evidence from exchange rate properties. Journal of Common Market Studies 39, 285-306
Frömmel, M., Menkhoff, L., 2003. Increasing exchange rate volatility during the recent float? Applied Financial Economics 13
Frömmel, M., Schobert, F., 2006. Exchange Rate Regimes in Central and East European Countries: Deeds vs. Words. Journal of Comparative Economics 34, 467-483
Golinelli, R., Rovelli, R., 2005. Monetary Policy Transmission, Interest Rate Rules and Inflation Targeting in Three Transition Countries. Journal of Banking and Finance, 183-201
Haldane, A.G., Hall, S.G., 1991. Sterling's relationship with the dollar and the deutschemark: 1976-89. Economic Journal 101, 436-443
Halpern, L., Wyplosz, C., 1997. Equilibrium exchange rates in transition economies. IMF Staff Papers, 430-461
Hamilton, J., 1994. Time Series Analysis. Princeton University Press, Princeton.
Hartsenko, J., 2002. Estonian Monetary System and Banking Development on Way to the Euro Zone. Effect of Accession to the European Union on the Economic Policy of Estonian. In: Scientific and Educational Conference, pp. 65-71. Berlin Verlag Arno Spitz GmbH, Berlin
Hausmann, R., Panizza, U., Stein, E., 2001. Why do countries float the way they float. Journal of Development Economics 66, 387-414
Holub, T., 2004. Foreign Exchange Interventions under Inflation Targeting: The Czech Experiences. CNB (Czech National Bank) Internal Research and Policy Note
Horváth, R., 2009. The time-varying policy neutral rate in real-time: A predictor for future inflation? Economic Modelling 26
Hristov, K., Zaimov, M., 2003. Shadowing the euro: Bulgaria's monetary policy five years on.
Hughes-Hallett, A., Anthony, M.L., 1997. Exchange rate behaviour under the EMS regime: Was there any systematic change? Journal of International Money and Finance 16, 537-560

IMF, 2003. IMF Country Report.
Juhn, G., Mauro, P., 2002. Long-run determinants of exchange rate regimes: A simple sensitivity Analysis. IMF Working Paper Series 02/104
Kiss, G., 2005. Monetary policy issues in Hungary on the eve of EU membership.
Kóbor, Á., Székely, I., 2004. Foreign exchange market volatility in EU accession countries in the run-up to Euro adoption: Weathering uncharted waters. Economic Systems 28, 337-352
Kocenda, E., 1998. Altered band and exchange volatility. Economics of Transition 6, 173-181
Kocenda, E., 2002. Exchange rate movements in European transition economies. Nova Science, New York.
Kocenda, E., 2005. Beware of breaks in exchange rates: Evidence from European Transition Countries. Economic Systems 29, 307-324
Krugman, P.R., 1991. Target zones and exchange rate dynamics. Quarterly Journal of Economics 106, 669-682
Levy-Yeyati, E., Sturzenegger, F., 2005. Classifying exchange rate regimes: Deeds vs. words. European Economic Review, 1603-1635
Maria-Dolores, R., 2005. Monetary Policy Rules in Accession Countries to EU: Is the Taylor Rule a Pattern? Economic Bulletin 5, 1-16
McKinnon, R., Schnabl, G., 2004. The East Asian dollar standard, fear of floating and original sin. Review of Development Economics, 331-360
Mohanty, M.S., Klau, M., 2004. Monetary Policy Rules in Emerging Market Economies: Issues and Evidence. BIS Working Papers
Moons, C., Van Poeck, A., 2008. Does One Size Fit All? A Taylor-rule Based Analysis of Monetary Policy for Current and Future EMU Members. Applied Economics 40, 193-199
Mussa, M., Masson, P., Swoboda, A., Jadresic, E., Mauro, P., Berg, A., 2000. Exchange rate regimes in an increasingly integrated world economy. IMF Occasional Papers
NBR, 2001. NBR (National Bank of Romania) Annual Report 2001. 63
NBS, 1999. NBS (National Bank of Slovakia) Menovy Program na Rok 2000 (Exchange Rate Program for the Year 2000).
Obstfeld, M., 1997. Destabilizing effects of exchange-rate escape clauses. Journal of International Economics 43, 61-77
Obstfeld, M., Rogoff, K., 1995. The mirage of fixed exchange rates. Journal of Economic Perspectives, 73-96
Paez-Farell, J., 2007. Understanding Monetary Policy in Central European Countries using Taylor-type Rules: The Case of the Visegrad Four. Economics Bulletin 5, 1-11
Peersman, G., Smets, F., 1999. The Taylor Rule: A Useful Monetary Policy Benchmark fo the Euro Area. International Finance 2, 85-116
Popper, H., Lowell, J., 1994. Officially floating, implicitly targeted exchange rates: Examples from the Pacific Basin. In: Glick R & Hutchison M (eds.) Exchange rate policy and interdependence: Perspectives from the Pacific Basin. Cambridge University Press, Cambridge.
Reinhart, C.M., Rogoff, K., 2004. The modern history of exchange rate arrangements: A reinterpretation. Quarterly Journal of Economics, 1-48
Reitz, S., Taylor, M.P., 2008. The Coordination Channel of Foreign Exchange Intervention: A Nonlinear Microstructural Analysis. European Economic Review 52, 55-76
Repse, E., 1999. Speech on monetary policy in Latvia and exchange rate strategies. In: Central Bank Articles and Speeches. BIS, Basel
Rogoff, K., Husain, A.M., Mody, A., Brooks, R., Oomes, N., 2004. Evolution and performance of exchange rate regimes. IMF Occasional Papers

Rozkrut, M., Rybinski, K., Sztaba, L., Szwaja, R., 2007. Quest for Central Bank Communication: Does it Pay to be Talkative? European Journal of Political Economy 23, 176-206

Sachs, J.D., 1996. Economic transition and the exchange rate regime. American Economic Review 86, 147-152

Sarno, L., Taylor, M.P., 2001. Official Intervention in the Foreign Exchange Market: Is It Effective, and if so, How Does It Work? Journal of Economic Literature, 839-868

Scalia, A., 2008. Is Foreign Exchange Intervention Effective? Some Microanalytical Evidence from the Czech Republic. Journal of International Money and Finance, 529-546

Schnabl, G., 2004. De jure vs. de facto exchange rate stabilization in Central and Eastern Europe. Aussenwirtschaft 59, 171-190

Stancík, J., 2007. Determinants of exchange rate volatility: The case of the new EU members. Czech Journal of Economics and Finance 57, 414-432

Svensson, L.E.O., 2000. Open-economy Inflation Targeting. Journal of International Economics 50, 155-183

Szapáry, G., Jakab, Z., 1998. Exchange rate policy in transition economies: The case of Hungary. Journal of Comparative Economics 26, 691-717

Taylor, J.B., 1993. Discretion versus Policy Rules in Practice. Carnegie-Rochester Conference Series on Public Politics, 195-214

Taylor, J.B., 2001. The Role of the Exchange Rate in Monetary Policy Rules. The American Economic Review 91, 263-267

Taylor, J.B., 2002. The Monetary Transmission Mechanism and the Evaluation of Monetary Policy Rules In: Loayza N & Schmidt-Hebbel K (eds.) Monetary Policy: Rules and Transmission Mechanisms. Central Bank of Chile, pp. 21-46.

Vitale, P., 2007. A Guided Tour of the Market Microstructure Approach to Exchange Rate Dermination. Journal of Economic Surveys, 903-934

Yilmazkuday, H., 2008. Structural Breaks in Monetary Policy Rules: Evidence from Transition Countries. Emerging Markets Finance and Trade 44, 87-97

Chapter 2

News, Liquidity Dynamics and Intraday Jumps: Evidence from the HUF/ EUR Market

News, Liquidity Dynamics and Intraday Jumps: Evidence from the HUF/EUR Market*

Michael Frömmel, Ghent University, BELGIUM[a]
Xing Han, Ghent University, BELGIUM[a]
Frederick Van Gysegem, Ghent University, BELGIUM[a]

Preliminary work: please do not quote or cite without permission of the authors.
This version: December 1, 2013

Abstract

We study intraday jumps on a pure limit order FX market by linking them to news announcements and liquidity shocks. First, we show that jumps are frequent and contribute greatly to the return volatility. Nearly half of the jumps can be linked with scheduled and unscheduled news announcements. Furthermore, we show that jumps are information based, whether they are linked with news announcements or not. Prior to jumps, liquidity does not deviate from its normal level, nor do liquidity shocks offer any predictive power for jump occurrence. Jumps emerge not as a result of unusually low liquidity but rather as a result of an unusually high demand for immediacy concentrated on one side of the book. During and after the jump, a dynamic order placement process emerges: some participants endogenously become liquidity providers and absorb the increased demand for immediacy. We detect an interesting asymmetry and find the liquidity providers to be more reluctant to add liquidity when confronted with a news announcement around the jump. Further evidence shows that participants submit more limit orders relative to market orders after a jump. Consequently, the informational role of order flow becomes less pronounced in the thick order book after the jump.

