THESIS ON ECONOMICS H29

# The Efficiency of Interest Rate and Foreign Exchange Markets in the Euro Area and Central and Eastern Europe

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Declaration:

Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

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**CONTENTS**

# INTRODUCTION

This doctoral thesis is focused on testing market efficiency in interest rate and foreign exchange markets. On one hand, different testing methodologies are applied and their effectiveness is assessed. On the other hand, the efficiency of money and currency markets is assessed, both for the euro area and for Central and Eastern European (CEE) countries. Market efficiency has been often debated during the last 40 years in financial economics, and the debate gained renewed attention during the last global financial crisis. There are many reasons why the efficiency of financial market is an important subject.

The first reason of why market efficiency is important (not only in financial markets) comes from the fact that prices should help to avoid misallocation of resources. If the main objective of markets is to allow buyers and sellers to meet and exchange assets, then the mechanism that governs price setting is fundamental in making the markets work efficiently, without waste of resources.

Market prices are often used not only to allocate resources efficiently, but also to extract information about the economy, and the quality of the information is dependent on the efficiency of the market (i.e. the quality of prices).

Besides the information quality contained in prices, the possibility for investors to use superior information and to gain positive return from securities prices on a consistent basis has been subject of discussion, while also being a part of the Efficient Market Hypothesis (EMH) debate.

Market efficiency is extremely relevant also from a purely theoretical point of view. Many of the arbitrage conditions upon which equilibrium relationships in financial markets are extracted are based on EMH.

Section 1 is dedicated to a review of the academic debate around EMH. Section 1.1 starts with the seminal contribution by Fama (1970) and illustrates how the EMH debate has evolved during the last 40 years, explaining the main contributions, particularly in the equity markets research. Section 1.2 looks into the empirical applications to interest rates and foreign exchange markets. This sets the stage for the analysis of five articles that form the core of the thesis, and that are described in Sections 2.1 to 2.5.

The five different applications have brought to the two following general conclusions. First, the choice of testing methodology is crucial in assessing the efficiency of a market. In particular, methodologies that take into account varying risk premium, tend to perform better than other, simpler methodologies. Second, arbitrage relationships, which should hold in case the efficient market hypothesis holds, often do not hold in the markets analyzed in the thesis. The effects of the recent global financial crisis on market efficiency and measuring methodologies have also been analyzed and assessed in some of the articles.

Together with the main question about the degree of efficiency (or non-efficiency) of financial markets, the five articles of the thesis are united by other common themes or specifications, partly already mentioned above. The first aspect to highlight is that the thesis covers two main markets, the *interest rate* *market* and the *foreign exchange market*. The bulk of literature on market efficiency focuses on equity markets, but the information carried by both the interest rate market and the foreign exchange market has also been explored in the last two decades. Two seminal works on information contained in the bond market are Cochrane & Piazzesi (2005) and Ang & Piazzesi (2003).

The first and second article of the thesis focus on the interest rate market. Namely, what kind of information about the future path of interest rates can be extracted from money market rates, or, in other words, what financial markets expect from monetary policy authorities in terms of the base rate. The question is relevant and has been widely analyzed because, on one hand, financial market participants use expected interest rates in deciding their investment strategies, and on the other hand, central banks need to know the expected interest rates to understand how their policy is perceived and understood. For example, during the first ten years of operation of the European Central Bank (ECB), a lot of attention was dedicated to the ability of the newly established ECB to communicate its policy to market participants (see e.g. Wilhelmsen & Zaghini (2005), Perez-Quiros & Sicilia (2002), Bernoth & von Hagen (2004)). The current analysis focuses on the euro money market in the pre-crisis period.

When the *global financial crisis* erupted in 2007, the focus of financial market participants, monetary authorities and the academic community shifted to the effects of the crisis on the global economy in general, and on global financial markets in particular. Inevitably, this has influenced the evolution of the thesis. The financial crisis started within a particular and relatively small sector in one country, the sub-prime mortgage sector in the USA, but spread to the entire global economy in a very short time. The rapid spread of the crisis underscores the need to understand the way in which crises propagate. The link between information, interest rates and foreign exchange markets, and transmission of shocks has been explored in the articles reproduced in Appendixes 3, 4 and 5 of the thesis. A more extensive discussion is given in the following sections but, in summary, it can be said that the financial crisis had a disrupting effect on the information content of asset prices. For the two markets analyzed here, while their role as information channels being questionable in 'normal' times, with the arrival of the crisis this role is further reduced. Some signals of a crisis arriving can be extracted, but there is still much work to do on this subject, particularly in terms of finding models of asset price behaviour that would be satisfactory in both low- and high-risk aversion environment.

The *regional* element is also a distinctive feature of the thesis. Most of the existing literature on market efficiency in money markets focuses on the biggest and most liquid markets, in particular markets in the USA. The clear advantage of this approach is that theories can be tested empirically under the very favourable conditions of high liquidity and long history of data. One of the contributions of the thesis is to focus on markets that are less developed and liquid in order to try to understand how much information is contained in (and/or can be extracted from) less explored and less liquid markets.

The European Central Bank policies have been carefully monitored by financial market participants, considering the size of the European economy and the growing relevance of the euro currency in global trade and financial markets. This brings to relevance the question of how much information about the future path of interest rates the euro money market contains. This aspect is discussed in the first and second article.

With the eruption of the global financial crisis, the question of transmission of disruption across markets also becomes extremely important. The convergence of Central and Eastern European countries toward Western European economies began with the collapse of the Soviet system, but the road has been far from smooth. In the first part of the 2000s, the process was in an acceleration phase, with new countries joining the European Union and with the first adoption of the euro by a country from the former Eastern Block in 2007 (Slovenia). The global financial crisis gave rise to new issues concerning the convergence process, and some of them are tackled in the thesis. In particular, the scope has been widened from the functioning of euro money markets to the linkage between euro and local money markets, and the role of both money markets and currency markets in the transmission of the financial crisis.

In all five articles of the thesis, a link between *time dimension*, *risk aversion* and market efficiency emerges, and it is addressed in different ways. The theme (and measure) of risk premium will be recurrent across all five articles in the thesis. As explained in more detail in Section 2, when trying to measure the efficiency of financial markets, the presence and nature of the risk premium must be accounted for. In the different articles not only the nature (and change) of the risk premium is analyzed, but also the problems related to its measurement from a methodological point of view are addressed.

The first two articles are dedicated to information contained in the euro area money markets. The third and fourth article focus on the efficiency of the foreign exchange markets in Central and Eastern Europe. The last article considers money markets and foreign exchange markets in Eastern Europe, while paying more attention to their role in the transmission of the crisis.

The main objective of the doctoral thesis is the analysis of the **Efficient Market Hypothesis**. The subject of market efficiency has become again extremely important during the recent global financial crisis. The high volatility of asset prices and the sharp decrease in liquidity in financial markets during the crisis has caused renewed interest, both among the academic community and practitioners, in market efficiency, in particular the assumption that prices are formed on the basis of all information available. The doctoral thesis first reports the main research issues, followed by the results of research and novelty of the thesis.

The research questions are as follows.

1. The first two articles assess the **efficiency of the euro area money market**. This is particularly relevant for the euro area because of the short history of the European Central Bank. In the first article, a comparison between different money market instruments is drawn with the objective to assess the relative efficiency of these instruments.
2. The first two articles address also the **methodology for testing efficiency**. In particular, whether, the choice of the testing methodology is relevant in the rejection or acceptance of the hypothesis, as often found in literature. Furthermore, alternative testing methodologies are explored.
3. The thesis assesses also the **efficiency of the foreign exchange markets**, both in terms of the Covered Interest Parity (CIP) and the Uncovered Interest Parity (UIP) for some of the **Central and Eastern European Countries**. In assessing the efficiency of these markets, two other research issues are covered too.
4. First, the degree of **convergence** of different CEE countries is assessed.
5. Second, the effects of the recent **global financial crisis** on these arbitrage relationships are analyzed.
6. The last research question, tackled in the fifth article, again concerns the crisis on CEE countries, but this time with the objective of finding **indicators of the arrival of the crisis**, and the possible **internal and external factors** in the unwinding of the crisis.

The main results and novelties of the thesis are summarized in the following.

1. In the first article, a comparison of different money market instruments is drawn for the first time (according to the author's knowledge) for the euro area, and the ability to extract information from the prices of these instruments is assessed. The main finding is that the Euribor and the Libor rates can be considered the instruments carrying a higher degree of information on future monetary policy decisions of the European Central Bank.
2. As for the second research question, the novelty of the first two articles lies in the employment of rolling regressions and the Kalman Filter in testing the Efficient Market Hypothesis on the euro area money markets. Both methodologies reveal the presence of the time varying risk premium, and, most interestingly, in the second article the direct link between the time varying risk premium and the economic cycle is assessed.
3. The research question of the efficiency of foreign exchange markets provides contradicting results depending on the arbitrage relationship used. In particular, while the Covered Interest Parity has been empirically confirmed (at least before the eruption of the global financial crisis), the opposite has been found for the Uncovered Interest Parity.

4. The degree of convergence of CEE countries was different before the global financial crisis, and this difference is captured when testing the CIP and the UIP. In particular, UIP and CIP both show that the Czech Republic and Hungary were at a more advanced degree of convergence before the crisis than other CEE countries analyzed in the thesis, such as Romania or Croatia.
5. In the third and fourth articles, CIP and UIP are tested for the first time (according to the author's knowledge) for CEE countries. including in the sample also the recent global financial crisis, and the effect of the crisis are assessed. Two results can be highlighted here. First, the crisis did not leave any country or market unaffected. Second, and more interestingly, the CIP analysis reveals that countries in the CEE have responded very differently to the crisis. While the Czech Republic has behaved more as a safe haven country, some others (Poland and Hungary) demonstrate a deviation from CIP that was not only significant in size, but also persistent over time.
6. The last article of the thesis measures, for the first time, the exchange market pressure (EMP) and the interest rate market pressure (IMP) for three CEE countries (the Czech Republic, Hungary and Poland), and uses panel data methodology in order to detect whether some internal or external factors are linked to the arrival of the crisis. The main finding is that relevant factors can be found only for the exchange market pressure, and that these factors are primarily linked to the banking sector.

The following articles have been published in the course of research.


Filipozzi, F. (2009). Market-Based Measures of Monetary Policy Expectations and Their Evolution since the Introduction of the Euro. Economic Notes, 38(3), 137–167.

Filipozzi, F. (2011). Modelling the Time-Varying Risk Premium by Using the Kalman Filter: the Euro Money Market Case. Professor Wladislav Milo (ed.). FindEcon Monograph Series: Advanced in Financial Market Analysis. Poland: Lodz University Press.

Filipozzi, F.; Staehr, K. [Forthcoming]. Covered Interest Parity and the Global Financial Crisis in Four Central and Eastern European Countries. Eastern European Economics.

Filipozzi, F.; Staehr, K. [Forthcoming]. Uncovered Interest Parity in Central and Eastern Europe: Convergence and the Global Financial Crisis. Discussions on Estonian Economic Policy . Berlin: Berliner Wissenschafts-Verlag.

Filipozzi, F.; Harkmann, K. (2010). The Financial Crisis in Central and Eastern Europe: the Measures and Determinants of the Exchange Market Pressure Index and the Money Market Pressure Index. Research in Economics and Business: Central and Eastern Europe, 2.

Author’s contribution

Article 3. The author of this thesis organized the collection of the data, took active part in the definition of the empirical methods, and ran the empirical analysis. The author also participated in the discussion of the results.

Article 4. The author of this thesis organized the collection of the data, took active part in the definition of the empirical methods, and ran the empirical analysis. The author also participated in the discussion of the results.

Article 5. The author of this thesis took active part in the collection of the data, discussion of the methodology employed in the research, and formulation of the conclusions of the research.

Overview of the approval of research results

Article 1. A preliminary version of the article was presented at the "Doctoral Summer School 2008", organized by the University of Tartu and the Tallinn University of Technology in Väimela, Estonia, in July 2008.

Article 2. The results of the article were presented by the author at the conference "Forecasting financial markets and economic decision-making 2009", organized by the University of Lodz in May 2009.

Article 3. A preliminary version of the article was presented by the author at the "Doctoral Summer School 2011", organized by the Doctoral School in Economics and Innovation in Viinistu, Estonia, in July 2011.

Article 5. The results of the article were presented by the author at the conference "Economies of Central and Eastern Europe: Convergence, Opportunities and Challenges", held in Tallinn in June 2010. The results of the research were presented also by the co-author at the "Doctoral Summer School 2010", organized by the Doctoral School in Economics and Innovation in Viinistu, Estonia, in July 2011.

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# 1. THE EFFICIENT MARKET HYPOTHESIS

In this section, the Efficient Market Hypothesis literature is reviewed and the ground for the discussion on the results of the doctoral thesis is prepared. The concept of market efficiency is analyzed, and the empirical evidence on efficiency of financial markets is reviewed. As explained by Yen and Lee (2008), it is the stock market that has been in the focus of empirical evidence on the Efficient Market Hypothesis, because it is often the first capital market to develop in emerging economies, and therefore the relevance of information is considered higher in that market. From this comes the choice of dedicating, at first, attention to the evidence in equity markets. In Section 1.2 the focus moves to fixed income and money markets (markets analyzed in the doctoral thesis), and finally to the foreign exchange market.

## 1.1. The concept of the Efficient Market Hypothesis

The starting point is the seminal article written by Fama in 1970. In that article, Fama holds that a market is efficient if “prices always ‘fully reflect’ available information” (Fama 1970, p. 383). While the concept is apparently simple and straightforward, there is an ongoing discussion on the interpretation and practical implications of the market efficiency concept. Just to give a hint on how wide the spectrum of opinion about this subject is, while the New Palgrave dictionary of economics (2008) dedicates a whole chapter to the Efficient Market Hypothesis written by Andrew Lo, Guerrien and Gun, in their extensive review of the literature on the subject, conclude that “Only ideological reasons – efficiency is a very sensitive question in economies – can explain why scholars continue to refer to this meaningless ‘hypothesis’” (Guerrien & Gun 2011, p. 19).

The main point of discussion is around the meaning of ‘fully reflect’ in the definition of market efficiency. This was already acknowledged by Fama in his 1970 paper. Fama states that one way to test market efficiency is to measure if the market price of a given security corresponds to its equilibrium price, or (equivalently) if the expected extra return (adjusted for risk) from investing in this security is equal to zero. This comes from the hypothesis or assumption that if the (risk adjusted) extra return is positive, then investors will use this profit opportunity and will drive the security price quickly up to a level where the extra return disappear. The absence of excess return possibilities has been defined by Fama as a ‘fair game’ assumption.

One of the main building blocks of the Efficient Market Hypothesis is the rational expectations hypothesis. Rational expectations hypothesis has been first formulated by John F. Muth (Muth 1961), and it is based on the idea that the realized prices of a security depends at least partly on the buyers and sellers expectations about what the price will be. In the contest of the EMH, assuming rational expectations is equivalent to say that investors, when deciding their investments, will form expectations on future prices using all the available information. If this is the case for all investors, the price today will be change immediately in order to incorporate all information about the future, therefore no excess return will be left.

The empirical version of the Efficient Market Hypothesis entails one important issue. Namely, in order to test if excess return exists, it is necessary to know the equilibrium price of the security. In other words, a model that would allow us to measure the ‘right price’ of the security is needed. This means that tests on the market efficiency hypothesis are, in fact, tests on two contemporaneous hypotheses: market efficiency and equilibrium model validity. If the test fails, it is not possible to assess whether the equilibrium model is wrong or whether the market is inefficient. This problem is known as the joint hypothesis problem, as pointed out by Jensen (1978).

Fama (1970) also defines three forms of market efficiency: weak, semi-strong and strong, and recaps the results of the empirical evidence on these three forms of market efficiency. The distinction between the three forms resides in the set of information contained in securities prices. As regards the weak form of efficiency, it is assumed that only past information is contained in prices. In the semi-strong form of efficiency, prices adjust instantly to present public information. In the strong version of market efficiency also private information is reflected in the prices. The general conclusion by Fama is that the first two forms of market efficiency are confirmed by the empirical evidence, while conclusions on the third form are not unanimous; i.e. corporate insiders seem to be able to use their information in order to have positive excess return.

Fama article does not *per se* contain any new insights on the market efficiency theory, but it is considered a watershed because it defines systematically what market efficiency is, and classifies systematically the empirical evidence on the subject at that time, which is strongly in favour of the Efficient Market Hypothesis. It can be said that with Fama’s article the concept of market efficiency becomes the main paradigm as regards the behaviour of financial markets.