JEL: F31, G15

Keywords: microstructure, foreign exchange, jumps, liquidity, Hungary, limit order book

*We would like to thank the Bijzonder Onderzoeksfonds (Special Research Fund) of Ghent University for financial support and the Magyar Nemzeti Bank (Hungarian National Bank) for sharing the data. We would also like to thank Kris Boudt, William De Vijlder, Paolo Mazza, Lukas Menkhoff, Michael J. Moore, Thibaut Moyaert, Marliese Uhrig-Homburg, David Veredas and Christian Westheide for comments and helpful suggestions.

a Department of Financial Economics, Ghent University, St. Pietersplein 5, 9000 Ghent, Belgium

Chapter 2

News, Liquidity Dynamics and Intraday Jumps: Evidence from the HUF/EUR Market

1. Introduction

Jumps, which are significant discontinuities in asset prices, have been an important topic in financial research over the last few decades. Empirical research shows that jumps in financial time series are common and contribute greatly to asset volatility. As an integral part of the underlying price process, they pose extreme price risk for traders and they are of vital importance for risk management purposes.

Our study investigates intraday jumps on the exchange market and their relation to macroeconomic news releases and the liquidity dynamics of the limit order book. We study the interbank HUF/ EUR exchange market over a two-year sample period (2003 and 2004). First, we detect jumps and document their prevalence and size on an emerging foreign exchange market, which is characterized by relatively low trading volumes. In previous research, jumps have been related with macroeconomic news of various sorts. We investigate to what extent these results also hold for this market. Besides scheduled macroeconomic announcements, we also incorporate real-time, unscheduled announcements in our dataset. Furthermore, it has been put forward by Lahaye *et al.* (2011) that jumps which cannot be related to news announcements can be caused by insufficient market liquidity.

However, the concept of liquidity is elusive as it has multiple dimensions (Amihud 2002; Pástor & Stambaugh 2003; Acharya & Pedersen 2005). For example, Liu (2006) defines liquidity as the ability to trade large quantities quickly at low cost and with little price impact. Four dimensions, namely trading quantity (depth), trading speed (immediacy), trading cost (tightness), and price impact (resiliency) emerge from this definition. As one of our motives is to pin down the cause of the jump, we map the different dimensions of liquidity that can be observed in the limit order book, and investigate whether there is any systematic pattern prior to the jump. We find that the jump itself influences the behavior of market participants, and we shed a new light on how traders formalize
jump. We link our work with empirical regu
strategy, and investigate to what extent they still hold under extreme market conditions.

By definition, jumps are latent as they are an integral part of the price process, which makes them difficult to estimate. In their seminal work, Barndorff-Nielsen and Shephard

(2004) show that under maintained conditions the quadratic variation process could be decomposed into an integrated variation component and a jump component. Moreover, they provide two non-parametric measures of volatility designed for the discrete nature of empirical high-frequency data: realized variance and realized bipower variation. The former measures the quadratic variation while the latter measures the integrated variation. The difference between the two provides a consistent estimate of the jump component under maintained conditions. In their later work, Barndorff-Nielsen and Shephard (2006b) propose several finite sample jump detection statistics based on asymptotic distribution theory. Huang and Tauchen (2005) further provide extensive simulation evidence in support of the finite sample properties of these jump test statistics. The jump detection method has been applied in empirical researches of various settings. For example, Andersen *et al.* (2007a) confirm the existence of jumps in FX, equity and treasury markets and make important progress in the forecasting realized volatility by separating the jump component from its continuous sample path counterpart. Beine *et al.* (2007) find that coordinated interventions by central banks in FX markets cause fewer but more pronounced jumps after accounting for the announcement effect.

More recently, various attempts have been made to modify the jump identification method, so that it can pin down the exact timing of the jump at the intraday level. Andersen *et al.* (2007b) and Andersen *et al.* (2010) present a recursive jump detection method for identifying intraday jumps, thereby providing superior information on jumps. Alternative methods to detect intraday jumps have also been presented by Lee and Mykland (2008), Jiang *et al.* (2011) and Boudt and Petitjean (201x) among others.

The advances made in jump detection methods enjoy a burst of recent analysis on the link between macroeconomic fundamentals (news) and jumps on various financial markets. Huang (2007) confirms that jumps occur more frequently on news-days than on non-news days in US futures market. Focusing on US treasury market, Dungey *et al.* (2009) find that the majority of cojumps are associated with scheduled news releases, which is later confirmed by Jiang *et al.* (2011). Placing more emphasis on the general regularity of jump dynamics across different asset markets (US stock, Treasury and USD/EUR market), Evans (2011) documents that around one-third of the intraday jumps occur immediately after the release of news and that the informational shocks explain large proportions of the jump magnitude. In their seminal work, Lahaye *et al.* (2011) analyze the difference in size, frequency and timing of jumps across three US stock index futures, one treasury bond futures and four major currency pairs, and further link these dynamics to their likely sources (such as informational shocks).

Several stylized facts emerge from their work: first, foreign exchange markets experience significantly more jumps while the average jump magnitude is smaller compared to other asset markets. Second, the link between macroeconomic news and jumps is weaker in foreign exchange markets than in other asset markets, which Lahaye *et al.* (2011) attribute to the restricted news dataset and other possible sources of jumps such as idiosyncratic liquidity shocks commonly observed in the currency markets during the slow trading process.

Related high frequency studies have also examined the relation between liquidity dynamics of the market and jumps. Bajgrowicz and Scaillet (2011) find that trading volume, as a rough gauge of market liquidity, explains independently a small portion of jumps in the US stock market, as trading volume reaches its highest value during the 5 minute interval prior to the jump. Using a probit model, Jiang *et al.* (2011) confirm that lagged liquidity shocks are able to predict the occurrence of jumps after accounting for the effect of informational shocks. Using an event study approach, Boudt and Petitjean (201x) document that jumps are largely driven by a sharp rise in the demand for immediacy, as the number of trades increases dramatically prior to jumps, while market depth at the best price does not decay as commonly expected. To sum up, potential economic sources of jumps in financial markets include scheduled macroeconomic news, unscheduled news releases, and market liquidity shocks.

An independent strand in the microstructu submission strategies in limit order book markets : the classical make or (see Bloomfield *et al.* 2005, among others). On the theory side, Cohen *et al.* (1981), Glosten (1994), Seppi (1997), Harris (1998), Parlour (1998), Foucault (1999), Sandås (2001), Hollifield *et al.* (2004), Foucault *et al.* (2005) and Roku (2009) develop liquidity-based models of limit-order book. The main predictions of these models include that (1) the proportion of limit orders relative to market orders increases subsequent to a rise in asset volatility, (2) the proportion of limit orders relative to market orders increases subsequent to the widening of spreads, and (3) own side depth encourages the submission of market orders. On the empirical side, Biais *et al.* (1995), Griffiths *et al.* (2000), Ahn *et al.* (2001), Ranaldo (2004) and Cao *et al.* (2008) have provided consistent evidence with these predictions. More recently, experimental and empirical studies based on information-based models of the limit order book uniformly suggest that informed traders tend to use, under certain conditions, limit orders at the side where liquidity is needed (see Bloomfield *et al.* 2005; Kaniel & Liu 2006 , among others). Bloomfield *et al.* (2005) posit that, under certain conditions, informed traders change their order aggressiveness over the trading period by submitting limit orders at the side where liquidity is scarce as they are less subject to adverse selection costs.

Jumps are sudden price spikes that pose significant price risk to investors. Obviously, it is interesting to examine decisions under these extreme market conditions. Moreover, it is of great interest to test whether the predictions regarding traders’ order placement strategy still hold conditioning on the occurrence of jumps with and without macroeconomic news. In spite of the relevance of the topic, there are to the best of our knowledge no works that investigate the order placement strategies around intraday jumps.

Our article contributes to the empirical studies on jumps in at least three ways: First, we apply an established jump identification method to a small and less liquid exchange rate market in contrast to existing work which focuses on the most liquid major currency pairs such as USD/EUR and USD/GBP. Our aim is to examine to which extent the jump dynamics exhibited in these major currencies could be generalized to the other currencies, in particular the Hungarian forint. One could expect jumps would be more prevalent in the HUF/EUR market than in major exchange rate markets due to its illiquidity and relatively small market capitalization as examined in Frömmel *et al.* (2011). Our results confirm that jumps are large and prevalent in a relatively illiquid market such as HUF/EUR market. Around 18.2% of our sample days are identified as containing at least one intraday jump with the jump component contributing nearly one-half of the realized volatility during these jump days.

Secondly, we extend the announcement effect literature by investigating the link between jumps and news releases of various sorts. Our enlarged news dataset covers not only the scheduled macroeconomic news announcements, but also the unscheduled news announcements which will change investors’ enlarged news dataset also enables us to (informally) compare the relative importance of different news categories. Our results suggest that both scheduled and unscheduled news are related to jumps with the unscheduled news such as polls, surveys, forecasts and analysis on (future) fundamentals producing the most of the jumps (30.4%).

Thirdly, to the best of our knowledge, our work is the first to bridge the gap between jump-related literature and the order placement literature. Using event study methodology, we zoom in on the dynamics of various liquidity dimensions around jumps, providing a comprehensive picture on how the limit order book looks like before, during and after the jump. We are the first to do this for this type of analysis for the foreign exchange market. Furthermore, we test whether the predictions from limit order book models for order placement still hold under these extreme market conditions. We find only a very weak, if any, pattern in liquidity prior to jumps after controlling for the announcement effect. Consistent with Boudt and Petitjean (201x), we find that jumps do not emerge as a result of unusually low liquidity, but as a result of an unusually high demand for immediacy concentrated on one side of the limit order book, implying increased information asymmetry across traders during the jump period. Moreover, more limit orders are added to the ask (bid) side subsequent to a positive (negative) jump, confirming the existence of discretionary liquidity providers who supply liquidity at the side where it is needed the most. We also observe an interesting asymmetry in post-jump resiliency, which is clearly higher for negative jumps than for positive jumps. Finally, we perform an additional regression-type analysis to show that post-jump transaction order flow is less informative, as more limit orders relative to market orders are submitted to the order book subsequent to jumps. Overall, our results confirm the predictions from limit order book models: the submission of limit orders is encouraged by the widening of the spread and increased volatility caused by a jump.