This happened not only because the evidence against it was not strong or widespread enough, but also because the Efficient Market Hypothesis could be seen as in line with, or as an additional piece of, theory in a broader academic environment, where the so-called new classical economics were in the centre of academic research, and in particular the notion of rationality of economic agents. The idea that rational agents quickly drive prices to their equilibrium values was perfectly in line with the new classical macroeconomics paradigm (see Guerrien & Gun 2011).

As noted by Jensen (1978), after a paradigm has become widely accepted, according to Kuhn’s theory of scientific revolution, the emergence of evidence against it is initially discharged, and only when a sufficient amount of dispersed evidence emerges, the belief on the validity of the paradigm starts to vacillate. The literature in the 1970s and 1980s on the subject casts increasing doubts on the validity of EMH. Jensen (1978) attempts to collect a more systematic body of evidence against EMH. In particular, the main problems emerging during this period are related to the joint hypothesis test. The evidence presented by Jensen shows that following earnings or dividends, it is possible to gain abnormal (even if small) excess return, and it is not clear if this is because the asset pricing model used in different articles is incorrect, or if the market is inefficient.

Another milestone in the path of contestation of the Efficient Market Hypothesis was presented by Shiller in 1981, bringing up the so-called excess volatility puzzle. If the price of a stock is the present value of the cash flows coming from the stock (i.e. projected future dividends), then, assuming that in the future dividends and discount rates will have the same degree of volatility as observed in the past, the realized volatility of stock prices is much higher than the volatility of their 'true value'. In other words, in order to explain the volatility of stock prices it is necessary either to assume that valuation of claims on stocks changes dramatically, or that the model used to find the 'fair', or 'right', value of the stock is wrong. As Shiller pointed out later (2003), it seemed that prices changed without any fundamental reason.

Given mounting disagreement on the validity of the Efficient Market Hypothesis, and in particular the observation that it is not only equity markets that have, on average, higher volatility than can be fundamentally explained, but also sharp intraday movements seem to be caused by hoarding behaviour, a new branch of research emerged, gaining more and more popularity in the last twenty years. In modelling the changes in financial asset prices, behavioural finance tries to also incorporate the behavioural peculiarities observed in human beings.

Today, the question of market efficiency, and even more importantly, of the possibility of testing market efficiency, is still open. In 2003, Shiller and Mankiel published independently two papers in the same year (2003), trying to summarize the status of the Efficient Market Hypothesis in financial economics, and reached rather opposite conclusions. Mankiel (2003, p. 60) claims:

> I conclude that our stock markets are far more efficient and far less predictable than some recent academic papers would have us believe. Moreover, the evidence is overwhelming that whatever anomalous behavior of stock prices may exist, it does not create a portfolio trading opportunity that enables investors to earn extraordinary risk adjusted returns.

Shiller (2003, p. 101) states:

> We should not expect market efficiency to be so egregiously wrong that immediate profits should be continually available. But market efficiency can be egregiously wrong in other senses. For example, efficient markets theory may lead to drastically incorrect interpretations of events such as major stock market bubbles.

The recent global financial crisis has reinvigorated the debate on the efficiency of financial markets, in part because many markets that were considered liquid and transparent have seen sharp prices changes and sudden decrease of liquidity. As Ball (2009) and Brown (2011) point out, the belief in market efficiency has made many economists, investors and regulators become confident that market prices are the 'right prices' that reflect all available information, and therefore should not be subject to the above-described phenomena (sharp drops, disappearance of liquidity, etc.). Both authors use the argument, set out already in Mankiel (2003), that the problem lies with the interpretation of the Efficient Market Hypothesis. While regulators and legislators expect markets to be rightly priced at any moment, EMH only states that no excess return can be generated from available information in a systematic way, not that price bubbles will never happen.

The question is therefore still open, and it seems that most of the disagreement comes from the definition of EMH. If efficiency is measured in terms of possibility of implementing consistently profitable strategies (the 'fair game' hypothesis), then evidence supports the Efficient Market Hypothesis. On the other hand, when efficiency is measured in terms of 'correctness' of securities prices, then evidence is more against the hypothesis. The latter concept is more demanding. If in efficient markets prices were always 'correct', then no bubbles or sharp changes in prices would happen (unless due to sharp changes in fundamental values of securities). According to the 'fair game' approach, bubbles or sharp changes in prices are still compatible with market efficiency until they cannot be systematically used to generate profitable strategies.

## 1.2. The Efficient Market Hypothesis in interest rate and foreign exchange markets

Most of the empirical evidence outlined above comes from research on stock markets. The details of findings in the stock market are outside the scope of this thesis, and are not discussed here. What is important here is to analyze the peculiarities of empirical literature on interest rate markets, in particular in bond markets.

Since the beginning of the 1970s, the test of EMH has usually been conducted in conjunction with the test of the *expectation hypothesis* (Sargent 1972, Hamburger & Platt 1975). The yield curve of a given issuer represents the annual yield to maturity, as expected by market participants when investing in bonds issued by the same issuer for different maturities. Given that the only difference in the yields on the term structure is given by the length of investment, the arbitrage argument implies that yields on longer bonds must be the compounded sum of returns of short-term bonds from today to the maturity of the given issue. The level of future short-term rates implied by the current term structure is the forward rates.

The main focus of empirical literature on bond markets is on the expectation hypothesis, which links forward rates with future realized spot rates. The expectation hypothesis is linked to the Efficient Market Hypothesis because, if the test fails, i.e. future realized short-term rates and forward rates differ systematically, the arbitrage argument does not hold and it is possible to construct a portfolio of forward rates that will give a positive return in a 'systematic way'.

One of the first contributions on this subject emerged at the beginning of the 1970s. Hamburger & Platt (1975) focus on the treasury bills market and find that future realized short-term rates differ significantly from the forward rates, while forward rates do not significantly differ from the short-term rates at the present time. Both findings are against the expectation hypothesis, but not necessarily against EMH. The authors test the weak form of EMH, showing that past rates are not relevant for forecasting future realized rates, and also that errors in forecasting that are done using forward rates are equal to changes in actual short-term rates plus a constant (interpreted as liquidity premium). These findings seem to point to the fact that present information is fully used in forming expectations. The semi-strong form of EMH is tested by using monetary and income variables in order to forecast future short-term rates, as an alternative to the forward rates. The latter provides a better forecast, therefore the treasury bills market appears to be efficient.

Another important contribution on EMH in fixed income markets has been made by Fama & Bliss (1987). They try to answer two questions. First, if forward rates are a good predictor of the future realized rate. They look at longer rates (one to five years) than did Hamburger & Platt (1975), and find that the forecasting ability is dependent on time, and more precisely that expected term premiums are time-varying. This is, again, against the pure expectation hypothesis (as in Hamburger and Platt), but brings up the idea of a time-varying risk premium, which will be in focus in articles published later (for example Cochrane & Piazzesi 2005, Piazzesi & Swanson 2008), and also in this doctoral thesis.

The other question tackled by Fama and Bliss concerns the information contained in long-term bonds. In particular, they observe that forward rates extracted from the prices of long-term bonds are able to predict up to 48% of future short-term rates, and Fama and Bliss attribute this to the mean reverse tendency of short-term rates. This is one of the relevant evidences against EMH, because actual forward rates give a sign of the future direction of short-term rates, therefore a strategy that bets on lower (higher) interest rates in the future when forwards are above (below) their historical average has a positive expected return.

Another step in the same field has been made by Campbell & Shiller (1991). They generalize the results in Fama & Bliss (1987). In particular, the relation between short-term and long-term rates is generalized as follows: when the difference between short-term and long-term rates is large, then short-term rates tend to increase (which is in accordance with the pure expectation theory), while long-term rates tend to decrease (which is against the pure expectation hypothesis). The conclusion of their paper is particularly relevant for the direction taken by researches in this field in the 1990s and 2000s. The authors state that deviations from the expectation theory can be attributed either to wrong estimation of future short-term rates by market participants (i.e. EMH does not hold), or by a time-varying risk premium (i.e. the model used to describe expectations is not complete). This is shortly the joint hypothesis testing problem that was highlighted in the previous section. The literature of the following two decades focuses on the second aspect, trying to improve the modelling strategy of expectations in order to account for changes in the risk premium and changes in expectations formation.

An example of this development is provided by Cochrane & Piazzesi (2005). Their analysis of excess returns (which should not be predictable according to the expectation theory) suggests that there is a single factor, common to all maturities, which can predict the excess return, and this factor is time-varying and countercyclical. The direct link to macroeconomic variables is not tested in the paper, but the fact that there is a common risk premium term is important in two ways. First, it shows how to enrich the modelling strategy of the term structure, and second, the concept of risk premium tending to increase in worsening economic conditions and to decrease in better times is important in the following literature, and also in this thesis.

Other relevant literature for the thesis is discussed in Sections 2.1 and 2.2. There is yet another important remark by Piazzesi & Swanson (2008). Their article is in line with the ones described above, but focuses on the FED fund futures contract, which is directly linked to the article presented in Section 2.1. In the introduction, Piazzesi & Swanson (2008, p. 678) write:

> Throughout this paper, we will often use the label "risk premia" to refer to "predictable returns in excess of the risk-free rate." This use of language should not be interpreted as taking a particular stance on the structural interpretation of our results. The existing literature has proposed several appealing explanations for why excess returns on these contracts might be predictable. Some of these explanations are based on the utility function of investors: for example, investors may exhibit risk aversion which varies over the business cycle, or care about the slow-moving, cyclical consumption of items like housing. Other explanations are based on beliefs that do not satisfy the rational expectations assumption, for example because of learning or for psychological reasons. It is not easy to make the case for just one of these explanations: beliefs and other preference parameters often can often not be identified separately. We therefore set aside these issues as beyond the scope of the present paper.

The citation is important from a methodological point of view. The authors state that the presence of predictable return is not an issue for their research, and they limit the scope of the paper on the best modelling of the risk premium. In some sense, the issue of market efficiency is set aside, and the joint hypothesis test problem is implicitly solved in pointing to the modelling strategy as the solution, not to the 'non rationality' of investors.

Turning to *foreign exchange markets*, the main discussion of market efficiency has regarded the uncovered interest parity (UIP) and the forward premium anomaly (see Froot & Thaler 1990 for an early survey and Olmo & Pilbeam 2011 for a more recent review of the evidence). Given capital mobility and freely floating exchange rates, the no arbitrage condition already discussed above for the fixed income market should, in principle, hold also for the currency markets. After the collapse of the Bretton Woods system in 1971, the efficiency of currency markets under floating exchange regimes gained the attention of researchers. From that time on, the main focus of market efficiency has been on the forward premium puzzle (sometimes also called 'simple efficiency'): in an efficient market, forward rates should be a 'good' predictor of realized spot rates, i.e. forward rates should on average not differ from the future realized spot rates. The empirical evidence has shown that not only this is not true, but, even more difficult to explain, the difference between forward and today spot rates (forward premium) is negatively correlated with the change of spot rates (Boothe & Longworth 1986).

The same puzzle has regularly appeared in the testing of uncovered interest parity. Following the same line of reasoning, the change in spot exchange rates in a given period should correspond to the interest rates differential between two countries, and, in particular, a positive interest differential should lead to a depreciation of the currency with higher interest rates, as an arbitrage opportunity would otherwise emerge.

Boothe & Longworth (1986) review the empirical findings on the forward premium at that time. They present three main ways how the problem had been addressed at that time. First, the existence of risk premiums could explain the anomalous behaviour of forward rates. Second, the econometric methods used to test the forward premium could be incorrect. Third, the relation between forward and realized spot rate cannot be profitably implemented, therefore foreign exchange markets could be still efficient. The presence of transaction costs and of margin requirements (for strategies implemented using derivatives) are highlighted as the main impediment to profitable implementation of theoretically profitable strategies. The main findings suggest that the forward premium anomaly is largely unexplained. The forward premium anomaly has generated profitable strategies, risk premiums are present, but their ability to explain the puzzle is not convincing and a lot of work remains on the econometric side.

Olmo & Pilbeam (2011) review the most recent empirical evidence on the uncovered interest parity, and their general conclusion is not much different from the one by Booth and Longworth: the anomaly is still largely unexplained. The profitability of trading strategies based on the uncovered interest parity violation has not been explored further recently (an exception is Burnside et al. 2006).

As regards the uncovered interest parity, attempts to solve the puzzle has gone in the direction of accounting for the volatility persistence in the foreign exchange markets (Baillie & Bollerslev 2000), adding additional variables in empirical tests (Pilbeam & Olmo 2011), or allowing for non-linearities in the relation between interest rates and changes in exchange rates (Sarno et al. 2006). While these adjustments help in improving the empirical tests and in understanding the puzzle, the forward premium anomaly still seems to be far from reach. Tests on the profitability of the forward bias have been less common, the main recent example being done by Burnside et al. (2006). They find that even if trading strategies give positive results in theory, the frictions arising from actual implementation of the strategies, like bid offer spreads or size limits, make the strategies not profitable in practice.

The above discussion suggests that UIP violation is a serious problem in terms of foreign market efficiency theory, and this puzzle is still unsolved. But the forward premium anomaly does not seem to generate systematically profitable strategies; therefore the foreign exchange market seems to be efficient from the 'fair game' perspective.

# 2. RESULTS

In this section the five articles reproduced in Appendixes 1 to 5 are discussed briefly. The first two articles focus on the information contained in the euro area money markets. The third and fourth articles are devoted to the interest parity relations, covered interest parity (CIP) and uncovered interest parity (UIP) are tested for some CEE countries. The last article focuses on crisis indicators extracted from both interest rate and foreign exchange markets for three Eastern European countries. Together with the description of the analysis conducted and the results of each article, their link to EMH is also explained.

## 2.1. Market-based measures of monetary policy expectations and their evolution since the introduction of the euro

The first article analyzes monetary policy expectations in the euro area. When the ECB started to operate in 1999, market participants and researches have focused on two issues. First, the attention has been drawn to the ability of the new central bank to communicate its decisions to market participants. Second, and strictly related to the first subject, the focus is on how many of the monetary policy future decisions are already priced in money market instruments. The article presented here contributes to this stream of research in two ways.

With the creation of a new currency, new money markets have been created (or developed from previously existing euro area local money markets). Expectations on future monetary policy decisions, relevant for all market participants, can be derived from different markets and they most probably differ among themselves. The question which market can be considered the 'most efficient' for reading monetary policy expectations has been already tackled for the US market (Gürkaynak et al. 2007), but not for the euro area money market.

In order to run comparisons between markets, it has been assumed that the expectation hypothesis holds. This means that the model of forming expectations used in the article is 'correct', meaning that all investors form expectations as the model foresees. This is the way in which the joint hypothesis testing problem has been assumed away. If the model is correct, and when applying different money market instruments to the same 'correct' model, then the ability of different instruments to price monetary policy future path can be compared.

The expectation hypothesis, and in particular the link between observed spot interest rates and forward rates, has been derived through a no arbitrage condition, and has brought to a testable equation. The derivation of the equation is described in detail in the article in Appendix 1. The basic idea is that the spot short-term rate realized after *m* months from today has been regressed, using OLS, on the forward rate observed today with the settlement date in *m* months, *m* being the 'distance' of the forwards. If the expectation hypothesis is correct, the expectation today (measured by the forward rate) should match the realized rate in the future (measured by the realized spot short term arte), i.e. the left and right side of the estimated equation should be 'on average' equal. This means that the slope coefficient of the regression ($\beta$) should be equal to one, the constant ($\alpha$) should be equal to zero, and the residuals should have zero expected value and should be uncorrelated. As elaborated in Section 1.2, the empirical results of this test have not been encouraging (e.g. Hamburger & Platt 1975, Gürkaynak et al. 2007) and different reasons for this failure have been analyzed. In the first part of the article, the assumption that this model is 'correct' gives us the possibility to avoid this discussion and to focus on the comparison of different instruments. If the model is 'correct', a money market is 'more efficient' when the coefficients, estimated using the model, are closer to the value implied by the theory. This means not only that the constant $\alpha$ is closer to zero and the slope $\beta$ is closer to one, but also that the regression should have higher $R^2$ and a less volatile error term.