To presage our results, the rest of the paper proceeds as follows. Section 2 describes a pure order-driven FX market in general and our unique dataset in particular. Section 3 explains our theoretical framework regarding the jump detection method. Section 4 presents our empirical findings regarding the jump dynamics and the announcement effect. Section 5 presents our event-study results on the liquidity dynamics around jumps. Section 6 provides further evidence on pre-jump and post-jump liquidity patterns. Section 7 concludes.

2. Data

The foreign exchange market

The foreign exchange market is a two-tier market. Trades on the foreign exchange market can be divided into customer trades, i.e. trades between a bank and customers (the ultimate end-users, for instance importing and exporting firms, mutual or hedge funds, governments and central banks) and interbank trades. In this work we focus on the interbank market, to which customers do not have access. It is here that the price formation takes place. The market is a pure order-driven market, without designated market maker. Participants can submit orders 24h a day. The majority of trades on this market are nowadays done via electronic broking systems. Since their introduction in 1992 their share in total transaction volume has steadily increased, depending on the country, from 4 to 6 per cent in 1995 to more than 55% of the interbank market in 2010 (BIS 1996, 2010).[14]

There are two main platforms competing in the foreign exchange market: Reuters D3000 and EBS (Electronic Broking System). In our analysis we rely on the Reuters D3000 system. As an electronic limit order book it contains buy and sell orders in a price-time priority. Euro sale and purchase offers are placed at limit prices. Besides these limit orders, consisting of the maximum respectively minimum price and the quantity offered to be traded, it is also possible to place a market order, i.e., an order without a specified price. They are immediately matched with the best corresponding limit order and thus more aggressive. While limit orders add liquidity to the limit order book, market orders take liquidity from the book. The following matches may lead to a trade: two limit orders that are matched up by the system, or a market order that is matched up with the best limit order on the opposite side.

The HUF/EUR market

Our dataset consists of all quotes, i.e., limit and market orders, on the HUF/EUR interbank market that have been placed during the years 2003 and 2004 via the Reuters D3000 broking system. Because at this time the competing system EBS did not offer services for the HUF/EUR market, the dataset covers the complete trading on electronic brokerage platforms, and thus the major part of the total market activity (which would also include OTC trades). The HUF trade accounted during or sample period for only 0.22% of the global turnover on the FX market (BIS 2005). This dataset was also described in Gereben and Kiss M. (2006). In Table 1 we present various summary statistics for the activity on this market, such as the number of quotes and trades and the distribution over trade size for the whole sample period and for each year individually.

The reconstruction of the limit order book

Our dataset contains the price, the quantity in euro that was offered or asked, whether it was a market or a limit order and the exact time when the order was placed and when it disappeared. We observe whether the order was withdrawn or whether it was executed, i.e., matched with another limit or market order. We do not observe the identity of the traders.Our analysis requires information on the state of the limit order book at the intraday level. We therefore reconstruct the order book, and update it whenever a new event occurs (limit order submission, market order submission, limit order cancellation). When a new limit order is

[14] The share of electronic trading in interbank trading is by some authors even estimated at 85% of the total interbank activity (Sager & Taylor 2006).

submitted, the order book is (re-)calculated by adding all activated limit orders to the relevant side of the book.[15] When a new market order is submitted, it is verified whether the activated orders that leave the book upon submission of the order cover the market order. If not, the liquidity available for the activated limit orders at the opposite side of the book is adapted. A marketable limit order is treated in the same way as a market order, but if it has not been filled completely it will stay in the book with a reduced volume. [16] Cancelation of existing limit orders is also taken into account: it is verified whether orders leave the book before the next order is submitted to the trading platform. Each time this happens, a new event is identified and added to the time series of limit order book states. The event time will here be the removal time of the order. To obtain the new order book state the post-event orders are sorted according to price and time priority.

The output of the limit order book reconstruction process is a series of observations in event-time, with for each event a timestamp at 10 ms. precision and all orders at the bid and ask side (with their respective quotes, quantities, record numbers, entering and removal times). For very short periods zero or negative spreads can be observed. Their presence can be explained by the absence of clearing agreements between certain banks (in this case, the two banks who have posted the best orders at the respective sides of the book do not have such an agreement). As other banks, which do have clearing agreements with the issuers of the best orders from both sides, can take advantage of this situation, these zero or negative spreads are short-lived.

We leave out legally recognized holidays in Hungary and weekends.[17] Figure 1 shows graphically the evolution of the HUF/EUR quote and the volume traded via the electronic limit order book. Furthermore, we only use data from 7am till 7pm CET. Figure 2 shows the bimodal intraday distribution of ticks (with e.g. the quantity of ticks displayed at 5 containing all ticks between 5am till 6am). After the time filter, we still cover almost the complete market activity. Table 2 shows key characteristics of the orders submitted to the market over the sample period, split up per half-year. The type of orders is shown to be very stable over time: 15-16% of the orders are market orders, 54-60% of the orders are limit orders which are cancelled without execution and 25-30% of the orders are limit orders which are partly

[15] Activated orders are the orders which have been entered before the event time, and which have not left the book at the event time. Activated orders should not be confused with active orders (i.e. orders which initiate a trade).

[16] A marketable limit order is a limit order that can be immediately executed, because its price is equal to or better than the best quote from the opposite side of the book.

[17] For 2003 these were: 1/01, 15/03, 21/04, 1/05, 9/06, 20/08, 23/10, 1/11, 25/12 and 26/12. For 2004 these were: 1/01, 15/03, 12/04, 1/05, 31/05, 20/08, 23/10, 1/11, 25/12 and 26/12.

matched with market orders or with marketable limit orders. This implies that only 30-35.20% of the limit orders are executed to some extent. This share is fully in line with what has been found for the GBP/ USD and the EUR/ GBP pair, for which the identical ratio was respectively 36.10% and 27.50% over 2003 and 2004 (Kozhan *et al.* 2012). Cancellations are used strategically by foreign exchange traders: they are used to display liquidity which is removed before it can be taken, but also environment. When we look to the order size, we find that major part (71-79%) of the orders have a size of ú 1 mi The fact, that trades for the minimum size minin dominate is consistent with a widespread use of order splitting strategies by traders (in an attempt to minimize the market impact, see also Kyle (1985). Table 3 presents basic descriptives of the limit order book. The quoted spread increases in the second half of 2003 (from 0.31 to 0.39 HUF/EUR) and decreases in 2004 (till 0.24 HUF/EUR). The average breadth (the quantity available at the best quote) is, interestingly, always bigger on the bid side. The same accounts for the average depth over the whole order book. In the second half of 2003 and the second half of 2004 we observe a sudden and large increase in depth at the bid side. This unusually high depth is caused by positive outliers: in the periods 24/9/2003-9/10/2003 and 10/11/2004-31/12/2004 there are unusually high orders added to the bid side (however, away from the best quote). The number of price levels at the bid side is on average 6-7. At the ask side there seems to be a slight increase in the average number of levels (from 5.64 in the first half of 2003 till 7.35 in the second half of 2004).

The advantage of our dataset for the analysis of jumps and their link with liquidity is threefold. First, on the foreign exchange market orders can be submitted on a continuous basis. There are, in contrast to for example equity markets, no opening or closing sessions that can affect the data. As the observed price and liquidity can never be driven by these artificial operations, the dynamics between announcements and liquidity should become clear more easily. Secondly, we are able to observe the complete liquidity as there are no orders which display only part of their total volume (iceberg orders). By consequence we have a clear view on the supply and demand on the market. Thi activity on the HUF/EUR market (most of the trading activity on the HUF/EUR market takes place via electronic limit order books, and we completely cover this form of trading). Compared to other studies, our dataset is unusually rich. This is to our knowledge the only study in which a complete tick-by-tick database and a full order book over a timespan as long as two years is used for the foreign exchange market.

3. Methodology

3.1. Jump Detection

Realized variance and Bipower variation

We assume that the log-price $p(t)$ of the underlying asset follows a continuous-time jump-diffusion process (i.e. a Brownian semimartingale with finite jump process), as is traditionally used in asset pricing (Andersen et al. 2007b; Lee & Mykland 2008; Evans 2011):

$$dp(t) = \mu(t)dt + \sigma(t)dW(t) + k(t)dq(t), \quad 0 \le t \le T \qquad [3.1]$$

where $\mu(t)$ is the continuous and bounded drift term, $\sigma(t)$ a strictly positive stochastic volatility process with a sample path that is right continuous and has well defined limits, $W(t)$ a standard Brownian motion, $q(t)$ is a counting process with possible time-varying intensity $\lambda(t)$ (which implies $P[dq(t) = 1] = \lambda(t)\,dt$), and $k(t) \equiv p(t) - p(t-)$ is the size of the corresponding discontinuous jump in the underlying log-price movement, provided the jump exists.

Given the above theoretical setup, the quadratic variation (QV) for the cumulative return process over a fixed time interval T, consists of both, the continuous volatility component and the contribution of jumps to volatility. It is defined as:

$$QV_T = \int_0^T \sigma^2(t)\,dt + \sum_{0 < t \le T} k^2(t) \qquad [3.2]$$

According to Barndorff-Nielsen and Shephard (2004), a non-parametric measure of the daily return variation, realized variance (RV), is defined as the summation of the M high frequency intra-daily squared returns within day i:

$$RV_i = \sum_{j=1}^{M} r_{i,j}^2 \qquad [3.3]$$

where $r_{i,j}$ is the return in the interval j out of M intervals on day i.[18]

Based on the theory of quadratic variation (Barndorff-Nielsen & Shephard 2004, 2006a), realized variance converges to its probability limit, the increment of the quadratic variation process as the sampling frequency M tends to infinity:

[18] We refer to r_i as the return on day i, and to r_{ij} as the return in interval j on day i. Therefore daily and intradaily returns are linked by $r_i = \sum_{j=1}^{M} r_{i,j}$, with a total of M subintervals for each day.

$$RV_t \rightarrow \int_{t-1}^{t} \sigma^2(s)\,ds + \sum_{t-1<s\le t} \kappa^2(s) \qquad [3.4]$$

Therefore, the realized variance is a consistent estimator of the total return variation regardless of the existence of within-day jumps.

To decompose the continuous sample path component from the *QV* process, Barndorff-Nielsen and Shephard (2006a) introduce the scaled realized bipower variation (*BPV*), defined as the summation of the product of adjacent absolute high frequency returns standardized by a constant:

$$BPV_t = \mu_1^{-2} \sum_{j=2}^{M} |r_{t,j}|\,|r_{t,j-1}| \qquad [3.5]$$

where $\mu_1 = E(|u|) = \sqrt{2/\pi}$ and $u \sim N(0,1)$.

Under some further assumptions[19] regarding the underlying log-price dynamics in equation [3.1], the (scaled) realized bipower variation converges uniformly in probability to the integrated volatility as *M* tends to infinity (for a proof see Theorem 2 in Barndorff-Nielsen and Shephard (2004)):

$$BPV_t \rightarrow \int_{t-1}^{t} \sigma^2(s)\,ds \qquad [3.6]$$

Therefore, the difference between the realized variance and the (scaled) realized bipower varition provides a consistent estimation of the pure jump contribution to the quadratic variation process within the day, as *M* tends to infinity:

$$RV_t - BPV_t \rightarrow \sum_{t-1<s\le t} \kappa^2(s) \qquad [3.7]$$

Based on the relation between realized variance and bipower variation it is then possible to construct tests for the occurrence of jumps, see Huang and Tauchen (2005) for a survey. We rely on the ratio test statistics (*Z*) to identify statistically significant jumps (See Huang and Tauchen 2005):

[19] As is further demonstrated in Barndorff-Nielsen and Shephard (2006a), the only additional assumption required is that the stochastic volatility $\sigma(t)$ is independent of the standardized Brownian motion $W(t)$ in equation [3.1]

$$z = \frac{(RV_t - BPV_t)\,RV_t^{-1}}{\sqrt{\left(\left(\frac{\pi}{2}\right)^2 + \pi - 5\right)\frac{1}{n}\max\left(1, \frac{TQ_t}{BPV_t^2}\right)}} \rightarrow N(0,1) \qquad [3.8]$$

with the tripower quarticity (TQ) defined as

$$TQ_t = n\,\mu_{4/3}^{-3} \sum_{j=3}^{n} |r_{t,j}|^{4/3}\,|r_{t,j-1}|^{4/3}\,|r_{t,j-2}|^{4/3} \qquad [3.9]$$

Where $\mu_{4/3} = 2^{2/3}\,\Gamma(7/6)\,\Gamma(1/2)^{-1} = E(|Z|^{4/3})$, $Z \sim N(0,1)$

Under maintained assumptions, equation [3.8] implies that the ratio statistic follows standard normal distribution. Following the literature we set the significant level to α = 0.0001 and therefore the critical value is $\Phi^{-1}_{0.9999} = 3.719$.

Microstructure noise and jump measurements

In practice, the assumed regularity of the log-price movement is contaminated by market microstructure frictions such as discrete price tick, bid-ask spread bounce and etc. On the one hand, the existence of microstructure noise in the underlying log-price process renders realized variance an inconsistent estimator of its probability limit (the quadratic variation) (Andersen et al. 2007b). On the other hand, both the realized bipower variation and tripower quarticity are biased against the finding of significant jumps due to the noise-induced first-order autocorrelation revealed in the high frequency return series. To alleviate the adverse effect of microstructure noise on jump detection scheme, we tackle the problem in two ways: first, we choose a ten-minute sampling frequency at which the microstructure frictions no longer present a distorting influence on realized variance (Andersen et al. 2010)[20]. Second, we modify the calculation of realized bipower variation and tripower quarticity by replacing the adjacent absolute returns in equation [3.5] and [3.9] with their staggered counterparts to break up the spurious autocorrelation pattern observed in the high frequency return series (similar to Andersen et al. (2007a); Beine et al. (2007); Evans (2011); among others):

[20] The volatility signature plots in Andersen *et al.* (2010) suggests that a systematic decline pattern in the realized variance measure as the sampling frequency increases in the range of 5 to 300 seconds, which destabilizes our measurement of *RV* (and hence the difference between *RV* and *BPV*), therefore, a 10-minute sampling scheme seems an appropriate, albeit somewhat conservative, method to control microstructure noise.

$$BV_{1,i} = \mu_1^{-2}\frac{M}{M-2}\sum_{j=3}^{M}|r_{i,j}||r_{i,j-2}| \quad [3.10]$$

$$TQ_{1,i} = M\mu_{4/3}^{-3}\frac{M}{M-4}\sum_{j=5}^{M}|r_{i,j}|^{4/3}|r_{i,j-2}|^{4/3}|r_{i,j-4}|^{4/3} \quad [3.11]$$

The staggered version of realized bipower variation and tripower quarticity is then used in equation [3.8] to compute the new ratio test statistic for jump detection. Huang and Tauchen (2005) show that the ratio Z-statistic with staggering offers improved size and power properties in finite sample simulation and is quite robust to the size of microstructure noise.

When the null hypothesis that there is no intraday jump is rejected based on the daily test statistic, we apply the sequential intraday jump detection scheme proposed by Andersen et al. (2010) to identify all the intraday jumps and their associated timing within the day. [21] This sequential intraday jump detection scheme consists of several steps. If the ratio statistic (*Z*) is significant at day *i*, we first assume that only one intraday return contributes to the significant *Z*-stat and then proceed as follows:

Step 1: We record the significant ratio statistic Z_i and extract the series of the *M* intraday (geometric) returns $\{r_{i,1}, r_{i,2}, \ldots, r_{i,M}\}$ within day *i*.

Step 2: For each intraday return $r_{i,j}$ ($j = 1, 2, \ldots, M$) at day *i*, we generate a modified series $\{r_{i,1}, r_{i,2}, \ldots, r_{i,-j}, \ldots, r_{i,M}\}$ by replacing the *j*th element with the average of the remaining *M-1* returns (denoted as $r_{i,-j}$) while keeping the rest unchanged. Then we recalculate the *RV* measure and its corresponding *Z*-stat (denoted as Z_i^{j}) with the following two formulas:

$$RV_i^{j} = \frac{M}{M-1}\sum_{k=1,k\neq j}^{M} r_{i,k}^2 \quad [3.12]$$

$$Z_i^{j} = \sqrt{M}\,\frac{(RV_i^{j} - BV_{1,i})(RV_i^{j})^{-1}}{\sqrt{(\mu_1^{-4} + 2\mu_1^{-2} - 5)\max(1, TQ_{1,i}BV_{1,i}^{-2})}} \sim N(0,1) \quad [3.13]$$

[21] Jiang and Oomen (2008) and Jiang *et al.* (2011) use a similar sequential jump identification scheme with the slight difference that they use the median of the remaining intraday returns to calculate the revised ratio statistics.

Hence, we obtain a series of *M* revised *Z*-stats $\{Z_i^{(1)}, Z_i^{(2)}, \ldots, Z_i^{(M)}\}$ for the *i*th sample day.[22]

Step 3: We calculate the differences between the original *Z*-stat and (each of) the new *Z*-stats $\{Z_i - Z_i^{(1)}, Z_i - Z_i^{(2)}, \ldots, Z_i - Z_i^{(M)}\}$. The significant jump return $r_{i,j}$ is identified when the following mathematical expression achieves its maximum.

$$\hat{Z}_i = \arg\max_{j \in \{1, \ldots, M\}} \left(Z_i - Z_i^{(j)} \right) \quad [3.14]$$

Step 4: We retain the revised *Z*-stat ($\hat{Z}_i$) identified in Step 3. If $\hat{Z}_i$ is less than the pre-set critical value, we conclude that there is only one jump on day *i*. However, if it still exceeds the critical value, we then assume that a second intraday jump exist on day *i* and start over again from Step 1 to Step 4 with the new geometric return series $\{r_{i,1}, r_{i,2}, \ldots, r_{i,j-1}, r_{i,j+1}, \ldots, r_{i,M}\}$ of *M-1* elements.[23]

The above recursive procedure continues until all the intraday jumps within day *i* are identified. In this way, we are able to detect all the intraday jumps throughout the 2-year sample period.