The second question addressed in the article is the dynamics of monetary policy expectations, in particular how the market participants' ability to predict the ECB's monetary policy actions have changed during the first decade of the ECB's operations. Considering that the ECB has a short history and that its monetary policy influences a wide economic area, the changes in perception of the central bank ability to communicate its decisions to the market participants has been a relevant question for both policy makers and investors. The question was addressed already a few years after the ECB started to operate, and some mixed answers have been provided. Some studies find that the ECB has been able to communicate to the market in a credible way, so the ability of market participants to predict the actions of the ECB has been as good as for other central banks with a longer history (Bernoth & von Hagen 2004, Perez-Quiros & Sicilia 2002). Some studies, on the other hand, find the ECB to be less predictable than its peers (Ross 2002).

Four money market instruments have been used for the comparison in the first part of the article, all of them with a one-month maturity: the Libor forward rate, the Euribor forward rate, the Bubill (German treasury bills) forward rate and the Eonia one-month futures. The first three rates are forwards calculated from the Libor, Euribor and Bubills spot curves, while the last one is a quoted rate. These were the main money market instruments used in the euro area from the beginning of 1999 to July 2007, just before the global financial crisis. Some of the instruments were not traded in 1999, so for some of the regressions the sample was shorter.

A total of 24 separate regressions were run for each instrument and also for each forward distance. The number of regressions comes from the number of financial instruments (4) and the 6 different distances ($m$ takes value from one to six) of forwards/futures used for each instrument. Different distances are used because it is expected for the monetary policy to be less predictable, the longer is the forecast horizon. Estimations were affected by autocorrelation of order 1 in the residuals, therefore the estimations were rerun by adding an AR(1) term for the residuals.

The results of the regressions showed some common elements across all instruments. In particular, the more distant the forecast, the higher is the risk premium (the absolute value of $\alpha$ increases with the increase in distance). This result is in line with results in other studies (Piazzesi & Swanson 2008, Gürkaynak et al. 2007). Also, the coefficient $\beta$ is close to one for the first two forwards and decreases substantially with the increase of the distance. In light of the discussion on the Efficient Market Hypothesis, while the increase in $\alpha$ can be explained in terms of a higher risk premium, it is more difficult to accommodate the fact that $\beta$ decreases without relaxing the efficiency hypothesis (or, alternatively, the model misspecification). Leaving this aspect aside, the comparison of different instruments showed that Libor and Euribor forwards 'behaved better' than Eonia futures and Bubill forwards. Bubill forwards showed higher volatility in the residuals and lower $R^2$, while for Eonia futures the $\beta$ coefficients showed, for all maturities, values more distant from one. For both instruments the problem lies with low liquidity, in particular for Eonia futures, which have a much shorter history.

If Euribor and Libor forwards 'behave better' than the other two instruments, the Libor has been used for trying to answer the second question of the article, namely how the perception of the ECB policy changed during the first nine years of its operation. The regressions have been run, incorporating the dynamics through the estimation of equations on different sub-samples, performing rolling regressions on 3, 4 and 5 years windows. An improvement in communication and understanding of ECB policies would be confirmed by decreasing values of $\alpha$ (lower risk premium), values of $\beta$ being closer to one and increasing $R^2$ of the estimations (as well as the lower variability of the residuals). The focus of the analysis is on the first two forwards; for longer forwards the error made in the prediction is probably caused more by 'unexpected events', therefore it is likely that it is not linked to market efficiency or communication issues. The results confirm that the first years of operation were a learning process for the ECB and that market participants have improved the forecasting ability of the central bank policy. In particular, $\beta$ for the first two forwards has become closer to one, and also the $R^2$ of the regressions has increased. The signal from the risk premium is not so clear, but in this case the presence of a time-varying risk premium, not modelled in this article, but considered in the article presented in Section 2.2, seems to be the main cause for the somewhat unclear result from $\alpha$ coefficients. While the results are in line with previous studies, their robustness is not guaranteed. Two comments should be made here. First, the sample is short, and rolling regressions show that there is a certain dependence of the results on the sample chosen. For example, regressions results are strongly affected by the period of 2000-2001, when interest rates increased quickly. Previous studies (e.g. Piazzesi & Swanson 2008) show that those risk premiums are generally time-varying, while in this article they are taken to be constant (measured by $\alpha$).

The last comment brings us back to the general picture, the question of market efficiency. The first article of the thesis is based on the hypothesis of market efficiency in order to make a relative assessment of different markets, as done by other authors (Gürkaynak et al. 2007 for the US money market). The results reported in the second part of the article indicate that the hypothesis about the 'correctness' of the model is restrictive in the sense that risk premiums seem to vary over time, but this does not necessarily hinder the results on relative performance of different instruments obtained in the first part of the article.

## 2.2. Modelling time-varying risk premium by using the Kalman filter: the euro money market case

The second article addresses the problems emerging from the restrictive assumption in the previous article, namely that risk premiums are assumed to be constant over time. As explained above, if the market is efficient, then forecasting errors should not be systematic; otherwise it would be possible to use the systematic errors for a profitable investment strategy. If the expectation hypothesis, as formulated in the first article, is rejected, it can simply be because the model used for testing is not correct (the joint hypothesis testing problem). The first alternatives to the expectation hypothesis are derived from other possible explanations for the shape of the term structure offered in literature, i.e. liquidity preference and preferred habitat. Both suggest that, together with expectations, there are other components determining the shape of the term structure. Keeping the distinction between different causes of deviation from the expectation hypothesis aside, these deviations have been summarized by using the single term *risk premium*. In this branch of literature it can be said that *risk premium* stands for everything added or subtracted from the pure expectations of future rates.

In the previous article, this was captured by the constant term $\alpha$. In the current article, a more flexible specification of the risk premium is investigated. In the previous article, most of the analysis on the dynamics of coefficients focused on the first two forwards, i.e. within a two-month period of forecast. As already found in other studies on short-term structures of interest rates (e.g. Piazzesi & Swanson 2008), the term premium tends to increase in absolute value with the distance of the forward analyzed, i.e. with the distance of the forecast. This is an indication that in order to improve the ability of the model in describing how expectations are formed, it must be taken into account that the more distant the forward is, the higher is the uncertainty.

In this article one-month forward rates derived from Euribor rates are used, for a period of almost ten years, from the beginning of 1999 to June 2008, monthly data. The equation used in the previous article is estimated using a slightly longer sample, and the results obtained are largely in line with the results obtained before. In particular, the residuals of the regressions are serially correlated of order one. In this case, the correction for the serial correlation is done by adding the one period lag term of the dependent variable on the right-hand side of the equation. The new estimations show that lagged variables coefficients are statistically significant, $\alpha$ is not statistically different from zero and $\beta$ is below one. This means that the lag term captures the entire (time-varying) risk premium, making the fixed part $\alpha$ insignificant. This can be interpreted as a confirmation that modelling risk premium as fixed is too restrictive.

In the article two modelling strategies are employed in order to account for the time-varying risk premium. Given that previous studies (Cochrane & Piazzesi 2005, Piazzesi & Swanson 2008) found a direct link between risk premium and economic cycle for the US fixed income and money markets, an indicator of business cycle is added to equation. While Piazzesi & Swanson (2008) use the unemployment rate in US, in Europe this variable is extremely sticky, arguably due to the different legal structure of the job market. In the article the euro area economic confidence indicator compiled by the European Commission is used. The estimations show that the coefficient of the economic cycle indicators is statistically significant, the sign is positive, as expected (better economic environment caused realized rates to be higher than expected rates), and the absolute size of the coefficient increases with the increase of the forecast horizon. Coefficient $\alpha$ remains insignificant and $\beta$ is still much lower than one.

If the previous results confirm that the risk premium is time-varying and linked to the business cycle, the dynamics of the risk premium can be better analyzed when estimated directly and not modelled with a business cycle proxy.

This gives the advantage of not imposing any *a priori* view on the nature of the risk premium, and gives the opportunity to extract it directly from the financial instruments' time series. This is done by employing the Kalman filter technique. In particular, the pure expectation model, as described in the previous section, has been modified in order to allow changes through time of the risk premium. A state space representation of the relation between short-term rates realized after $m$ periods from today and forward rates observed today with the settlement date after $m$ periods has been specified, $\alpha$ being the state variable. This means that $\alpha$ is allowed to change through time, and that its value in each period is extracted directly from the data using the Kalman filter. The only assumption made is that $\alpha$ has random walk behaviour.

While the values of $\beta$ are similar to the ones obtained with the OLS estimation (remaining statistically lower than one), interesting considerations can be done looking at the dynamics of the risk premium. In particular, while the risk premium remains stable for the first two forwards, the size of the risk premium for more distant forwards is similar to the OLS estimation, but its variability increases with the distance. When adding the economic indicator to the state space specification, it is possible to distinguish between a *business cycle risk premium* and a *pure risk premium*. The pure risk premium appears to be more stable than the business cycle risk premium.

Considering again the perspective of the Efficient Market Hypothesis, the general idea of the article was to see if the rejection of the expectation hypothesis in the euro area money markets is due to the model specification used in the first article, or if using a different specification (and in particular allowing time-varying risk premium) could bring the results in line with the expectation hypothesis prescriptions.

Two main conclusions can be drawn. First, the model specified in the article is able to capture the expectation formation better than the standard model defined in the previous article. In particular, the state space representation allows to take into account the time variation of the risk premium, both in the component linked to the business cycle and in the component of pure risk premium.

The other important conclusion is that also in this 'better specified' model the efficiency of the market has been rejected, because $\beta$ is found to be statistically lower than one. This means that forward rates tend to underestimate consistently the realized rates. This raises the possibility that the model employed here is still not well specified, either because the risk premium should be defined differently or because there are other components in the expectation formation not considered in the model.

## 2.3. Covered interest parity and the global financial crisis in four Central and Eastern European countries

In the third and fourth article of the thesis, the focus was on the interest rate parity relations between the euro area and Central and Eastern European countries. Two main points of interest are, on one hand, the fact that covered interest parity (CIP) and uncovered interest parity (UIP) are some of the key assumptions in international economics. They rest on the idea that returns on domestic and foreign assets are equalized by arbitrage; therefore their test can provide information as to whether these markets function so that all the gains from trade are exploited, i.e. whether the markets are efficient. On the other hand, the analysis of CEE countries and the inclusion of the recent global financial crisis in the sample can help to gain insight on the convergence of these countries towards the euro area, and the effects of the crisis both on the convergence process and the arbitrage relations.

The third article focuses on CIP. The relation is assessed for four countries (the Czech Republic, Hungary, Poland and Romania) for the period between 2004 and the end of 2011, using monthly data. First, the deviations from CIP are calculated as the difference between the annualized forward premium (capital gain which the investor attains if the forward rate differs from the spot rate) and the spread between the domestic and foreign interest rates. In literature, the empirical validity of CIP is typically confirmed in case markets are deep and financial markets are not affected by major turbulence or disruption. Latest tests including the global financial crisis found instead persistent deviations of CIP.

The graphical analysis shows some interesting results. Prior to the outbreak of the global financial crisis, the Czech Republic, Hungary and Poland had only small deviations from CIP, fluctuating around zero and with modest variation, while in the case of Romania the deviations were very large, probably due to the slower speed of integration into the European economic structure of the Romanian economy. In the period around the outbreak of the global financial crisis, the four countries exhibited very diverging developments. In the Czech Republic deviations from CIP were small, suggesting that investors saw investment in the Czech *koruna* as entailing a small risk, essentially a 'safe haven' currency. In Hungary and Poland, the global financial crisis led to the opening of large and negative deviations from CIP. Both central banks intervened in order to help the domestic banking sector, in particular to ensure liquidity in the FX swap markets. While in Poland the deviations from CIP were reduced, signalling a gradual return to normality, in Hungary the deviations increased again in 2010-2011. In Romania the global financial crisis led to a very large negative deviation from CIP which lasted half a year, but in a context of general rejection of CIP also before the crisis.

In the second part of the article, possible causes of CIP deviations are investigated in regression analyses by using two explanatory variables that capture the riskiness of investment in different markets. The first variable is the

VIX index, the volatility of US equities calculated from options on the S&P500 index over the next month. This is a proxy of the global level of risk aversion, and a higher value of the variable indicates increased risks. The other variable is the CDS spread for five-year government bonds in each of the four countries. An increase in the spread implies higher perceived riskiness of the country's bonds; therefore the CDS spread can be taken as a proxy of local or country-specific financial market risk.

Before proceeding, the global component, VIX, is removed from the measure of local risks, CDS, in order to obtain the variation in CDS that cannot be explained by global developments, or the 'pure' local component of market risk.

The CIP deviation is then regressed on the two indicators of global and local risk (all variables demeaned) by using OLS, separately for the four countries. The interest rate spread is also included in the regression as a control variable in case interest rate differentials do not feed into the forward premium one-to-one.

The results confirm the graphical analysis, namely that the differences between countries are striking. The Czech Republic stands out as a country for which global risks are of little importance (or even associated with a lower risk premium), and the constant risk component is negligible. This is the picture of an advanced economy, which may even be seen as a safe haven as long as global risk developments do not spill over to local risks. The results for Hungary and Poland are very similar, as in their cases the risk premium in the CIP condition increases when both global and country-specific risks increase. Romania stands out because deviations from CIP are extremely large and apparently unrelated to global or local risk factors. The overall picture is one of an emerging economy, where the pricing of forward exchange is very volatile and unrelated to risks.

In terms of market efficiency, CIP is considered as one of the fundamental arbitrage conditions in international economics, and it is often confirmed also in empirical tests. This is, among other things, due to the fact that both interest rates and foreign exchange levels are agreed upon at the beginning of the investment period. The results of the paper do not confirm the Efficient Market Hypothesis, at least in the period and for the countries analyzed here. The main contribution of the article is that the causes of EMH violation are outlined and analyzed, and the differences between the countries are explained. While the absence of a deep and integrated financial market is the main cause for rejection for Romania, the time varying risk aversion (both global and local) is the main cause for rejection for Poland and Hungary. The effect of risk on CIP is, of course, amplified in the global financial crisis; it can be reversed or at least tamed by intervention by central banks and governments (as in Poland for example). The Czech Republic stands out as an example of how even sudden adverse events (global financial crisis) do not affect the EMH owing to deep financial markets and sound policies.

## 2.4. Uncovered interest parity in Central and Eastern Europe: convergence and the global financial crisis

The fourth article of the doctoral thesis tackles the same questions as the previous article (namely, no arbitrage possibilities between domestic and foreign assets, convergence of CEE countries towards Western Europe and the effects of the global financial crisis on convergence and arbitrage relations), but focuses on the uncovered interest parity. The first objective is to check how the UIP relation has been working for the countries with a floating exchange rate regime. The second objective is to see if and how the recent global financial crisis has changed the UIP relation for the region. Five countries are analyzed in the article – Hungary, the Czech Republic, Poland, Romania and Croatia – and they have been chosen because of having operated under a floating exchange rate regime during the period considered. The sample of the analysis covers the period between the launch of the euro (1999) and the end of 2010.

As described in Section 1.2, most of the analysis of efficiency in this market concerns the forward premium anomaly, or the empirical disconnection between the changes in nominal exchange rates and the level of interest rates differentials. In theory, a positive interest differential should lead to a depreciation of the currency with higher interest rates, as an arbitrage opportunity would otherwise emerge. Empirical tests not only usually reject the arbitrage condition, but often the opposite is found: higher interest rates bring to an appreciation of the currency (in nominal terms).

In the article, UIP is tested by running a regression between the monthly changes of the nominal exchange rate between the local currencies of these five countries and the euro (dependent variable) and the differential between local three-month interbank offered rates and the three-months Euribor (independent variable). For UIP to hold, the constant ($\alpha$) of the regression should be equal to zero and the slope ($\beta$) equal to one.

As stated above, UIP is usually rejected. The causes for rejection can differ: from the existence of transaction costs or low liquidity of the market to information costs.

On one hand, all these impediments to the UIP relationship do not justify the frequency and degree of rejection of UIP. Empirical results indicate not only that $\beta$ is different from one, but that it is often negative. On the other hand, the rejection of UIP does not necessarily mean that markets are inefficient. As for the usual joint hypothesis problem, it could also be the case that the model used is incomplete or at least partly incorrect.

At first instance, the usual UIP estimation is run with OLS. The results are in line with the previous literature: UIP is generally rejected, the explanatory power of the regression is very low, and $\beta$ coefficients are not statistically different from zero.