3.2. Event study methodology

Following the literature, we analyze the intraday liquidity dyanamics around jumps using the intraday event study methodology in Section 5 (see Boudt & Petitjean 201x; Gomber *et al.* 2013; Mazza 2013 , for similar application). We employ a variety of liquidity measures commonly used in the empirical literature to capture the different dimensions of the market liquidity (eg. Boudt & Petitjean 201x; Mazza 2013). Appendix I gives a full-fledged definition of all the liquidity measures used in the study.

The event study approach proceeds as follows: first, we construct a centered jump event window which includes the six 10-minute intervals before and after the jump event. Second, we exclude intraday jumps which are clustered in time in order to avoid contagion effect. That is, when two jumps occur within the same day, they must be separated in time by at least two hours. Otherwise, both of the jumps are excluded from our sample. For similar concerns, days

---

22 Following Andersen *et al.* (2010) and Jiang *et al.* (2011), we do not change the value of *BPV* and *TQ* based on the revised intraday return series. The theoretical justification is that *BPV* and *TQ* are asymptotically robust to the existence of jump(s).

23 More generally, after identifying *n* jumps (*n*>1), we filter out the *n* significant jumps to obtain a new series of geometric returns with *M-n* elements. The revised *RV* measure is then computed by first summing up the squared returns of the remaining *M-n* elements, and then scaling the summation by a factor of *M/*(*M-n*).

with three or more jumps are also excluded from the final sample. Third, all liquidity measures are standardized to make them comparable across days and intraday periods. Given the fact that liquidity measures are highly skewed at the intraday level and have strong seasonal patterns, we opt for the novel standardization procedure highlighted in Boudt and Petitjean (201x). Appendix II provides a detailed description on the standardization procedure. Fourth, we aggregate across individual jump events for a single point estimate. We favor the median value, rather than the mean value, of the standardized liquidity measure across individual events as our point estimator. The rationale behind our preference is well-grounded. First, liquidity measures such as number of trades, trading volume, and depth (per ten minutes) have a lower bound of zero, while in theory they do not have an upper bound. Therefore, the distribution of their standardized value remains highly skewed, which is also confirmed in our sample. Second, as argued by Boudt *et al.* (2011), the median of the standardized liquidity measures on non-jump days will be 1 for depth and volume measures and 0 for order and depth imbalance measures by construction. In that case, the interpretation of the median of the standardized liquidity measure is quite straightforward: it shows the (percentage) deviation from the typical levels during the same time of the day. Fifth, a Wilcoxon rank sum test on the median is performed to evaluate the null hypothesis that price jumps do not have any effect on liquidity. In order words, liquidity measures tend to stay at their normal level around jumps (median value of the standardized liquidity measures is zero). The alternative hypothesis is that liquidity measures are either abnormally lower or higher than their normal level around jumps.

It is important to mention that we explicitly distinguish between positive jump events and negative jumps events, as positive jumps are mostly linked with large market buy orders combined with the paucity of liquidity at the ask side while negative jumps are linked with large market sell orders combined with the paucity at the bid side. In other words, we expect the liquidity dynamics around positive jumps and negative jumps to mirror each other in the mechanical sense: what we, for example, see on the bid side during a positive jump interval should be compared with what we see on the ask side during a negative jump interval. Therefore, we distinguish in our final event study between positive jump events and negative jump events. For each category, we further divide them into positive (negative) jumps events associated with news announcements and positive (negative) jumps events without news announcements.

4. Jumps and news announcements

Prevalence and size of jumps

In this subsection, we investigate the jump intensity and magnitude for the HUF/EUR rates, which is a relatively illiquid market compared to major currencies such as USD/EUR. The results are summarized in Table 4. We detect 90 realized jump days with at least one intraday jump. There are 125 intraday jumps in total (see Table 5). The jump intensity ð defined as the ratio of realized jump days to total trading days ð is 18.2% for our sample period, which is quite similar to the jump frequency found in prior literature on the major currency markets: Beine *et al.* (2007) report a jump intensity of 10% ï13% for the USD/EUR and JPY/USD markets between 1987 and 2004. Andersen *et al.* (2007a) document a 14% jump frequency for the DEM/ USD rates between 1986 and 1999. Lahaye *et al.* (2011) report that the jump frequency lies within the range of 22% ì25% for the USD/EUR, USD/GBP, USD/JPY and USD/CHF markets between 1987 and 2004. We further find that the average time length between two jump days (in the li
is 6.6 days. We also calculate to what extent the jump component contributes to the realized variance on realized jump days. On average, 42.59% of the price variation on jump days can be attributed to jumps. This is also in line with previous work on major currencies. For example, Evans (2011) report a jump contribution of 35.80% on the the USD/ EUR market.

When comparing positive and negative jumps (see Table 5), we find that the differences both in terms of frequency and magnitude are small and not statistically significant. Therefore, we can conclude that jumps are symmetric in terms of both frequency and size. This is consistent with previous research on major currency markets (Lahaye *et al.* 2011).

We find that intraday jumps are concentrated on two periods, one in the morning (between 8:00 and 8:20 (CET)) and one in the afternoon (between 15:50 and 16:50 (CET)). We see that 66.67% of the jumps takes place during these timespans.

Jumps and public news announcements[24]

By theory, price tends to jump to the new equilibrium level immediately after new information (shocks) has been revealed to the market. Therefore, one obvious source of jumps is prescheduled macroeconomic news. These announcements represent potential shocks to the market if the statistics released do not match the market expectations.[25] Previous research in

[24] The data on news announcements is collected from the Dow Jones Factiva database, which contains all the historical (news) data from the leading newswires such as Reuters and Dow Jones newswires.
[25] Unfortunately, we cannot observe the surprise component of the announcement.

this field suggests that nonfarm payroll, central bank announcements, and trade balance shocks are the major news items that are most closely linked with foreign exchange jumps (Neely 2011). In this work, we also adopt a variety of macro news items such as the releases of GDP, PPI and trade balance information in Hungary and the European Union. To account for possible cross-currency pressure such as cojumps and global liquidity shocks (see Banti *et al.* 2012), we also include the macroeconomic announcements from the United States, leading EU countries such as Germany and France, and neighbouring CEEC countries such as Poland.[26, 27] Following Lahaye *et al.* (2011), we attribute the jump occurrence to a news event using a 60-minute matching window centered around the jump. That is, if a news event takes place between the 30 minutes before and 30 minutes after the jump interval, we assume that the jump is directly linked with it. Table 6 summarizes our findings for the 125 intraday jumps we identified. We can link 16% of the detected jumps with scheduled news announcements. The conditional probability of observing a jump given a particular sort of news item is the highest for GDP releases for Hungary (25%), followed by inflation releases for Germany (8.33%) and inflation releases for Poland (8.33%). Given a jump, there is no clear pattern as which type of news has a high probability of having caused the jump (not a single type of news has a higher conditional probability than 1.60%).

In addition to linking jumps with prescheduled macroeconomic announcements, we also investigate the linkage between unscheduled news announcements and the jumps. The theoretical justification behind is that real-time news reports also influence market participantsô expectatio exchange rates. A more detailed fundamenta illustration on the theoretical underpinning of the exchange rate determination is given in (Evans & Lyons 2005). Following Copeland (2005), we restrict the potentially relevant, unscheduled news items to one of the following categories of news reports: 1) central bank interventions, 2) polls, surveys, forecasts, analyses by financial institutions and leading economists, and 3) political changes and/or natural disasters. Table 7 presents our results in

[26] The motivation for incorporating macroeconomic announcements for other economies is two-folded. First, market participants form their expectations on macroeconomic statistics for the European Union based on the release of national statistics, which takes place earlier than the release of the aggregated statistics. Secondly, recent empirical evidence on cojumps on foreign exchange markets showed that fundamental shocks to one currency pair can put substantial risk on linked markets (Lahaye *et al.* 2011; Neely 2011).

[27] Our list of the prescheduled macroeconomic news items is comprehensive. We include CPI, GDP, current account balance, public sector balance, MPC meetings-base rate decisions, retail sales for Hungary; PPI, CPI, GDP, unemployment rate, retail trade, indusrial production, current account balance, public sector balance, external trades, labor costs, M3 for EU, Germany and CEEC courntries (if available); PPI, CPI, non-farm payroll, GDP advance, GDP preliminary, GDP final, trade balance, industrial production, umemployment rate, consumer confidence, new home sales, construction spending, ISM index for the US. Contrary to the conventional wisdom, US non-farm payroll, GDP releases and unemployment rates do not cause any jumps during our sample periods.

detail. We can link a significant part of the jumps (30.4%) with unscheduled news announcements. Amongst the 15 largest jumps, 4 jumps can be explained by this type of news (as much as the number of jumps that can be explained by scheduled macroeconomic news announcements). Overall, our results suggest that unscheduled, real-time news is another important source of jumps. Still, nearly half of the jumps remain unexplained, which is possibly due to the prevalence of private information in the FX market. Informed traders capitalize on their private information by taking up the liquidity of the order book, forcing the price to jump to a new level. Section 5 and 6 provide more in-depth evidence on our conjectures of informed trading by examing the liquidity dynamics around the jump.