Given these first results, two issues are explored. First, the influence of the global financial crisis on the UIP relationship is analyzed. Using rolling regressions of the basic UIP relation, with a window of a five-year span, it is observed that for three of the countries analyzed (Hungary, the Czech Republic and Romania) there is a remarkable change in the $R^2$ of the regressions of around 20% to 30% before the global financial crisis, which drops to nearly zero when the period from 2008 on enters the sample. At the same time, the value of the parameters $\alpha$ and $\beta$ are quite volatile, confirming what found in previous literature, namely that estimation results are instable and sensitive to changes in the sample.

As sometimes claimed in literature, the problem does not lie with UIP, but with the way how it is empirically specified (the joint hypothesis testing problem). In this case, a different specification can help improve the results. Two improvements to the model have been tried. The first arises from the observation that UIP tends to hold better when the interest rate differential is higher (i.e. the arbitrage opportunity are more profitable), as pointed out by e.g. Froot & Thaler (1990) and Lothiana & Wu (2011). This observation can be incorporated in the model by using two explanatory variables. The series of interest rates differentials have been split into two series, one with only a low level of the differential (and zero otherwise) and another with only a high level of the differential for a higher level of interest rates. If UIP holds better in higher spreads environment, the $\beta$ of the second explanatory variable should be closer to one. Two non-linear specifications of the model have been also tested, but not reported in the article.

The other change to the model is in line with what analyzed in the previous articles. Namely, the risk aversion is not constant over time, and when it is high, it can disrupt an otherwise functioning arbitrage relationship, such as UIP. This is accounted in the model by adding a VIX (the implied volatility calculated from options on S&P 500 equity index, often used as an indication of the level of risk aversion in financial markets) term on the right-hand side of the equation.

The results of the modified models are not very encouraging. Accounting for different interest rates regimes and different risk aversion regimes does not bring to any substantial change in UIP parameters or explanatory power. The only result worth to comment is that the risk aversion coefficient is generally statistically significant, confirming the results obtained in the previous articles that in modelling financial relationship, the time-varying risk premium must be taken accounted for.

The results of the article are generally in line with previous literature, namely that UIP is empirically broadly rejected. This holds also for the five Central and Eastern European countries for the period considered here. The modifications of the base model explored (high and low interest rates regimes, risk aversion) do not change the substance of the results. Overall, it seems also that if the global financial crisis had any impact, it was on the side of disrupting the UIP relation even further.

In terms of market efficiency, a question arises whether the UIP rejection is a clear sign of foreign exchange markets being inefficient. Foreign exchange market is considered one of the most liquid markets, thanks to both its size and number of participants. Also, the results illustrated in the previous section would suggest that foreign exchange markets are either efficient (Czech Republic) or the cause of inefficiency can be detected (Poland and Hungary). This makes the degree of unanimous and continuous rejection of UIP in literature extremely puzzling. The usual explanations justifying the rejection of arbitrage conditions (transaction and information costs, illiquidity etc.) do not seem strong enough to justify such a strong rejection of UIP. A better specification of UIP relation, together with an improvement in econometric methods, seems the most promising way towards a solution to the puzzle. The attempts made in the article have shown that different interest rate spreads regimes and time varying risk premiums exhibit substantial explanatory power, but the picture is not uniform across the countries and UIP is still rejected.

## 2.5. The financial crisis in Central and Eastern Europe: the measures and determinants of the exchange market pressure index and the money market pressure index

The last article of the thesis discusses how the global financial crisis has affected the formation of exchange rates and interest rates in three major Central and Eastern European countries: Poland, Hungary and the Czech Republic. In the article, two measures of pressure on these two markets are constructed and discussed. Also, the two measures of pressure are regressed on several different explanatory variables to understand the impact of both internal and external factors on these measures and their role and effects on the development of the crisis.

There is a more than thirty years long stream of research that tries to define measures and understand currency crises and their determinants (one of the first contributions being Krugman 1979). This branch of literature has been progressively broadened to encompass also other types of crises. Moreover, the focus has moved to the linkages between different financial markets and financial institutions, and to the transmission of financial crises. The recent global financial crisis has increased interest in currency crises further.

Taking literature on global financial crises as the starting point, the article contributes in different ways. First of all, most of the research on the causes, spread and consequences of financial crises focuses on Latin American or Asian economies, while few have considered Central and Eastern European countries. Second, the focus of the article is more on the ability to build measures of fragility, i.e. the vulnerability of individual countries to external contagion.

In literature, the attempts to explain how crises arrive and propagate have been grouped in three generations. The first-generation models point to weak economic fundamentals, for example too expansive fiscal and monetary policies or weak external position of a country (Krugman 1979, Flood & Garber 1984). The second-generation models try to incorporate changes in market sentiment and investor expectations (Obstfeldt 1994, Belker & Setzer 2004). The third-generation models consider the institutional framework, and also the role of financial institutions and the banking sector (Krugman 1998, Kaminski & Reinhart 1999, Vaugirard 2007).

The common characteristic of all these models is that they try to find causes of crisis and contagion, and to highlight what to look for in order to forecast the arrival of a crisis. This article aims to compact some of the information analyzed by the three generations of crisis models in two numerical measures of pressure. The two measures used are the exchange market pressure (EMP) and the interest market pressure (IMP). These indexes are constructed for the three CEE countries analyzed (the Czech Republic, Poland and Hungary) between February 2001 and September 2009.

The EMP index is more commonly used in literature than the IMP index (Girton & Roper 1977, Eichengreen et al. 1996, Bird & Mandilaras 2006). The version used in this article is the composition of the change in nominal exchange rates, the change in nominal short-term rates and the change in international reserves (the latter being with a negative sign). The weight of each variable is the inverse of its standard deviation, which ensures that the most volatile component does not dominate the index. A positive high value of the index is a signal of a higher probability of the arrival of a crisis.

The IMP appeared in literature recently (Hagen & Ho 2007), and indicates crisis emerging from the interest rate channel. In the version calculated in the article, two components are used: the change in the ratio of central bank funds on total bank deposits and the change in the nominal interest rate. As for EMP, a higher value of the index points to a higher probability of a crisis.

The graphical analysis of the EMP and IMP indexes shows that between summer 2007 and autumn 2008 both measures of pressure reach their peak for the sample considered here. The timing of the arrival of the global financial crisis is different for the three countries, but none of them remained untouched. Furthermore, the jump in the two indexes (in particular in EMP) is bigger for Poland and Hungary than it is for the Czech Republic. This is in line with what found in the previous article, namely that the crisis affected the Czech Republic less negatively than Hungary and Poland.

The other objective of the article is to measure if and how the measures of foreign exchange or interest rate market pressure are related to other economic variables. This is done by running regressions with IMP and EMP as dependent variables against nine independent variables. These variables can be clustered into four groups as banking sector variables (the difference between the local and euro area three-month interbank interest rates, the ratio between the net foreign liabilities and assets of a bank, and the change in domestic credit), real economy related variables (the consumer price index, local stock market return, growth in the ratio between M2 and foreign reserves), fiscal variables (the growth rate of government borrowing) and external balance variables (REER and decline in exports). The choice of variables is, in part, guided by the results of previous researches.

Three sets of regressions are run. Firstly, panel regressions to study the relationship between IMP and EMP and the nine variables listed above, under both random and fixed effect hypothesis. Second, panel logit regressions are run, using the same independent variables but binary versions of EMP and IMP, which take value of one, if the original EMP and IMP is above a certain threshold and zero otherwise. Third, a distinction is made between variables that indicate growing vulnerability of the economies to exchange rate and interest rate crisis, and variables that move contemporaneously with crisis indicators.

The first two sets of regressions indicate that, of the four groups of variables used in the analysis, the one related to the banking sector is the more influential. This is also in line with what found in the article reproduced in Section 2.3, namely that deviations from CIP have been lasting for longer in countries where the authorities were forced to intervene directly in the FX swap market, which became illiquid during and after the crisis and caused problems of hedging the currency exposure of local banks. Credit growth and the level of foreign liabilities of the banking sector seem to be strongly related with the emergence of pressures on the exchange rate and, to a lesser extent, on the interest rate. The fiscal situation exhibits a negative sign in the EMP regression, probably because the creation of deficits has rather been a reaction to the crisis than a cause. The economic situation and the external balance are found to be not relevant.

The third set of regressions confirms the role of the banking sector in explaining the increase in exchange rate market pressure. The government role is also clarified: the government borrowing variable is not significant when it enters the equation as a lagged variable, while having a negative sign when it enters as a contemporaneous variable. The increase in government borrowing was not a factor in causing a crisis, but it was a supportive factor when taming the effects of the crisis.

Comparing results of the analysis of IMP and EMP, all the regressions show that the EMP relation with some of the fundamental variables is easily captured, while any link between the money market pressure and the variables employed here seems to be hard to capture. The difficulty to find significant explanatory variables to IMP could be due to the fact that, in floating exchange rate regimes, the nominal exchange rate is the major shock absorber, while short-term interest rates are mainly controlled by central banks and are not allowed to change abruptly.

In terms of market efficiency, the results of the article show that it is possible to extract signals on incoming crisis from the two market pressure indicators constructed. Efficient markets should be characterized by prices that already contain all available information, which is not the case if there are variables that are able to at least partially forecast the arrival of a financial crisis. In particular, it was found in the article that variables linked to the banking sector where able to explain future levels of EMP. This can be another signal of possible inefficiency of the foreign exchange markets, in line with what found in Sections 2.3 and 2.4, but the subject must be explored further.

# CONCLUSIONS

The objective of the thesis and the five articles presented in the introduction and reported in the appendixes was to test the Efficient Market Hypothesis in interest rate and foreign exchange markets in the euro area and in Central and Eastern European markets.

The first two articles focused on the money markets in the euro area, and the main conclusion for the analysis conducted was that the detection of market efficiency is very much dependent on the methodology employed. In particular, more simple versions of EMH tests, which do not account for the presence of time varying risk premiums, usually reject the hypothesis. The rejection of EMH is less straightforward when the methodology that is employed to test it allows for risk premiums to change through time. In the second article, the correlation between risk premium and economic cycle indicators was detected, and the utilization of a Kalman filter methodology showed promising results. Nevertheless, EMH was not confirmed by the analysis conducted in the first two articles.

In the other three articles of the thesis the attention shifted to EMH tests in the interest rate and foreign exchange markets, focusing on Central and Eastern European countries. Together with the validity of EMH, also the degree of convergence of the financial markets of these countries towards Western Europe and the effect of the global financial crisis on EMH were analyzed.

The third and fourth article focused on the interest parity relations, CIP and UIP. Both relations were found to hold if EMH holds. While CIP is generally confirmed by empirical tests, UIP is, on the contrary, generally rejected. In the third article, CIP analysis showed interesting results. First, for the countries with a higher degree of convergence and deeper financial markets (the Czech Republic, Hungary and Poland) CIP was holding before the crisis, while that was not the case with Romania. Second, the effect of the crisis was found to be different for the countries in question. While the Czech Republic was not affected by it (looking more like a safe haven country), in Poland and Hungary the effect of the crisis on CIP was significant and lasting, signalling that besides deep financial markets also sound policies are important for keeping arbitrage conditions to perform also under stress scenarios.

The fourth article was devoted to UIP, and in this case results for the CEE countries were more in line with previous empirical studies, namely a complete rejection of UIP. When time varying risk aversion indicators were included in the test (in line with what was done in the first and second article), they proved to be significant, but not enough to make UIP accepted. UIP rejection therefore seemed to be not due to testing methodology issues only, but probably also due to rejection of EMH.

The last article considers measures of market pressure and their ability to signal a potential crisis. When applying these measures to CEE countries over the last decade, the main finding was that the global financial crisis reached the countries through the interest rate as well as the foreign exchange channel (both EMP and IMP peaked between summer 2007 and autumn 2008), but the impact was not equal for all countries, and it was possible to find significant explanatory variables for EMP only (mainly linked to the banking sector).

To sum up, the empirical validity of EMH is highly dependent on the markets and countries analyzed, on the sample covered and, last but not least, on the methodology used for the tests. The analysis conducted in the five articles of the thesis showed that the time varying risk premium must be accounted for when testing EMH. This is particularly true when turbulent periods, such as the recent global financial crisis, are added to the sample. CIP and UIP tests also showed that EMH holds better for countries with deep financial sectors and between more integrated markets. Nevertheless, particularly as regards UIP, it is difficult to attribute the EMH rejection only to transaction costs or flaws in empirical methodology.

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**Filipozzi, Fabio; Staehr, K.** [Forthcoming]. Uncovered Interest Parity in Central and Eastern Europe: convergence and the global financial crisis. Discussions on Estonian Economic Policy. Berlin: Berliner Wissenschafts-Verlag

**Filipozzi, F.; Staehr, K.** [Forthcoming]. Covered Interest Parity and the Global Financial Crisis in Four Central and Eastern European Countries. Eastern European Economics

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# APPENDIX 1

## Market-based measures of monetary policy expectations and their evolution since the introduction of the euro

FABIO FILIPOZZI

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# Market-Based Measures of Monetary Policy Expectations and Their Evolution Since the Introduction of the Euro

FABIO FILIPOZZI*

*The paper considers the relation between monetary policy expectations and financial markets in the case of Europe. A number of money market instruments are compared, with the result that the 1-month forward interest rates extracted from the Libor yield curve has the best prediction power of the future monetary policy path. These forward rates have been used to study the evolution of market expectations regarding the monetary policy of the European Central Bank (ECB). The sharp increases and the following decreases in interest rates during 2000–2001 have reduced the predictive power of money market instruments, but smoother management of interest rates and better communication from the ECB has helped to improve the forecasting power of money market instruments.*

*(J.E.L.: E52, E58, G1).*

## 1. Introduction

One of the main drivers of the developments on financial markets, both equity and fixed income markets, is decisions on short-term interest rates by monetary policy authorities. This is a key reason why so much interest has been paid to understand how markets forecast central banks' decisions.

One possible approach in economic literature has been to focus on extracting the forecasts of central bank's behaviour from asset prices. In particular, money market instruments have been used for two reasons. First, there is a strict link between the central bank's target rate and short-term money market interest rates, which shows that central bank's decisions have a strong influence on short-term money market rates. Second, many market participants use derivatives on money market instruments in order to hedge the interest rate risk. This means that the prices of future money

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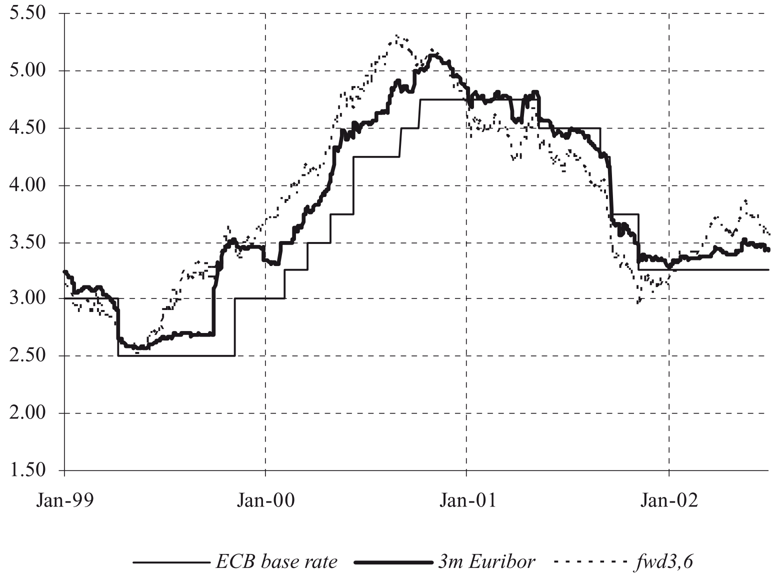


Figure 1: ECB's Target Rate, 3-Month Euribor and 3-Month Forward Rate in 3 Months

market rates are directly observable in the market, and they can be used to measure expectations of future short-term interest rates. Figure 1 illustrates these two facts for the case of Europe.

The most common approach adopted in literature has been to use the prices of derivatives (in this example the forward rate) to extract expectations of the central bank's target rate (in this example the ECB's target rate). This implies, as shown later, testing the expectation hypothesis. In brief, if markets are efficient and market participants are rational, derivatives on short-term interest rates should assess exactly the future path of short-term (and monetary policy) interest rates (when adjusted for the risk premium).

The objective of the paper is twofold. In the first part, assuming that the expectation hypothesis holds and that market participants therefore assess the future path of short-term interest rates 'correctly', I build a framework to compare a range of money market instruments available today in the European money markets. I also try to establish their quality with regard to assessing monetary policy actions.