5. Jumps and liquidity dynamics

In addition to investigating the link between public news and jumps, a proper understanding of jumps and where they come from requires an in-depth analysis of the interaction that takes place in the book around jumps. Conventional wisdom suggests that a jump reflects the inability of the limit order book to absorb relatively large market orders quickly. Therefore, large market orders have to walk up or down the book for execution. However, this mechanical view neglects the role of limit order flows when a jump occurs. In fact, the limit order book is a platform where interaction, among informed traders, market makers (liquidity providers) and noise traders, takes place via market and limit orders. The sudden increase of volatility impacts the liquidity of the market as traders (dynamically) revise their order placement strategy (such as order aggressiveness and order size). Therefore, built on theoretical models of the limit order book developed in previous research (Glosten 1994; Foucault 1999), we further develop hypotheses on the dynamic relation between price jumps and the different dimensions of liquidity.[28] We compare our findings with results for Dow Jones stocks, and these are currently the only other results for this type of analysis.

In this section we describe the liquidity dynamics prior to, during and after jumps, incorporating both the mechanical and dynamical view (as they both can matter). The findings in this section shed a new light on what the cause is of jumps, whether there is a stylized liquidity pattern that preceeds jumps and how the jump affects the interaction that takes place. We apply here the event study approach (cf. supra). We are concerned about potential

[28] Here we use a broader definition of news, which includes now also private news such as the customer order flow observed by the market participant. The assumption that jumps are information-based is supported by the fact that we observe an increased imbalance of the order flow during jumps, which is a common proxy for information. Additional evidence can be found in the price reversal pattern after the jump (See Figure 4)

contagion between individual jumps, and therefore exclude jumps which are clustered. After the filtering procedure (cf. supra), 80 intraday jumps remain in our sample. These jumps will be used for the liquidity analysis. For clarification purpose, we present here mainly the liquidity dynamics around positive jumps as the liquidity dynamics around positive jumps and negative jumps mirror each other.[29] The detailed results can be found in Table 8 (positive jumps) and Table 9 (negative jumps).

Figure 5 till Figure 13 present boxplots for various indicators on the state of the limit order book (and this for each 10 minute interval from 1 hour prior to the jump till 1 hour after the jump). The central mark is the median, and the edges of the box are the 25th and 75th percentiles. The whiskers point at the most extreme observation which is still no outlier.[30]

5.1 Liquidity dynamics prior to the jumps

Hypotheses: origin of jumps

Previous literature suggests that lagged liquidity shocks in the order book such as a widened spread, decreased market depth and levered number of trades indicate the occurrence of jumps (Boudt & Petitjean 201x; Jiang *et al.* 2011). Our event study setting provides a straightforward way to validate the above predictions. In case there are pre-jump liquidity shocks, we should observe the median value of some liquidity variable during the pre-jump periods to be significantly different from zero. We distinguish three potential relations between preceding liquidity in the book and the occurrence of jumps:

H1: A price jump will occur when the liquidity in the limit order book is unusually low, and cannot absorb a normal market order flow.
H2: A price jump will occur when the liquidity in the limit order book is normal, and the market order flow is unusually high.
H3: A price jump will occur when a high level of liquidity triggers an even higher flow of market orders which cannot be absorbed by the liquidity in the limit order book.

[29] And where this is not the case, we mention it explicitly.
[30] Observations are considered to be outliers if they are larger than $q_3 + 1.5*(q_3-q_1)$ or smaller than $q_1-1.5*(q_3-q_1)$ with q_1 is the 25th percentile and q_3 is the 75th percentile.

Results

Prior to a positive jump, there is no significant change in the size-weighted proportional quoted spread (tightness).[31] Nor do we observe any strong trend in trading activies during the 60 minutes prior to the jump, as trading volume stays at its normal level and transactionorder flow is balanced (immediacy). Furthermore, the volume of outstanding limit orders (both overall and at the best quote) on the side that has to absorb the jump shows no universal pattern in the 60 minutes prior to the jump (depth and breadth). This supports H2. Our findings have implications for the predictability of jumps based on the liquidity in the book, a topic that we explore further (See: 6.1 Predictability of jumps using probit analysis).

5.2 Liquidity dynamics during and after the jump

Hypotheses: interaction during jumps

In order to interpret our observations during and after the jump, we introduce here three types of participants, who follow each different order placement strategies (if any). Participants can at each point of time be classified according to the strategy they are following. Especially on this type of interbank market, the same agent can apply different strategies depending on his specific sitation at that time.[32] We formulate ex ante predictions on the overall outcome of a dynamic order placement strategy by these heterogenous agents.

We distinguish respectively:

- *Informed traders:* Participants who act on private information on the future evolution of an asset, like they are introduced in Kyle (1985). On the foreign exchange market, their information can be based on the customer order flow (Rime 2000). Informed traders can be patient (and submit aggresive limit orders) or impatient (and submit market orders). The motivation for informed traders to be patient includes lower price impact.[33] They will, however, be impatient when their information is short-lived, or, following Bloomfield *et al.* (2005), when their private valuation lies outside the range of the inside quotes. Both patient and impatient informed traders can be present at the same time on the market, because they can have heterogenous private beliefs.

[31] We rely on the size-weighted spread, as this measure overweights (underweights) firm (non-firm) quotes.
[32] In that sense, trader identities would here not be very informative.
[33] Evidence for the existence of patient informed traders can be found in, amongst others, Eisler *et al.* (2011) and Hautsch and Huang (2012). In these works it is shown that limit orders contain information, as they have a permanent price impact.

H4: The presence of patient informed traders will, upon arrival of positive (negative) information, lead to increased submission of limit orders at the buy (sell) side, against competitive quotes.

H5: The presence of impatient informed traders will, upon arrival of positive (negative) information, lead to increased submission of market buy (sell) orders.

¶ *Market makers:* Participants who primarily provide liquidity to the market. Although there are no designated market makers on the interbank foreign exchange market, participants can be attracted by the profit market making offers. The idea that a market making role emerges from the trading process is also referred to as endogenous liquidity provision.[34] Market makers set a spread between the best buy and best sell. This is the source of their revenues. When setting the spread, they take the following costs into account: order processing costs (representing per unit administration costs and fixed costs such as wages, floor space rent, é), inventor of holding an unwanted inventory) and adverse selection costs (a compensation for the risk of trading with a better informed counterparty).[35] They will typically submit competitive limit orders. After a jump, which we found to be trade induced in the previous paragraph, the spread rises in a limit order book because the market orders are highly imbalanced and one side of the market gets depleted. Market makers are attracted by this high spread and post limit orders.[36] This increase in supply of liquidity will improve the best prices, and will bring the spread back to its equilibrium value (eg. Goettler *et al.* 2005).

H6: The presence of market makers will, upon arrival of information, lead to an increased provision of liquidity at the market.

¶ *Noise traders:* Participants who do not trade based on information, but trade based on their liquidity needs. Their part of the flow is balanced over time. We do not observe noise traders in our results, as we only measure unexpected trading flows and unexpected liquidity.

[34] For a recent work dealing with the behaviour of endogenous liquidity providers in comparison to designated market makers, see Anand and Venkataraman (2013).

[35] For an analysis of the importance of these components on this market, see Frömmel and Van Gysegem (2012).

[36] As a consequence of this increased liquidity provision, the market enters then again a phase of high liquidity (which will afterwards again be taken away). This sequence of high liquidity ïlow liquidity is also referred to as a liquidity cycle (See e.g. Foucault *et al.* 2013) .

Results: tightness

As jumps appear to be trade-induced, the trading volume increases during a jump interval. The higher number of transactions consumes the liquidity available in the market, and the spread will consequencly in a mechanical way go up. Moreover, liquidity providers tend to place limit order further away from the midquote, to avoid being picked off due to the increased price risk. However, the widening of the spread in combination with the paucity of liquidity at one side of book makes it more rewarding to provide liquidity. Discretionary liquidity providers see which side of book requires liquidity and will submit more limit orders to this side. These limit orders are designed to benefit from the increased demand for immediacy.

This is also what we observe. During the jump, the spread increases with 25.09%. We see that liquidity providers are attracted by this spread, and bring it back to its normal level 20 minutes after the jump (H6). The spread returns slightly quicker to its normal level after negative jumps.

Results: immediacy

Previous theoretical work predicts that order submissions tend to be clustered over time (amongst others, Kyle 1985; Admati & Pfleiderer 1988; Wang 1994). These findings were empirically confirmed by amongst others Campbell *et al.* (1993) and Covrig and Ng (2004). One could expect that by consequence an increase in volume traded will persist for some time after the jump. However, as spreads remain high after a jump, transactions are more costly. This high spread will impact traders submitting less aggressive limit orders.

During a jump, market order submissions in the direction of the information increase drastically. As a result, the order flow gets more asymmetrical (with an increase of the imbalance with 57.89% towards more buy orders), and the trading volume increases by 180%. (H2, H5)

The increased trading activity continues up till 20 minutes after the jump, but there is no sign of order flow imbalance ex post positive jumps. Thus, it seems like the increased trading after the jump is more balanced. The increase in trading activity is smaller after negative jumps, and the activity also returns faster to its normal level.

Results: depth and breadth

Mechanically, one would expect that the depth and breadth become unusually low at one side of the book during a jump, because informed traders are using the liquidity in one side of the book. Within the framework of a dynamic limit order market, like it was developed by Foucault (1999) and Foucault *et al.* (2005), the increase of price risk caused by increased volatility is due to an increase in the information asymmetry across traders. Consequently, we expect an increase in the placement of limit orders relative to market orders (and thus an increase in depth) immediately after the jump. Patient traders would then make the book thicker at the opposite side. At the same time, the liquidity provision by market makers could restore the liquidity after the jump.

This is also what we see in the data. At the ask side we find that the depth decreases with 23.04%, due to the increased arrival of one-sided market orders (H5). At the same time, the total depth at the bid side is found to be 10.76% higher than expected. The liquidity at the best buy (breadth) is 14.82% higher than expected. This confirms the presence of patient informed traders (H4).[37] The breadth at the ask side is unusually high during the jump (8.07% higher), which is consistent with the prediction that market makers become active and start providing liquidity (H6).

Results resiliency

Using evidence from experimental asset markets, it was shown that a market making role emerges endogenously on a financial market (Bloomfield *et al.* 2005). This is in line with empirical evidence by Ahn *et al.* (2001), who highlight the importance of distinguishing between increased volatility arising from the bid side or from the ask side. Attracted by the increasing reward, traders will start to submit limit orders (and thus provide liquidity) at the side where liquidity is needed the most.

We do find in our results that the liquidity is restored after a jump, consistent with the emergence of market makers who add liquidity to the book. We see that the overall volume of limit sell orders entered after a positive jump is 127.27% higher than expected (See Table 12).[38] This is only partly the result of a quote updating process (as the cancellations at this side are only 86.87% higher than expected, unreported). While during the jump interval, the increased activity of patient informed traders dominates over the increase in limit orders posted by market makers, this reverts in the interval immediately after the jump. After the jump, market makers continue to provide unusually high liquidity up till 30 minutes after the

[37] For negative jumps, these patient informed traders seem to be active already before the jump. They post limit orders at the ask side in the 60 minutes before the jump and make the book unusually imbalanced. Their impact on the book is also bigger (respectively 22.46% and 24.11% more liquidity during and immediately after the jump compared to 10.76% and 16.50% after positive jumps).

[38] Later in this paper, we provide further evidence on order submission strategies (See p. 25, Post-jump order submission strategy).

jump. They bring the spread back to its normal level, and also restore the depth (from 20 minutes after the jump onwards).[39] Our findings illustrate the effectiveness of endogenous liquidity providers, even in a relative illiquid market and after a large price discontinuity.

Results: asymmetries between public and private news induced jumps

We find that for most liquidity dimensions, the dynamics of liquidity are very similar for jumps that are caused by public news announcements, and jumps for which this is not the case. A reason for this surprising symmetry could be that they are both linked with information, like we have argued above, and that they are in this sense also more similar than what one would expect. In Figure 4 we present the price reversal pattern, showing the median logarithmic return during the first two hours after the jump. We performed a Wilcoxon rank sum test on this return, and a star indicates that the return is statistically significant at the 5% level.

We find however one interesting and strong asymmetry in tightness: for jumps that can be linked with public news, the spread rises with 49.90% during a positive jump interval and 35.15% during a negative jump interval. For jumps that cannot be linked with public news, the spread rises only with respectively 18.52% and 17.75%. This may seem counterintuitive at first sight, because public information is symmetric and private information is not. We think this can be explained by the behavior of the liquidity providers, who are more reluctant to provide liquidity when a jump is caused by a public news announcement. It might be that they want to wait till consensus is reached on the interpretation of the news, and that they hesitate to provide liquidity when they know for sure that the movements are caused by information (even when this information is public). We find support for this in the price reversal pattern: the initial jump at both sides is reverted after public news announcements, while this is only to a much lesser extent the case for jumps that are not linked with a public news announcement. This also points at an insufficient liquidity provision in an early stage after the jump.

6. Further Analysis

The prior section provides a comprehensive view on how market liquidity evolves around the jump. However, several important issues remain unsolved: is it possible to forecast the jump occurrence using information available prior to the jump? Does the speed of price discovery remain unchanged after the jump? What kind of order placement strategy do traders

[39] After positive jumps, the depth an breadth become even unusually high till 40 minutes after the jump. This overshooting cannot be found back after negative jumps.

adopt after experiencing the extreme price risk due to jumps? In this section we provide further evidence on these issues.

6.1 Predictability of jumps using probit analysis

Despite the fact that we find only a very weak, if any, pre-jump liquidity pattern in the event study section, it is still possible that a certain dimension of the liquidity shocks is indicative of subsequent jumps, or multiple dimensions of the liquidity shocks jointly contribute to the occurrence and/or the magnititude of jumps. To formalize the linkage between jumps and liquidity shocks, we follow the literature by modelling intraday jumps as a non-linear function of liquidity shocks and news surprises (Boudt & Petitjean 201x; Jiang *et al.* 2011; Lahaye *et al.* 2011). To assess the predictive power of liquidity shocks prior to the jumps, we focus on all the single jump days and perform a probit regression as in Jiang *et al.* (2011). The restriction to days with only one intraday jump is necessary to avoid the contagion effect from consecutive jumps in the same day, which is common in the literature (Boudt & Petitjean 201x; Jiang *et al.* 2011). The explanatory variables in our probit regression are selected in an attempt to cover all dimensions of liquidity and are in line with Boudt and Petitjean (201x). The model specification of the probit regression looks as follows:

ῦ ὐ ῀Y ǖ ῦ ρ⫑╩

| ᛏ ˳῭Yὠ ῦ ῦ῭Y ᛏ .ὠ έ ὰ ό ά Ώ ˌ ᶊ ῞Ꞩ ᛏ ˰ Ü Ὸ [6.1]

ᛏ ˱ Ꞩ Ὸ ῞Ꞩ ᛚ ῞Ο ΰ ῭Ο ΰ ˗

where ῦ ὐ ῀Y ǖ ῦ ρ⫑╩ denotes the probability that a jump occurs conditional on a set of explanatory variables, ╧

In equation [6.1], the set of explanatory variables includes lagged values of spread (῭Yὠ ῦ ῦ), trading volume (ὠ έ ὰ ό), absolute order flow imbalance (ᶊ ῞Ꞩ), mean depth at the best price (Ü Ὸ) and absolute depth imbalance (Ꞩ Ὸ ῞Ꞩ) at the best price. In addition, a contemporaneous informational dummy (῞Ο ΰ ῭Ο ΰ) is also added to control for the possible announcement effect. The *iid* error term is denoted as ˗. All the liquidity variables used in [6.1] can be inferred from the Reuters screen, which is available to all market participants.

The estimation results are reported in Panel A of Table 10.[40] Consistent with our findings in the event study section, conventional liquidity measures offer weak, if any, predictive power in forecasting the occurrence of jumps after controlling the effect of informational

[40] Here we used maximum likelihood estimation.

shocks. First, none of the liquidity variables in equation [6.1] are statistically significant.[41] Second, the null hypothesis that the coefficients of all liquidity variables are jointly zero is not rejected at the 10% significance level.[42,43]

Although the results show that overall liquidity or a specific liquidity dimension do not predict the occurrence of a jump, it is still possible that liquidity can predict the magnitude of it. Therefore, in the next step, we evaluate the impact of liquidity shocks on the magnititude of the jump with a Tobit regression. The Tobit model can be seen as a truncated regression that determines the magnititude of the jump, given there is a price jump. The model specification is given as follows.

$$|J_{i,t}| = \begin{cases} J^*_{i,t} & \text{if } J^*_{i,t} > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$J^*_{i,t} = \text{[illegible]} \qquad [6.2]$$

where $|J_{i,t}|$ denotes the magnitude of the observed jumps and is measured as the absolute value of the logarithmic return during the 10-minute interval. $J^*_{i,t}$ denotes the latent jump magnitude. $|J_{i,t}|$ equals $J^*_{i,t}$ if $J^*_{i,t} > 0$ and is 0 otherwise. It further assumes that there exists a linear dependence between the latent jump magnitude and all the regression variables (which are the liquidity shocks and the information dummy). The regressors are defined identically as for Equation [6.1].

Panel B of Table 10 presents the result for the Tobit regression. None of the liquidity variables are significant at the 10% level, nor do they have the expected sign. The informational dummy, however, is significant and explains the magnitude of the jump: when the jump is caused by a public news announcement, it is on average bigger.

In sum, we find little evidence that liquidity shocks predict the occurrence of jumps or explain the magnititude of jumps in our sample after controlling the effect of news announcement. This contradicts with the findings by Jiang et al. (2011) and Boudt and Petitjean (201x).

---

[41] Here we used a (robust) t-test with Newey-West correction.
[42] Here we used an F-test.
[43] Our results remain unchanged when we use a logit regression. These results are available upon request.

6.2 Post-jump price discovery

In this subsection, we further examine the price discovery process after a jump in the FX market. We here follow the methodology used in Evans and Lyons (2002). Prior evidence suggests that the informational role of transaction order flow weakens subsequent to price jumps in the US bond and equity market (Boudt & Petitjean 201x; Jiang *et al.* 2011). We extend the work on post-jump price discovery to the FX market by examining all the single-jump days and non-jump days via the following model:

$$\Delta p_{t+1} = \alpha + \gamma D^{jump}_{t+1} + \beta_1 x_t + \beta_2 x_{t+1} + \beta_3 x_{t+1} D^{jump}_{t+1} + \varepsilon_{t+1} \quad [6.3]$$

where Δp_{t+1} denotes 100 times the change of the logarithmic mid-quote during the 10-minute interval *t+1*, x_t (x_{t+1}) is the signed volume of transaction order flow over the interval *t* (*t+1*) measured in millions of euros. D^{jump} is the post-jump dummy, which takes the value of one for the six 10-minute intervals immediately after the jump and zero otherwise.