A number of studies have compared different short-term instruments in the US, where similar financial instruments have been used for longer time and are generally more liquid, which is why also the quality of data is higher. Gürkaynak *et al.* (2007) compare different short-term instruments (as does this paper) and measure their effectiveness in predicting the US Federal Reserve's (FED) monetary policy. Interestingly, the authors are able to distinguish between very short-term surprises (disappearing within a 6-week horizon) and longer-term predictive ability.[1] Piazzesi and Swanson (2006) focus on the term premium effect on the predictive power of short-term instruments, pointing out that the size and time variation of the term premium effect can be relevant in assessing the instruments' predictive power. Favero and Mosca (2001) analyse the reaction of 6-month rates to current and future 3-month rates in the US and find that the expectation hypothesis is not rejected. Gürkaynak (2005) analyses the surprise on US monetary policy and differentiate between the level, slope and timing of the surprises.

Several contributions have been published on the relation between money market instruments and monetary policy implementation by the ECB. Some of them focus only on the ECB, whereas others compare the ECB with other central banks with longer history and experience. Sebestyen (2005) uses even tick-by-tick data on 3-month Euribor (Euro Interbank Offered Rate) future contracts and regresses them on monetary and economic data surprises, finding that short-term rates markets are, at least in the short term, influenced by central bank's 'talking', not only action. Ross (2002) has compared monetary policy perceptions for the FED, the ECB and the Bank of England (including 3.5 years of the existence of the ECB), finding that the ECB has, indeed, been less predictable than the other two central banks.[2] Perez-Quiros and Sicilia (2002) use daily data on short-term instruments to calculate monetary policy and other economic surprises with the objective of measuring how predictable the ECB has been in conducting its policy.[3] Bernoth and von Hagen (2004) have been among the first to take into account longer-term predictability of the ECB's monetary policy in this area. It appears that during the first years of the ECB's existence, market participants were able to predict short-term rates well, and this ability has improved with time.

The literature described earlier suggests that with regard to testing the expectation hypothesis, the ability to capture the dynamics of the risk premium can be an important factor in determining the results of the tests (see, e.g., Piazzesi and Swanson, 2006). This observation brings me to the second objective of the paper, which is to show how the market participants'

[1] Given the short history of the European market, the majority of analyses of that market are concentrated on very short-term surprises, as pointed out later in this section.

[2] Wilhelmsen and Zaghini (2005) also compare the ECB to 13 other central banks and, differently from Ross (2002) find that the predictability of the ECB has not been lower compared to other central banks.

[3] Perez-Quiroz and Sicilia (2002) also consider a different set of money market instruments, but instead of analysing them separately, as is done in this paper, they extract the principal components of the instruments' daily changes. This method has the advantage of reducing possible measurement errors stemming from a particular money market rate; at the same time, there is the risk of losing relevant information due to the fact that the principal component analysis gives equal weight to each series.

ability to predict the ECB's monetary policy actions has changed during the first decade of the ECB's operation. The change is suggested by anecdotal evidence.[4] This means that in testing the expectation hypothesis these dynamics must be captured in some way. I use one of the instruments analysed in the first part of the paper in order to perform this test.

The paper is organized as follows. Section 2 explains the theoretical background. Section 3 describes the data used in the empirical analysis. The empirical results for the first objective of the paper (comparison of different money market instruments) are presented and analysed in Section 4. Section 5 is dedicated to the analysis of regression results for the second objective of the paper (changes in the perception of the ECB's monetary policy). Section 6 concludes.

## 2. Theoretical Background

This section describes the theoretical framework supporting the present analysis.[5] As stated in the previous section, the first objective of this paper is to compare different short-term instruments in order to assess which one has been the most successful in predicting monetary policy actions in the case of Europe.

In conducting the analysis, I assume the expectation hypothesis to hold, which corresponds to assuming market efficiency and rational market participants. This implies that no arbitrage conditions hold for the markets considered here (derivatives of short-term interest rates). In brief, all information available at a given point in time is used to assess derivatives and the best estimate of future price of the underlying asset is the derivative price. Defining ${}_{m}s_{m,n}$ as the short-term interest rate $s$ observed at time $m$, starting at time $m$ and maturing at time $n$ (with $m < n$), and ${}_{t}fwd_{m,n}$ as the forward interest rate observed at time $t$, with settlement at time $m$ and maturity at time $n$ (with $t < n$), the no arbitrage condition tells us that the following holds:

$$(1) \qquad {}_{t}fwd_{m,n} = E_t[{}_{m}s_{m,n}] + \rho$$

For the no arbitrage condition to hold, the return on investment in forward rate $fwd$ with the starting date $m$ and the end date $n$ done at time $t$ must be equal to the expected return on investment with a short-term interest rate $s$ started on $m$ with maturity $n$. The term $\rho$ represents adjustment for the risk premium: the two investment decisions are taken at different times. The forwards is fixed at $t$, and the return on this investment is already known on $t$. On the other hand, investment with a short-term rate

[4] See Bernoth and von Hagen (2004), Jansen and De Haan (2006) and Blattner *et al.* (2008).
[5] The main reference for this section is the paper by Gürkaynak *et al.* (2007).

$s$ is started later, at time $m$, and the return on investment is known only on $m$. Investors require a positive or negative risk premium on returns due to the risk embedded in the time mismatch of the two investment strategies. A risk premium is imposed here, but it can also be derived analytically. As shown by Söderlind and Svensson (1997), the risk premium can be related to the covariance between spot rates and discount factors (used to model the entire term structure of interest rates). As the authors specify, these terms are not observable, which is why they use an empirical derivation of these terms and find that they do not vary significantly, at least as regards short-time risk premiums.

In the case of overnight interest rate (with a maturity of just one day), $n$ would be equal to $m + 1$, and Equation (1) can be rewritten in the following way:

$$ {}_{t}fwd_{m,m+1} = E_t[{}_{m}s_{m,m+1}] + \rho \tag{2} $$

In order to apply Equation (2) for the analysis of European money market instruments, some adjustments must be made.

First, forwards of overnight interest rates ${}_{t}fwd_{m,m+1}$ are usually not priced in the market. Therefore, they must be substituted with a money market instrument with a maturity greater than 1 day (typically 1 or 3 months) which has a price that can be observed in the market. These instruments are not set by central banks, but are highly influenced by the interest rates established by them.[6]

Second, some forward rates used in the following empirical analysis are not quoted in the market, but can be calculated from the spot curve.[7] In order to calculate forward rates from the spot curve, the following formula has been used:

$$ {}_{t}fwd_{m,n} = \left[ \frac{\left(1 + {}_{t}s_{t,n}\dfrac{d_n}{360}\right)}{\left(1 + {}_{t}s_{t,m}\dfrac{d_m}{360}\right)} - 1 \right] \frac{360}{d_n - d_m} \tag{3} $$

where $s$ are the spot rates, as defined earlier, and $d$ is the maturity of each spot rate ($d_n$ being the maturity for spot rate ${}_{t}s_{t,n}$, in a number of days). This equation can be used to calculate forward rates from spot rates observed at time $t$.

Along with the forwards/futures instruments, I also need the realized spot instrument in order to asses the ability of the forwards/futures to predict the spot. For some instruments, the spot rate is already available in

[6] For example, Piazzesi and Swanson (2006) use 1-month FED fund futures in the case of US in their empirical analysis.

[7] The spot curve is the curve as observed today at current market prices and it describes the return on investment with different horizons entered into today.

the market. For example, the 1-month Libor (London Interbank Forward Rate) forward starting in 2 months time can be compared with the 1-month Libor observed 2 months later. The same applies to Euribor forwards.

For two other instruments – 1-month Eonia (Euro Overnight Index Average) futures and forwards from Bubills (German Treasury bills) – the realized spot is not immediately available and must be calculated. The solution provided by Gürkaynak *et al.* (2007) is represented by the following equation, where daily overnight rates are compounded over a monthly period in order to obtain the monthly realized short-term rate ${}_t\overline{ON}_{m,n}$:

$$(4) \qquad {}_t\overline{ON}_{m,n} = \left[ \prod_{j=m}^{n-1} \left(1 + ON_j\right) - 1 \right]$$

The variable ${}_t\overline{ON}_{m,n}$ denotes the realized return on investment in the overnight rate $ON_j$ for the period from $m$ to $n$ (hence for $m - n$ days). On the left the subscript $t$ is reported, because it is compared to what follows with the expected rate observed in period $t$ for the period $m$ to $n$ [see Equation (5)].

As explained earlier, the 1-month Eonia future covers a calendar month, therefore $m - n$ spans from 28 to 31 days. In the case of German T-bills, $m - n$ represents the distance in days between two consecutive Bubills maturity dates and it spans from 27 to 41 days.

Third, Equation (1) is rewritten so that it can be studied empirically:

$$(5) \qquad {}_t\overline{ON}_{m,n} = \alpha + \beta_t fwd_{m,n} + \varepsilon_t$$

Equation (5) represents the linear regression of realized spot rates on forward/futures rates[8] with $\varepsilon_t$ representing the error term of the regression.

Some comments regarding Equation (5) are warranted. First, I treat futures rates, forward rates and forward rates extrapolated from the spot curve in the same way. This means that any consideration regarding convexity in the spot curve is left aside.

Second, Equation (5) is the testable version of Equation (1). The two equations are equivalent (let aside the error term) if $\alpha$ is equal to $-\rho$ and $\beta$ is equal to 1. This is the test conducted in the next section.

Third, in Equation (5) $\alpha$ is restricted to be a constant, which corresponds to the assumption that the risk premium is constant. This is, in general, recognized to be a restrictive hypothesis, but when dealing only with short-term interest rates it should not affect the results much. For

[8] An alternative way to test if forward rates are good predictors of future spot rates is proposed by Perez-Quiroz and Sicilia (2002). Cointegration between the two variables is tested, i.e. if the two variables present a unit root, they conclude that $\beta$ can be accepted to be equal to one.

example, Sack (2002) shows that, in the US case, monetary policy expectations extracted from money market rates using constant risk premium are fairly equal to those extracted using varying risk premium with a horizon of up to two quarters, and start to differ substantially over a 1-year forecast horizon.[9]

Fourth, the main test I use in the next section is on the value of $\beta$. The effectiveness of different instruments in predicting the future monetary policy path are assessed, testing how far the value of $\beta$ is from 1 and also how stable it is.

Fifth, another problem that can affect the testing of Equation (5) is that the variables could be co-integrated. Therefore, I follow the procedure used by Gürkaynak *et al.* (2007) and correct Equation (5) for the level, subtracting from both sides of the equation the level of overnight rate at time $t$, ${}_tON_{t+1}$, when forward and futures values are observed.

$$(6) \qquad {}_t\overline{ON}_{m,n} - {}_tON_{t,t+1} = \alpha + \beta({}_tfwd_{m,n} - {}_tON_{t,t+1}) + \varepsilon_t$$

This is the equation that I use for the test. Results are reported and commented in Section 4.

## 3. Data Description

As already pointed out in the Introduction, the history of the 'pan-European' money market is relatively short. This means that there is no 'European' short-term instrument with a data series starting before 1999, and most 'European' short-term instruments started to be traded even later. In this section, a description of different money market instruments is given.

Instruments with different maturities are employed: from 1-month Eonia futures to forwards calculated from the Euribor curve. In addition, for comparison, one instrument with data available before 1999 is also included in the analysis.[10]

The main characteristics of all the instruments are reported in Table 1. The analysis is limited to instruments with 1-month maturity, excluding those with 3-month maturity, mostly used in the literature described earlier. This choice is based on two arguments. First, the regressions reported below have also been run for the 3-month Euribor and Libor, with results very similar to the ones reported here. Second, the results regarding

[9] Piazzesi and Swanson (2006) use FED fund futures to show in the US case that the risk premium is not constant and also that it is countercyclical. Its changes through time can be predicted both by macroeconomic variables (such as unemployment) and financial variables (such as Treasury yield spreads).

[10] The Libor collected by the British Bankers Association was called Demlibor before 1999; Eurolibor (here Libor) is the successor of Demlibor since 1999.

Table 1: Data Description

| | One month instruments | | | | | |
|---|---|---|---|---|---|---|
| | Source | Day count | Maturity | Short-term | Start date | End date |
| Libor forward 1 month | BBA | Act/360 | Monthly (1–10) | 1m Libor | May 1996 | Jul 2007 |
| Euribor forward 1 month | Liffe | Act/360 | Monthly (1–10) | 1m Euribor | Feb 1999 | Jul 2007 |
| Eonia 1 month futures | Eurex | Act/360 | Monthly (1–10) | Eonia o/n rate | Mar 2003 | Jul 2007 |
| Bubill forward 1 month | Bloomberg | Act/360 | Monthly (1–5) | Fibor o/n rate | Dec 2002 | Jul 2007 |

*Note:* Libor forward, Euribor forward and German T-bills are spot rates. For the analysis, forwards have been extracted from their spot curve.

1-month instruments should be, at least in theory, more precise because it would allow reduction of the (small) term premium effect embedded in these instruments.

Some of the instruments reported in Table 1 are derivatives (futures and traded forwards), and some of them are spot rates. The distinction is relevant because spot rates are affected by convexity, that is the shape of the spot curve from today to the end of the period considered, where in the case of futures only the period between settlement and expiration matters[11]. Similar to Gürkaynak *et al.* (2007), I use forward rates extracted from the spot curve.

For every instrument in Table 1, the data source, the day count convention, the short-term rate used as the realized rate in the estimation, the starting point and the end point of the series utilized in the estimation have been reported. The end point of the estimation is the end of July 2007 for each instrument. This means that the sample analysed here ends before the current financial crisis. The analysis of this paper seeks to focus on ordinary periods, where extreme conditions are not causing malfunction or total breakdown of money markets, as was the case after the start of the crisis; that is, from summer 2007 until autumn 2009.[12]

In the remaining part of this section, a more detailed description of the four money market instruments used in the empirical section is given.

### *3.1. One-Month Libor Forward*

Libor rates are set by the British Bankers Association (BBA) each day at 11 a.m. London time, taking the average of deposits offered by a group of banks in the 1–12 months interbank market. From the beginning of 1999, the Euro Libor has been used. Sixteen banks are used as contributors, and every day the top and bottom quartile of the rates offered are excluded in the calculation of the average. These provisions make the data quality of Libor rates very high. Libor rates are also very important for the financial markets, because they are used to build most of the interest rates derivatives denominated in the euro. For the current analysis, I observe the series starting from May 1996 and use Demlibor data for the period prior to 1999.

### *3.2. One-Month Euribor Forward*

Euribor rates were launched at the beginning of 1999 with the introduction of the euro to provide a reference point for short-term rates

[11] In the case of not very distant forwards, this problem should not affect the results of the analysis.

[12] In a future work it would be interesting to explore what happened during the period of financial crisis.

in the euro area. They are very similar to Libor rates, the only difference being the pool of banks from which daily deposit rates are taken in order to calculate the average. Euribor rates are sponsored by the European Banking Federation, which collects quotations from European banks. The top and bottom 15 per cent of the quotations are excluded before calculating the average, which constitutes the daily fixing (at 11 a.m. Brussels time).

### *3.3. One-Month Eonia Futures*

This instrument was created by Eurex in January 2003. Even if the data series is quite short, it is interesting to include this instrument in the analysis because how it is constructed makes it the best proxy of benchmark rates expectation. It is constructed according to the same principle as the FED fund futures in the US[13]: the rate to be delivered is the monthly average of the Eonia reference rate, which is fixed by the European Central Bank. As already said, Eonia is not controlled directly by the central bank, but it is still the best available measure of the reference overnight rate. Taking the monthly average of Eonia as the underlying rate of the contract has the benefit of reducing noises on the single-day quotation, which are often due to the regulatory framework (minimum reserve requirements).

### *3.4. German T-Bills (Bubills)*

German T-bills are short-term zero coupon bonds issued by the German Treasury. They all have a 6-month maturity. Bubills have been issued every quarter from 1997, and then monthly from April 2002. The quality of data is not very good for the period before 2000; therefore, I have used them only in the monthly estimations, starting from December 2002. Again, forwards from the spot rates are calculated. For benchmark rate comparison, I used the return on investment in the German Fibor (Frankfurt Interbank Offered Rates) from Bloomberg.

## 4. Regressions Results: Comparison of Short-Term Interest Rates

The analysis of empirical results is divided into two parts. In the first one, a series of regressions has been conducted for different instruments and different time periods in order to assess the predictive ability of the short-term instruments discussed in Section 3 and to see how the results

[13] Gürkaynak *et al.* (2007) find that it is the best instrument to predict the FED's monetary policy.

are sensitive to time sample changes (Sections 4.1 and 4.2). In the second part (Section 5), I concentrate on the change in the perception of the ECB's monetary policy by performing Regression (6) and using different rolling time windows.

### *4.1. Comparison of Different Short-Term Instruments: Common Sample*

In this section, I compare how the four instruments described in Section 3 have been able to predict the monetary policy path. Table 2 reports the results of Regression (6) for the four instruments. The regressions have been conducted using the OLS method (as all the regressions in the remaining part of the paper). The data set is quite short (from July 2003) because the trade of 1-month Eonia futures started that year. Intuitively, if, as reported by Piazzesi and Swanson (2006), cyclical macroeconomic factors affect both $\alpha$ and $\beta$, having only one part of the interest rate cycle in the sample can affect the results of the test substantially.[14] It must be noted that even if I take into account only one part of the cycle to compare the four money market instruments, their relative performance can still be assessed.

Table 2 reports the results of the regression in four blocks, each for every money market instrument analysed. The left part of the table reports the results of Regression (6), with coefficients' values and *t*-stat for $\alpha$ and $\beta$, and $R^2$ and Durbin–Watson statistics. Each column reports the results for different forward rates (from 1 to 5).

$\alpha$ is different from 0 for every forward, suggesting that market participants required some risk premium when investing in money market instruments. $\beta$ is not different from 1 in most cases, with the exception of the first three Eonia futures.

The main thing to notice from the regressions' results is that residuals are autocorrelated (with the exception of the first two forwards). Therefore, an LM test has been conducted to detect the order of autocorrelation (see details in Appendix, Table A.1). Autocorrelation is limited to the first order; therefore, Equation (6) has been modified and estimated including an AR(1) error term in the following way:

$$
\begin{aligned}
{}_t\overline{ON}_{m,n} - {}_tON_{t,t+1} &= \alpha + \beta({}_tfwd_{m,n} - {}_tON_{t,t+1}) + e_t \\
e_t &= \rho e_{t-1} + \varepsilon_t
\end{aligned}
\tag{7}
$$

The error term of the original model $e_t$ is therefore modelled as depending on its first lag (with $\rho$ measuring the degree of dependence),

[14] In the first half of 2003, the ECB cut the interest rates from 2.75% to a record low level of 2.0%, and kept them unchanged until December 2005, when the robust upward cycle began. At the end of the present sample, the ECB increased the interest rates by 200 basis points.

Table 2: Regression Results for Four Money Market Instruments, Equations (6) and (7)[a]

| Monthly data, start date 31.07.2003, end date 31.07.2007, different instruments | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Without AR(1) coefficient | | | | | With AR(1) coefficient | | | | |
| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
| Bubill fwd | | | | | | | | | | |
| $\alpha$ | 0.092 | 0.093 | 0.077 | 0.111 | 0.095 | 0.097 | 0.099 | 0.137 | 0.179 | 0.203 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (7.761) | (5.971) | (4.487) | (5.155) | (3.430) | (6.273) | (3.958) | (2.324) | (2.580) | (2.196) |
| $\beta$ | 0.914[b] | 0.777[b] | 0.841[b] | 1.066[b] | 0.959[b] | 0.934[b] | 0.725[b] | 0.408 | 0.584 | 0.442 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (−0.722) | (−1.363) | (−1.358) | (0.485) | (−0.334) | (−0.672) | (−1.589) | (−6.577) | (−3.541) | (−3.878) |
| $\rho$ | | | | | | 0.349 | 0.424 | 0.790 | 0.759 | 0.779 |
| $t$-Stat | | | | | | (2.538) | (2.960) | (8.560) | (7.533) | (7.798) |
| $R^2$ | 0.560 | 0.334 | 0.540 | 0.588 | 0.597 | 0.618 | 0.444 | 0.778 | 0.779 | 0.781 |
| DW | 1.245 | 1.098 | 0.845 | 0.816 | 0.853 | 1.990[c] | 1.923[c] | 2.292[c] | 2.174[c] | 2.312[c] |
| Libor fwd | | | | | | | | | | |
| $\alpha$ | −0.016 | −0.017 | −0.011 | −0.014 | −0.010 | −0.016 | −0.014 | 0.098 | 0.109 | 0.216 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (−2.195) | (−1.354) | (−0.617) | (−0.597) | (−0.295) | (−2.204) | (−0.903) | (1.676) | (1.384) | (1.596) |
| $\beta$ | 0.875[b] | 0.867[b] | 0.870[b] | 0.952[b] | 0.916[b] | 0.874[b] | 0.843[b] | 0.348 | 0.501 | 0.323 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (−1.626) | (−1.720) | (−1.510) | (−0.507) | (−0.789) | (−1.641) | (−1.732) | (−5.008) | (−3.774) | (−5.321) |
| $\rho$ | | | | | | −0.024 | 0.173 | 0.801 | 0.823 | 0.875 |
| $t$-Stat | | | | | | (−0.163) | (1.178) | (9.313) | (9.328) | (12.263) |
| $R^2$ | 0.739 | 0.736 | 0.699 | 0.702 | 0.639 | 0.739 | 0.744 | 0.827 | 0.859 | 0.870 |
| DW | 2.074[c] | 1.616[c] | 0.942 | 0.691 | 0.589 | 2.033[c] | 1.869[c] | 1.828[c] | 1.961[c] | 1.892[c] |
| Eonia futures | | | | | | | | | | |
| $\alpha$ | 0.004 | 0.008 | 0.018 | 0.026 | 0.035 | 0.005 | 0.011 | 0.049 | 0.177 | 0.187 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (0.511) | (0.754) | (1.285) | (1.272) | (1.210) | (0.529) | (0.796) | (1.699) | (1.735) | (1.781) |
| $\beta$ | 0.705 | 0.816 | 0.827 | 0.854[b] | 0.871[b] | 0.701 | 0.793 | 0.623 | 0.327 | 0.393 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (−3.470) | (−2.573) | (−2.515) | (−1.856) | (−1.368) | (−3.255) | (−2.448) | (−3.173) | (−6.712) | (−4.750) |
| $\rho$ | | | | | | −0.017 | 0.216 | 0.555 | 0.879 | 0.833 |
| $t$-Stat | | | | | | (−0.108) | (1.452) | (3.999) | (12.144) | (9.630) |
| $R^2$ | 0.600 | 0.743 | 0.766 | 0.733 | 0.670 | 0.600 | 0.754 | 0.809 | 0.882 | 0.848 |
| DW | 1.898[c] | 1.570[c] | 1.189 | 0.821 | 0.657 | 1.879[c] | 1.915[c] | 2.177[c] | 2.180[c] | 2.139[c] |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Euribor fwd | | | | | | | | | | |
| $\alpha$ | −0.017 | −0.017 | −0.011 | −0.016 | −0.005 | −0.017 | −0.013 | 0.107 | 0.112 | 0.237 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (−2.237) | (−1.363) | (−0.584) | (−0.665) | (−0.146) | (−2.195) | (−0.866) | (1.727) | (1.380) | (1.662) |
| $\beta$ | 0.881[b] | 0.862[b] | 0.873[b] | 0.951[b] | 0.903[b] | 0.882[b] | 0.834[b] | 0.312 | 0.493 | 0.282 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (−1.508) | (−1.764) | (−1.422) | (−0.513) | (−0.906) | (−1.456) | (−1.809) | (−5.158) | (−3.932) | (−5.847) |
| $\rho$ | | | | | | 0.012 | 0.183 | 0.810 | 0.831 | 0.881 |
| $t$-Stat | | | | | | (0.086) | (1.237) | (9.711) | (9.634) | (12.770) |
| $R^2$ | 0.730 | 0.731 | 0.684 | 0.698 | 0.626 | 0.730 | 0.740 | 0.822 | 0.862 | 0.870 |
| DW | 2.001[c] | 1.609[c] | 0.939 | 0.675 | 0.591 | 2.022[c] | 1.877[c] | 1.834[c] | 1.967[c] | 1.895[c] |

*Note: fwd* 1 indicates the first forward, or $fwd_{1,2,}$ beginning 1 month after the price fixing (in $t$) and ending 2 months after the price fixing. Tests for the null hypothesis of $\beta$ equal to 0 has also been performed, but not reported here. The null hypothesis has always been rejected with 95% confidence.

[a]Tests for the null hypothesis of $\beta$ equal to 0 has also been performed, but not reported here. The null hypothesis has always been rejected with 95% confidence.

[b]The hypothesis of $\beta$ equal to 1 cannot be rejected with 95% probability.

[c]Residuals not autocorrelated with 95% confidence.

with $\varepsilon_t$ being the shocks to the autoregressive component of the model, assumed to be independent, with zero mean and constant variance. The results of the regressions on Equation (7) are reported in the right-hand side of Table 2. The same statistics are reported and also the values of coefficient $\rho$ with $t$-stat are shown.[15] It can be seen that DW statistics shows no autocorrelation in the residuals, confirming that the problem of autocorrelation is limited to the first lag and therefore, the estimated coefficients are not biased.

The results of the estimation of Equation (7) are reported in the right-hand side Table 2 and analysed here in some detail. Starting with $\alpha$, it is increasing in size with the distance of the forwards, as expected (more distant forecasts imply a higher risk premium). The size is quite small for the first two forwards, with the exception of the Bubills, where the risk premium is higher. It must be stressed here that both the size and standard errors of the parameters are influenced by the short sample considered (in order to compare all four instruments). Therefore, a more detailed analysis will follow later when a longer sample of Libor rates will be examined.

As regards $\beta$, the residuals' correlation has a major impact. For the first two forwards, the estimated $\beta$ coefficient is close to 1 (with the exception of the Eonia rate), and is very low for more distant forwards. This will be analysed in more details later. Focusing on the differences between different money market instruments, the only outlier is Eonia, for which $\beta$ is different from 1 also for the first two forwards. Eonia's behaviour can be explained by two factors. First, Eonia futures were launched at the beginning of the sample, which is why this financial instrument was more volatile and less efficient at the beginning of its life (this is relevant considering that the estimation with the common sample has been performed based on a very short sample). Secondly, Eonia futures are based on the Eonia rate, not on a monthly rate, and are thus more influenced by technical factors, such as the seasonality of the ECB's reserve requirement.[16]

The analysis of $R^2$ can also be useful for the comparison of the four instruments. In particular, if the expectation hypothesis holds, then higher $R^2$ should signal that the higher share of the variance of forward rates is explained by the realized short-term rate (and not by other factors not included in the regression). The $R^2$ of Libor and Euribor for the first two forwards is between 0.72 and 0.75 (for both regressions with and without the AR(1) term), but is lower for Bubills and Eonia futures, confirming that Libor and Euribor behave more in line with the expectation hypothesis theory.

[15] Regressions of Equation (7) were also performed with a correction for heteroskedasticity in the VCV matrix (White), but the results (not reported here) were not substantially different.

[16] The behaviour of Eonia will be interesting to reconsider when a longer sample will be available.

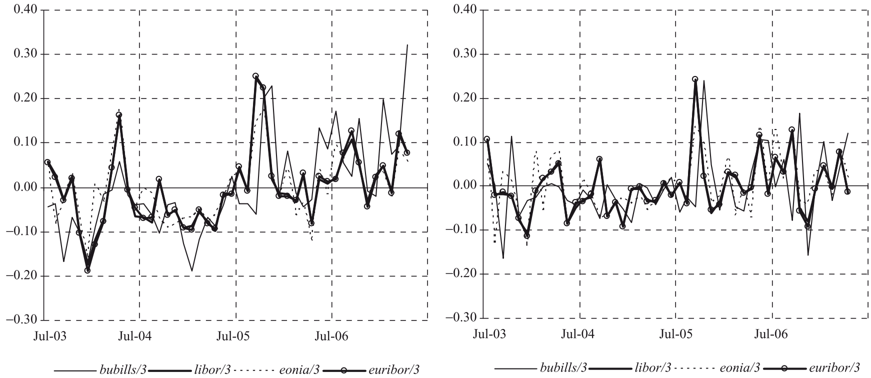


Figure 2: Residuals, *fwd* 3, 2003–2007

The analysis of the residuals of the previous regressions can also be useful for shedding light on our tests. First of all, in order to compare the four instruments I use the third forward [i.e. residuals from the estimation of (6) and (7) for ${}_tfwd_{3,4}$, reported as *fwd* 3 in Table 2] for the common sample (2003–2007).

Figure 2 depicts residuals from the regression of the third forward both with AR(1) regressor (right) and without it. In relative terms, the two graphs deliver the same message. The residuals from Bubills' regressions are more volatile, in particular in the second part of the sample, whereas the residuals from Eonia are more volatile than Euribor and Libor residuals in the first part of the sample (as noted earlier, this could be due to the lower liquidity of Eonia futures just after they have been launched).

The comparison on residuals for the first and second forward (not reported here) gives the same message, that is Euribor and Libor regressions behave 'better' than the other two instruments.

It is also noticeable that all residuals show a positive substantial hike at the end of 2005, when the ECB started to increase the interest rates, probably earlier than the market expected.

As regards the comparison of the four instruments for their common sample (July 2003 to July 2007), the following conclusions can be drawn:

1 The sample is rather short, not including an entire business (and interest rate) cycle, making the results reported here subject to some uncertainty.
2 Bubills seem inferior to the other instruments, both in terms of $R^2$ and autocorrelation in the residuals. This is probably due to liquidity matters, because most of the issues tend to finish in the books of investors that keep them until the maturity, and the secondary market quotations are therefore not as efficient as in the case of more liquid money market instruments.

3 Libor and Euribor give very similar results.
4 Eonia futures also display results similar to Libor and Euribor, with the exception of the tests for values of $\beta$ equal to 1, which is rejected for the first three futures in regression without AR(1) term, and for all the futures when AR(1) term is included.

Before addressing the problem of the short sample, I would like to comment on the value of $\beta$. The results of $\beta$ are the most affected by the inclusion of AR(1) terms in the regression. If $\beta$ is, in fact, generally close to 1 when AR(1) term is not included, correcting for the autoregression in the residuals provides a clear separation of results between the first two and the more distant forwards. More specifically, adding the AR(1) component does not change the results markedly for the first two forwards, whereas for more distant forwards $\beta$ becomes statistically different from 1 (lower) and $\alpha$ increases with the distance of the forwards. Also, the autoregressive coefficient $\rho$ is significant and with an average size of around 0.8. These results can be jointly interpreted as a signal that the model as specified here looses its explanatory power with the distance of the forward.

Two remarks should be made at this point. First, in building expectations, market participants most probably attach more uncertainty to forecasts that are distant in time, which is well captured by the increase in the value of $\alpha$ when the autocorrelation of the residuals is taken into account. Second, the difference between the realized rates and the forecasted ones increases with the distance of the forward, because more 'unexpected events' happen when more time passes. This cannot be captured by the model as specified here [both Equations (6) and (7)]. This does not mean that the expectation hypothesis must be rejected. On the contrary, it seems that the first two forwards (with a short time horizon) confirm the expectation hypothesis, and the fact that $\beta$ is different from 1 for more distant forwards is a signal of the necessity for a better specified model, not a signal of rejection of the expectation hypothesis. Moreover, this does not hinder using the results of the analysis for the comparison of different money market instruments.

The rest of the analysis is focused on the first two forwards, but the results for the more distant forwards are also reported and discussed.

### *4.2. Different Samples: Libor Case*

The following analysis uses Libor because it seems to be superior to Bubills and Eonia and is very similar to Euribor, but is available for a longer sample (dating back to May 1996).[17] In particular, I want to understand

[17] The longer sample is included in the regression even if it covers periods with two different monetary regimes: German Bundesbank until the end of 1998 and the European Central Bank

with the following analysis if the parameters estimated earlier have similar values when a longer sample is taken into account. Table 3 reports the estimation results for Libor rates in three different samples: from 2003, as initially; from 1999 when the euro was introduced, and from 1996.

The regressions results of a longer sample partly confirm and partly extend the conclusions of the short sample analysis. The most important change comes from the fact that the hypothesis of $\beta$ different from 1 cannot be rejected also for the first two forwards, when the model is corrected for autocorrelation of the residuals and a longer sample is utilized. Still, in absolute terms, the values of $\beta$ for the first two forwards are remarkably different from the values of more distant forwards. Focusing on the sample starting from the launch of the euro, the first two forwards $\beta$ are above 0.7, whereas the coefficients of more distant forwards are around 0.55.