We differ from previous studies such as Jiang *et al.* (2011) by including the lagged order flow (x_t) in the model specification to account for the possible price reversal in the next period as suggested by Pástor and Stambaugh (2003). That is, we expect that both the lagged and current order flow would impact price discovery process, but in the opposite direction. Therefore, the coefficient β_1 captures the liquidity effect of lagged order flow, β_2 captures the normal price impact of order flow, and β_3 captures the additional price impact of contemporaneous order flow immediately after the jump, which is robust to subsequent price reversals.

The results of the regression are presented in Table 11.[44] The coefficient on contemporaneous order flow is significantly positive, confirming the role of order flow in the price discovery process (see Evans & Lyons 2002). As expected, the coefficient on the lagged order flow is significantly negative but much less in magnitude than that on the current order flow, suggesting the existence of subsequent price reversal due to illiquidity. Finally, the coefficient on the interaction term between the post-jump dummy and the current order flow is significantly negative at the 5% level. This is consistent with prior literature that the informational role of post-jump order flow is less pronounced than during normal trading periods.

[44] We used Ordinary Least Squares regression to obtain these results. The t-statistics are Newey-West corrected.

While we confirm the stylized fact regarding post-jump price discovery, it remains interesting to investigate why order flow becomes less informative immediately after jumps. Jiang *et al.* (2011) attribute it to the possibly lowered dispersion of investor belief immediately following the occurrence of jumps. Motivated by our findings in the event study, we, however, perceive it differently: the reduced informational role of (transaction) order flow may as well be explained by the altered order submission strategy immediately after the price jump, which we investigate in the next subsection.

6.3 Post-jump order submission strategy

In this subsection, we investigate in depth the impact of jumps on the subsequent order placement strategy using regression analysis. Prior studies suggest that a higher proportion of limit orders relative to market orders emerges immediately after enlarged asset volatility or a widened spread (Biais *et al.* 1995; Griffiths *et al.* 2000; Ahn *et al.* 2001; Cao *et al.* 2008). Motivated by our findings in the event study section, we extend the order placement literature by focusing on the impact of intraday jumps, rather than volatility, on the subsequent order-flow composition. In particular, we estimate whether the occurrence of jumps leads investors to submit more limit orders relative to market orders, or the other way around.

To address these questions, we use the change of market depth available at the best price from interval *t* to *t+1* ($\Delta Depth_{t+1}$) as a proxy of the order-flow composition. As it is argued by Ahn *et al.* (2001), $\Delta Depth_{t+1}$ captures the difference between the net volume of newly placed limit orders and the volume of market orders executed during the time interval *t+1*. Therefore, we estimate the following empirical model which is similar to Equation 6 in Ahn *et al.* (2001).

$$\Delta Depth_{t+1} = \alpha + \beta D^{post}_{t} + \gamma \Delta Depth_{t} + \delta Vol_{t} + \theta Vol_{t} D^{post}_{t} + \sum_{k} \lambda_{k} Time_{k,t+1} + \varepsilon_{t+1}$$

[6.4]

where $\Delta Depth_{t+1}$ ($\Delta Depth_{t}$) is the change of mean depth available at the best price from interval *t* (*t-1*) to *t+1* (*t*), D^{post}_{t} is the post-jump dummy, which takes the value of one for the six 10-minute intervals immediately after the jump and zero otherwise, Vol_{t} is the volatility risk (measured as the square of the intraday return) during the interval *t*, $Time_{k,t+1}$ is an intraday dummy variable that takes the value of one if interval *t+1* belongs to the time interval *k* and zero otherwise, and ε_{t+1} is the *iid* error term.

Apparently, the coefficient [symbol] measures the autocorrelation pattern of the change of market depth, while [symbol] controls for the typical intraday "time of day" effect, [symbol] measures the effect of increased volatility on the subsequent order-flow mix and [symbol] captures the additional post-jump impact on order-flow composition, which is of our interest.

The result of the regression is presented in Table 13.[45] For the purpose of brevity, we only report the coefficients on the lagged changes of market depth, lagged volatility risk, the post-jump dummy and the interaction term. Consistent with prior literature (see Ahn *et al.* 2001, among others), the coefficient on the lagged change of mean depth is significantly negative, supporting the self-adjusting mechanism of the order flow. That is, there will be an influx of more limit orders than market orders when limit orders were relatively scarce in the prior period, which is consistent with the conventional wisdom that market depth tends to get replenished to its normal shape (resiliency). Similar to the results reported in Table III of Ahn *et al.* (2001), there is no strong evidence that increased transitory volatility would lead investors to submit more limit orders than market orders as [symbol] is insignificantly different from zero (the sign of the coefficient is in fact slightly negative).[46] Finally, the coefficient estimate on the interaction term between post-jump dummy and lagged volatility risk remains strongly positive at the 5% level, confirming our expectation that investors prefer to submit more limit orders instead of market orders subsequent to the occurrence of jumps. It should be noted that two forces contribute to the increased use of limit orders after a jump. On the one hand, the sudden increase of transitory volatility due to jumps makes it attractive for participants to adopt market making strategies, as the expected gain of supplying liquidity outweighs the expected loss of trading against an informed trader and holding an unwanted inventory for a short time span. On the other hand, even informed traders will opt for limit orders instead of market orders, because the cost of submitting a market order increases dramatically due to the rise in transitory volatility associated with the jump. As we do not have the identity of the traders, we cannot distinguish between these two forces.

Overall, our evidence on the post-jump order submission strategy is consistent with the results in the event study section: the jumps as more liquidity (depth) is built up in the book with newly submitted limit orders. The

[45] We used Ordinary Least Squares regression to obtain these results. The t-statistics are Newey-West corrected.
[46] One possible explanation for the insignificance of [symbol] is that the relation between transitory volatility risk and the change of market depth does not need to be monotonically increasing, nor linear. In an unreported regression we find that the coefficient on the quadratic risk is highly significant and positive, indicating the relation might not be linear.

reason for a weakened post-jump price discovery process become clear: transaction order flow become less informative with a thick order book.

7. Conclusion

Using a unique dataset (including the complete limit order book) over a two year timespan, we investigated the relation between intraday jumps, news announcements and liquidity dynamics in the HUF/EUR interdealer market.

First, our results conform to the general finding that jumps are frequent on financial markets. In a relatively illiquid FX market, such as our HUF/EUR market, we find that around 18.2% of the sample days contain at least one intraday jump with the jump component contributing to nearly one-half of the realized volatility during the jump day.

Secondly, we investigate the relation between jumps and news releases of various sorts. In particular, we employ a much broader dataset of news announcements which includes not only scheduled news releases, but also unscheduled news announcements such as polls, surveys, forecasts and analyses on future fundamentals. We find that scheduled news explains 16% of the jumps, while unscheduled news explains 30.4% of the jumps, confirming that both news on fundamentals (scheduled news), and news which will change the market expectations on future fundamentals (unscheduled news) are both important sources of large exchange rate movements. Still nearly half of the jumps remain unexplained by (public) news announcements. However, we show that jumps are information-based, independent whether they are linked with public news or not, as they have a similarly large permanent price impact and are both accompanied by highly imbalanced order flows.

Thirdly, we test the predictions from limit order book models under extreme market conditions by zooming in on the dynamics of various liquidity dimensions around jumps. Using an event-study approach, we find that prior to jumps the liquidity pattern does not deviate from that in normal trading periods. During the jump period, our results suggest that jumps do not emerge because of unusually low liquidity supply, but because of an unusually high demand for immediacy concentrated on one side of the order book. Moreover, a dynamic order placement process emerges after the jump: more limit sell (buy) orders are added to the book subsequent to a positive (negative) jump, which is consistent with the presence of endogeneous liquidity providers on the market. Attracted by the higher reward for providing liquidity, they submit limit orders at the side where it is needed the most. In addition, we detect a high level of resilience in the market, but this resilience is on average more pronounced for negative jumps than for positive jumps. Another interesting asymmetry is that the liquidity providers tend to be more reluctant to add liquidity when confronted with a news announcement around the jump. By consequence the spreads increase more dramatically in cases of jumps with news announcements than that of jumps without news events.

Finally, our further analyses offer more insights. First, the probit analysis shows that none of the liquidity variables offer predictive power for jump occurrence, which is consistent with the normal liquidity pattern prior to jumps documented in the event study section. Second, we find that post-jump order flow is in general less informative than in normal trading periods. This is in line with the additional evidence from the third analysis on order submission strategy: more limit orders relative to market orders are submitted to the book after the jump. Therefore, the informational role of order flow becomes less pronounced in the thick order book after the jump.

One direction for future research is to investigate the liquidity dynamics around jumps under different market microstructures (e.g. market with designated market makers, the customer FX market). This would be highly relevant for the purpose of optimal market design.

FIGURES

Figure 1: Average daily quote and total volume traded over the sample period.

Figure 2: Intraday distribution of ticks (CET).