Figure 3 shows how residuals behave in the case of different forwards in the sample starting from 1999. Two findings emerge from this picture. First, for more distant forwards residuals are more volatile (given that factors different from pure interest rate expectations play a role in determining the difference between forward rates and realized short-term rates). Second, in anticipation of the next paragraph, for all the residuals the first part of the sample is more volatile than the second part.

The main conclusions from this section are as follows:

1 The use of a longer sample for the regression and correction for autocorrelation in the residuals bring us to reject the expectation hypothesis.
2 $\beta$ coefficients continue to show a different behaviour for the first two forwards, being closer to 1.
3 The inspection of residuals suggests that changes happened within the sample (for the period starting from the launch of the euro) and, in particular, the volatility of the residuals is higher at the beginning of the period and lower in a later stage.[18]

## 5. Regression Results: Market's 'Learning Curve'

This section provides an analysis of the impact of the launch of the euro and the new setup of monetary policy in Europe. Various contributions

thereafter. Given that the ECB's regulative and monetary policy framework has been largely adopted from the framework of Bundesbank, the two regimes have not been explicitly distinguished here.

[18] FED Funds rates could be an important explanatory variable possibly missing from regressions (6) and (7). The rational behind this intuition is that external factors can be relevant in explaining ECB decisions on interest rates, and one of the most influential external factor could be monetary policy set by US central bank. Equations (6) and (7) have been tested adding the FED fund future term on the right side of the equations. Some of the results are reported in Table C in appendix. Regression results are not further commented here, because they are outside the main scope of the paper, but further analysis on external influence on European money markets could be relevant.

Table 3: Regression Results for the Libor Rates, Equations (6) and (7)

| Monthly data, Libor 1 month, different start date, end date 31.07.2007 | Without AR(1) coefficient | | | | | With AR(1) coefficient | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
| From 31.07.2003 | | | | | | | | | | |
| $\alpha$ | −0.016 | −0.017 | −0.011 | −0.014 | −0.010 | −0.016 | −0.014 | 0.098 | 0.109 | 0.216 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (−2.195) | (−1.354) | (−0.617) | (−0.597) | (−0.295) | (−2.204) | (−0.903) | (1.676) | (1.384) | (1.596) |
| $\beta$ | 0.875[a] | 0.867[a] | 0.870[a] | 0.952[a] | 0.916[a] | 0.874[a] | 0.843[a] | 0.348 | 0.501 | 0.323 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (−1.626) | (−1.720) | (−1.510) | (−0.507) | (−0.789) | (−1.641) | (−1.732) | (−5.008) | (−3.774) | (−5.321) |
| $\rho$ | | | | | | −0.024 | 0.173 | 0.801 | 0.823 | 0.875 |
| $t$-Stat | | | | | | (−0.163) | (1.178) | (9.313) | (9.328) | (12.263) |
| $R^2$ | 0.739 | 0.736 | 0.699 | 0.702 | 0.639 | 0.739 | 0.744 | 0.827 | 0.859 | 0.870 |
| DW | 2.074[b] | 1.616[b] | 0.942 | 0.691 | 0.589 | 2.033[b] | 1.869[b] | 1.828[b] | 1.961[b] | 1.892[b] |
| From 31.01.1999 | | | | | | | | | | |
| $\alpha$ | −0.026 | −0.059 | −0.068 | −0.094 | −0.115 | −0.025 | −0.042 | −0.005 | 0.021 | 0.056 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (−2.355) | (−3.828) | (−3.458) | (−3.887) | (−3.822) | (−2.115) | (−1.670) | (−0.071) | (0.202) | (0.430) |
| $\beta$ | 0.736 | 0.933[a] | 1.003[a] | 1.139[a] | 1.234 | 0.725 | 0.772 | 0.550 | 0.562 | 0.535 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (−3.808) | (−0.985) | (0.037) | (1.913) | (2.823) | (−3.705) | (−2.735) | (−6.209) | (−5.910) | (−4.606) |
| $\rho$ | | | | | | 0.060 | 0.446 | 0.780 | 0.863 | 0.864 |
| $t$-Stat | | | | | | (0.593) | (4.838) | (12.470) | (17.193) | (18.343) |
| $R^2$ | 0.538 | 0.656 | 0.688 | 0.716 | 0.698 | 0.539 | 0.715 | 0.833 | 0.890 | 0.893 |
| DW | 1.931[b] | 1.231 | 0.916 | 0.721 | 0.623 | 2.033[b] | 1.776[b] | 1.874[b] | 1.731[b] | 1.732[b] |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| From 31.05.1996 | | | | | | | | | | |
| $\alpha$ | −0.022 | −0.058 | −0.071 | −0.100 | −0.128 | −0.022 | −0.054 | −0.040 | −0.042 | −0.047 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (−2.203) | (−4.447) | (−4.345) | (−4.734) | (−4.898) | (−2.142) | (−2.659) | (−0.876) | (−0.506) | (−0.412) |
| $\beta$ | 0.645 | 0.902[a] | 0.971[a] | 1.054[a] | 1.155 | 0.647 | 0.822 | 0.615 | 0.546 | 0.570 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (−6.157) | (−1.676) | (−0.484) | (0.806) | (2.059) | (−5.962) | (−2.561) | (−5.677) | (−6.635) | (−4.957) |
| $\rho$ | | | | | | 0.064 | 0.418 | 0.736 | 0.845 | 0.868 |
| $t$-Stat | | | | | | (0.732) | (5.068) | (11.569) | (16.933) | (18.550) |
| $R^2$ | 0.486 | 0.643 | 0.671 | 0.661 | 0.648 | 0.492 | 0.704 | 0.808 | 0.859 | 0.871 |
| DW | 1.863[b] | 1.208 | 0.894 | 0.702 | 0.571 | 1.986[b] | 1.844[b] | 1.906[b] | 1.718 | 1.792[b] |

*Note*: *fwd* 1 indicates the first forward, or $fwd_{1,2}$, beginning 1 month after the price fixing (in $t$) and ending 2 months after the price fixing. Tests for the null hypothesis of $\beta$ equal to 0 have also been performed, but not reported here. The null hypothesis has always been rejected with 95% confidence.
[a]The hypothesis of $\beta$ equal to 1 cannot be rejected with 95% probability.
[b]Residuals not autocorrelated with 95% confidence.

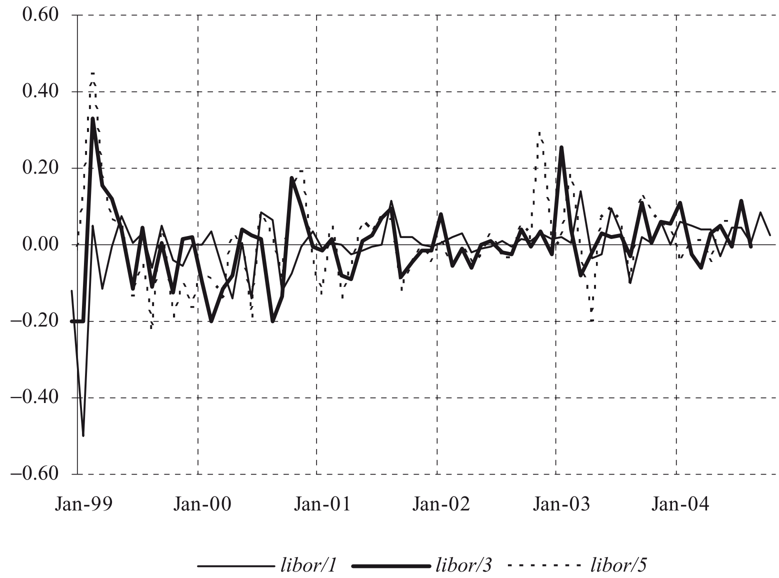


Figure 3: Residuals of Regression From 1999, *fwd* 1, *fwd* 3, *fwd* 5

in literature show the importance of the communication framework and central bank's credibility in conducting effective monetary policy.[19] The credibility of the newly established European Central Bank and the ability of financial markets to understand and forecast the ECB's policy decisions have been a subject of great debate in the first years of the single European monetary policy.

One way to test how the market perception of the ECB's policy has changed through time is to see how the parameters estimated with Regression (7) have evolved since 1999. Intuition suggests that if it is true that markets (in our case money markets) attached some degree of uncertainty regarding the way the European Central Bank conducted monetary policy at the beginning of its mandate, and that this uncertainty has diminished through time and the ECB's credibility has increased, then at least some of the following phenomena could be observed:

[19] An excellent overview of last decade literature on central banks communication is given by Blinder *et al.* (2008). For the ECB case studies on predictability of its monetary policy have conducted mainly with short-term horizon. Bernoth and Hagen (2004) use 3 months Euribor futures daily volatilities to test for monetary policy surprises and find that ECB's monetary policy perception by financial markets is improved from the beginning of its mandate. Gaspar *et al.* (2001) use Eonia rates also with a very short forecast horizon, and find that ECB policy action has been very well predicted by financial markets already from the beginning. Wilhelmsen and Zaghini (2005) compare 14 different central banks and find that ECB predictability in the very short term is in line with other central banks.

- A decreasing level of $\alpha$: if $\alpha$ can be seen as a measure of risk aversion, then it should have decreased in the last years.[20]
- A value of $\beta$ closer to 1: the forecasting error on the ECB rates should diminish.
- $R^2$ should increase, and also the residuals of Regression (7) should be less volatile. The intuition behind this hypothesis is that when market participants are able to anticipate monetary policy, the difference between forward rates and realized spot rates should be completely captured by risk premia $\alpha$. In other words, the explanatory power of Equation (7) should increase, and the errors in forecasting monetary policy should be smaller as well.

The experiment is conducted only for monthly Libor rates because the data span covers the period before 1999 and the results commented above indicate the best results for monthly data Libor rates. Moreover, the main focus lies on the first two forwards, where the model seems to work better in the case of explaining the expectation hypothesis, but comments are provided also for more distant forwards.

Rolling regressions have been performed with different windows size. I have concentrated on the results for the windows of 36, 48 and 60 months.[21] For the main statistics of the parameters estimated, see Appendix (Tables B.1(a)–(c) and B.2(a)–(c)).

Some conclusions can be drawn from the earlier described tests. First of all, $\alpha$ for the first forward is quite stable with all three rolling windows, showing only a slight decrease in absolute value with 48 and 60 rolling windows. It tends to diminish for the second forward (Figure 4 shows the evolution of estimated $\alpha$ for the first, second, third and fifth forwards), signalling that the required risk premium has, indeed, diminished over the last years. The increase in the risk premium between 2000 and 2001 seemed to be related to the sharp increase in interest rates in 2000, which was followed by a sharp decrease in 2001. After that monetary policy has been conducted more smoothly, letting the risk premium come down.

$R^2$ confirms this finding, as it is much higher when the 2000–2001 period is excluded from the regression sample. The graph with $R^2$ with 60 observations is particularly striking (Figure 5). $R^2$ increases constantly for all the forwards, in particular for the first and second one, where the communication of monetary policy is more important than economic surprises.

[20] As already pointed out by Gürkaynak *et al.* (2007), assuming that $\beta$ is equal to 1, $\alpha$ is a measure of the *average excess return (relative to rolling over overnight federal funds loans) that was earned over the sample by holding that instrument, which, in a long enough sample, will primarily reflect the risk premium on that instrument.*

[21] Longer windows are not used because of the overall short sample available. As discussed later, the results obtained suggest that a wider window would help improve the quality of the regressions and the stability of the parameters.

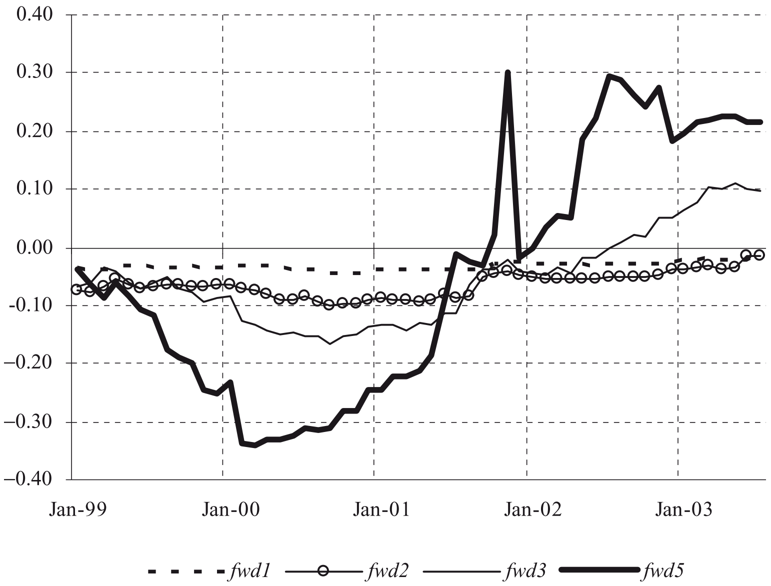


Figure 4: Monthly Data for $\alpha$, 1-Month Libor, Starting Date 31/1/1999, 48 Observations Rolling Window, First, Second, Third and Fifth Forwards

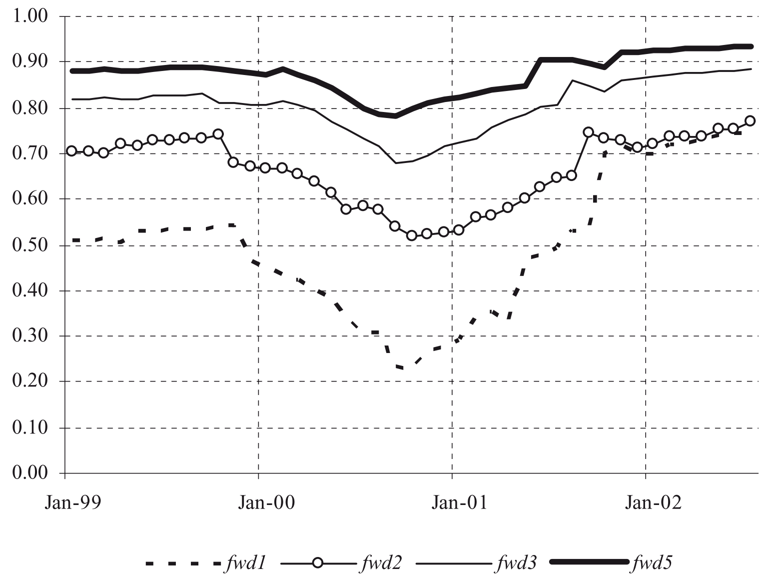


Figure 5: Monthly Data for $R^2$, 1-Month Libor, Starting Date 31/1/1999, 60 Observations Rolling Window, First, Second, Third and Fifth Forwards

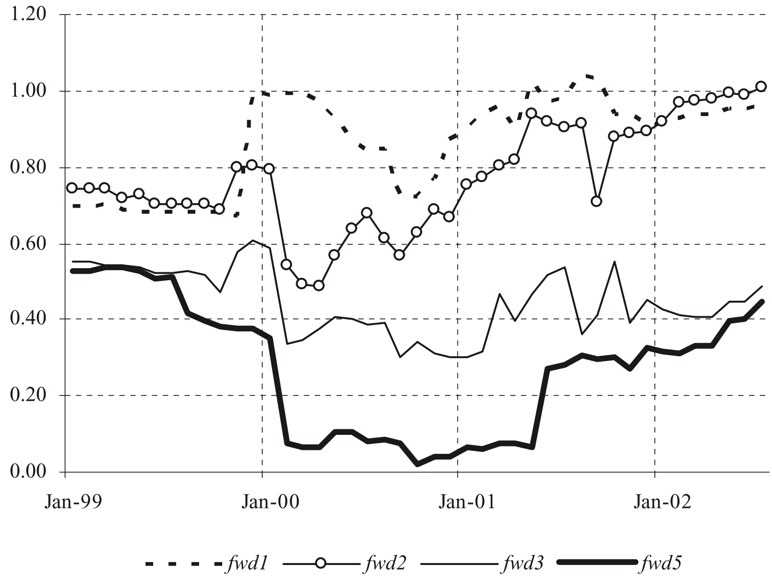


Figure 6: Monthly Data for $\beta$, 1-Month Libor, Starting Date 31/1/1999, 60 Observations Rolling Window, First, Second, Third and Fifth Forwards

Improved communication by the ECB after the first years of its existence has also been outlined by Jansen and De Haan (2006). According to their findings, it was due to less noise stemming from reduced communication by different members of the Governing Council of the ECB.

The most interesting results are given by the values of $\beta$, which were the most difficult to interpret on the full sample regressions reported in the previous paragraph. Figure 6 shows that $\beta$ for the third and fifth forward remain below 1 for the entire sample, and their absolute values (in particular for the third forward) do not change substantially. But for the first and second forwards the $\beta$ estimates are very close to 1 in the second part of the sample.

This suggests that during the first 9 years of the ECB's existence, there has been an improvement in the understanding of market participants on how the central bank is running monetary policy. For the first two forwards, where economic surprise is playing a limited role in the difference between expected and realized rates, the rolling regressions' exercise shows how $\beta$ has become very close to 1, $R^2$ has increased and also the risk premium $\alpha$ has slightly decreased in absolute value.

## 6. Concluding Remarks

The current research had two objectives. The first one was to identify money market instruments that can be used to forecast the future path of monetary policy in Europe. The second objective was to understand how this perception has changed over the first decade of the ECB's existence. Given the short history of the European money market, some of the instruments analysed in the paper have been introduced only recently. Therefore, it was interesting to see how well it is possible to extract from these instruments the monetary policy path perceived by the market. Four different instruments have been analysed. The method used has been derived from a no arbitrage condition (assuming therefore market efficiency) and provides a regression equation where both the monetary policy expectations and the risk premia can be measured.

The main result reached in the first part of the paper is that the forwards extracted by (monthly) Libor and Euribor rates display better forecasting ability regarding monetary policy. In the US case, FED fund futures have often been considered to have the best short-term rate in terms of forecasting ability. In Europe, a similar instrument (Eonia futures) has been introduced only 4 years ago, which is why it is worth testing again in the future when more data will be available.

In the second part of the paper, one of the money market instruments analysed in the first part (forward rates extracted from the Libor curve) was used to examine how markets have perceived the ECB's monetary policy. Anecdotal evidence has suggested that the ECB's credibility had to be built from scratch, being initially low and having increased over time.

The strategy adopted in this paper has employed rolling regressions with the objective to test how $R^2$ and the risk premium extracted from these regressions have changed through time, starting from January 1999. Results on monthly data show that after the period 2000–2001 the risk premium embedded in money market rates has gradually decreased, and the forecasting error of forward rates has diminished, that is $R^2$ of Regression (7) has increased. This shows that the market has undergone a learning process, and stable parameters witnessed in the last few years suggest that the market is now pricing the ECB's monetary policy more effectively. The analysis also indicated that in order to obtain stable parameters of estimations, it is necessary to include at least an entire interest rate cycle (at least 5 years). This proves that the time factor is an important determinant of the models for financial instruments assessing. Given this point of view, adding a dynamic dimension to Equation (6) would help to improve the power of the tests conducted here. For example, one possibility would be to model the dynamics of the risk premium.

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## Appendix

Table A1: LM Test for Equation (6)

| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
|---|---|---|---|---|---|
| Bubill fwd | | | | | |
| LM Stat | 8.439 | 9.189 | 17.125 | 19.642 | 15.692 |
| Prob | (0.015) | (0.010) | (0.000) | (0.000) | (0.000) |
| resid(−1) | 0.315 | 0.357 | 0.612 | 0.456 | 0.556 |
| Prob | (0.079) | (0.041) | (0.001) | (0.005) | (0.001) |
| resid(−2) | 0.210 | 0.187 | 0.244 | 0.378 | 0.155 |
| Prob | (0.212) | (0.281) | (0.159) | (0.019) | (0.356) |
| Libor fwd | | | | | |
| LM Stat | 0.777 | 3.467 | 13.297 | 19.399 | 21.935 |
| Prob | (0.678) | (0.177) | (0.001) | (0.000) | (0.000) |
| resid(−1) | −0.045 | 0.228 | 0.592 | 0.727 | 0.721 |
| Prob | (0.765) | (0.138) | (0.000) | (0.000) | (0.000) |
| resid(−2) | −0.124 | −0.199 | −0.093 | −0.087 | 0.001 |
| Prob | (0.423) | (0.195) | (0.572) | (0.598) | (0.996) |
| Eonia futures | | | | | |
| LM Stat | 0.300 | 3.123 | 7.455 | 15.892 | 19.739 |
| Prob | (0.861) | (0.210) | (0.024) | (0.000) | (0.000) |
| resid(−1) | 0.045 | 0.242 | 0.395 | 0.573 | 0.710 |
| Prob | (0.790) | (0.118) | (0.014) | (0.001) | (0.000) |
| resid(−2) | −0.070 | −0.157 | 0.039 | 0.079 | −0.039 |
| Prob | (0.647) | (0.309) | (0.809) | (0.635) | (0.816) |
| Euribor fwd | | | | | |
| LM Stat | 0.617 | 3.334 | 13.482 | 19.868 | 21.957 |
| Prob | (0.734) | (0.189) | (0.001) | (0.000) | (0.000) |
| resid(−1) | −0.005 | 0.229 | 0.599 | 0.736 | 0.701 |
| Prob | (0.975) | (0.137) | (0.000) | (0.000) | (0.000) |
| resid(−2) | −0.116 | −0.190 | −0.101 | −0.081 | 0.034 |
| Prob | (0.453) | (0.220) | (0.536) | (0.624) | (0.034) |

Table B1(a): Monthly Data for $\alpha$, 1-Month Libor, Starting Date 31/1/1999, 60 Observations Rolling Window

| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
|---|---|---|---|---|---|
| Mean | −0.032 | −0.061 | −0.056 | −0.066 | −0.050 |
| Median | −0.031 | −0.060 | −0.065 | −0.075 | −0.035 |
| Min | −0.040 | −0.083 | −0.128 | −0.185 | −0.275 |
| Max | −0.026 | −0.036 | 0.023 | 0.048 | 0.180 |
| S.D. | 0.004 | 0.012 | 0.049 | 0.075 | 0.147 |

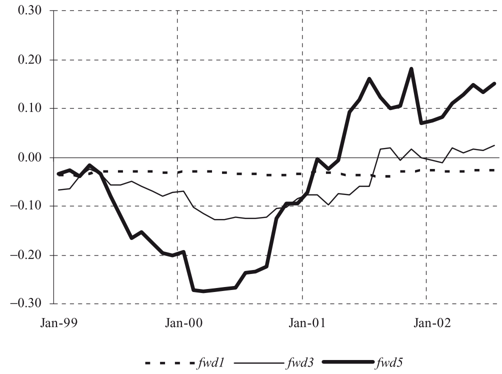


Table B1(b): Monthly Data for $\beta$, 1-Month Libor, Starting Date 31/1/1999, 60 Observations Rolling Window

| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
|---|---|---|---|---|---|
| Mean | 0.865 | 0.771 | 0.445 | 0.455 | 0.271 |
| Median | 0.913 | 0.743 | 0.446 | 0.438 | 0.305 |
| Min | 0.672 | 0.487 | 0.299 | 0.307 | 0.022 |
| Max | 1.043 | 1.010 | 0.605 | 0.582 | 0.536 |
| S.D. | 0.125 | 0.143 | 0.089 | 0.078 | 0.174 |

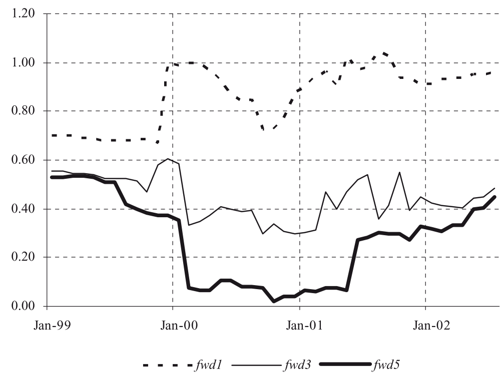

Table B1(c): Monthly Data for $R^2$, 1-Month Libor, Starting Date 31/1/1999, 60 Observations Rolling Window

| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
|---|---|---|---|---|---|
| Mean | 0.497 | 0.663 | 0.805 | 0.855 | 0.875 |
| Median | 0.510 | 0.678 | 0.814 | 0.869 | 0.882 |
| Min | 0.228 | 0.517 | 0.679 | 0.757 | 0.782 |
| Max | 0.750 | 0.769 | 0.885 | 0.913 | 0.936 |
| S.D. | 0.155 | 0.077 | 0.057 | 0.041 | 0.043 |

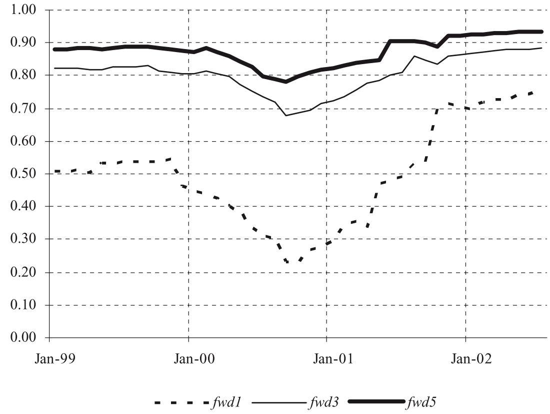


Table B2(a): Monthly Data for $\alpha$, 1-Month Libor, Starting Date 31/1/1999, 36 Observations Rolling Window

| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
|---|---|---|---|---|---|
| Mean | −0.030 | −0.061 | −0.042 | −0.072 | −0.053 |
| Median | −0.030 | −0.059 | −0.072 | −0.094 | −0.114 |
| Min | −0.058 | −0.123 | −0.214 | −0.295 | −0.596 |
| Max | −0.010 | −0.005 | 0.280 | 0.187 | 0.555 |
| S.D. | 0.012 | 0.036 | 0.115 | 0.145 | 0.286 |

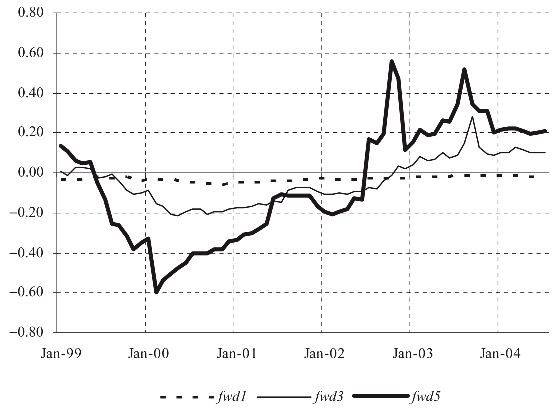

Table B2(b): Monthly Data for $\beta$, 1-Month Libor, Starting Date 31/1/1999, 36 Observations Rolling Window

| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
|---|---|---|---|---|---|
| Mean | 0.848 | 0.700 | 0.413 | 0.441 | 0.259 |
| Median | 0.863 | 0.704 | 0.431 | 0.425 | 0.259 |
| Min | 0.617 | 0.365 | 0.136 | 0.225 | 0.003 |
| Max | 1.077 | 1.062 | 0.651 | 0.779 | 0.607 |
| S.D. | 0.125 | 0.168 | 0.122 | 0.133 | 0.167 |

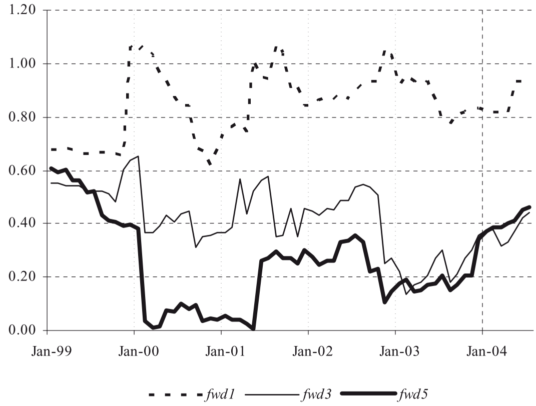


Table B2(c): Monthly Data for $R^2$, 1-Month Libor, Starting Date 31/1/1999, 36 Observations Rolling Window

| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
|---|---|---|---|---|---|
| Mean | 0.500 | 0.613 | 0.771 | 0.824 | 0.845 |
| Median | 0.522 | 0.620 | 0.797 | 0.847 | 0.871 |
| Min | 0.132 | 0.396 | 0.597 | 0.686 | 0.698 |
| Max | 0.773 | 0.764 | 0.833 | 0.890 | 0.902 |
| S.D. | 0.181 | 0.105 | 0.065 | 0.060 | 0.058 |

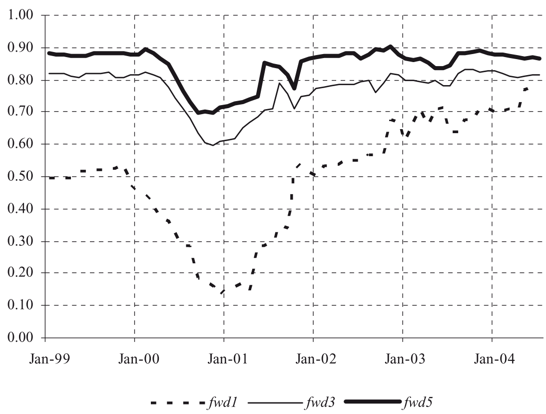

Table C1: Regression Results for the Libor Rates, Equation (7) and (A.1)

| | Without fed coefficient | | | | | With fed coefficient | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* | *fwd 1* | *fwd 2* | *fwd 3* | *fwd 4* | *fwd 5* |
| Libor fwd | | | | | | | | | | |
| $\alpha$ | −0.025 | −0.042 | −0.005 | 0.021 | 0.056 | −0.022 | −0.036 | −0.008 | 0.004 | 0.028 |
| $t$-Stat $\alpha$ ($H_0$: $\alpha = 0$) | (−2.115) | (−1.670) | (−0.071) | (0.202) | (0.430) | (−1.846) | (−1.528) | (−0.142) | (0.050) | (0.268) |
| $\beta$ | 0.72 | 0.77 | 0.550 | 0.562 | 0.535 | 0.73 | 0.74 | 0.557 | 0.594 | 0.571 |
| $t$-Stat $\beta$ ($H_0$: $\beta = 1$) | (9.756) | (9.271) | (7.585) | (7.584) | (5.308) | (9.860) | (9.044) | (7.673) | (8.218) | (5.891) |
| $\rho$ | 0.06 | 0.45 | 0.780 | 0.863 | 0.864 | 0.05 | 0.42 | 0.752 | 0.834 | 0.834 |
| $t$-Stat | (0.593) | (4.838) | (12.470) | (17.193) | (18.343) | (0.476) | (4.510) | (11.293) | (14.924) | (15.770) |
| $\lambda$ | | | | | | 0.044 | 0.091 | 0.057 | 0.100 | 0.111 |
| $t$-Stat | | | | | | (1.024) | (2.499) | (1.469) | (2.481) | (2.522) |
| $R^2$ | 0.539 | 0.715 | 0.833 | 0.890 | 0.893 | 0.544 | 0.732 | 0.836 | 0.897 | 0.899 |
| DW | 2.033 | 1.776 | 1.874 | 1.731 | 1.732 | 2.039 | 1.823 | 1.985 | 1.904 | 1.945 |

The table reports the results of estimation of Equation (7) on the left block and of Equation (A1) on the right block.

$$
\begin{aligned}
{}_t\overline{ON}_{m,n} - {}_tON_{t,t+1} &= \alpha + \beta({}_tfwd_{m,n} - {}_tON_{t,t+1}) \\
&\quad + \lambda({}_tfed_{m,n} - {}_tONF_{t,t+1}) + e_t \qquad \text{(A1)} \\
e_t &= \rho e_{t-1} + \varepsilon_t
\end{aligned}
$$

Equation (A1) is obtained adding the FED fund future (corrected for the level of US overnight rate) on the right hand side of the equation.

Here are reported only the results for Libor rates and for the sample starting from 1999. It can be seen that even if parameter λ is significant, it does not affect the value of other.

**Non-technical Summary**

The paper considers the relation between monetary policy expectations and financial markets in the case of Europe. The objective of the paper is twofold. In the first part, assuming that the expectation hypothesis holds and that market participants therefore assess the future path of short-term interest rates ‘correctly’, I build a framework for comparing a range of money market instruments available today in the European money markets, and try to establish their quality with regard to assessing monetary policy actions. The method used has been derived from a no arbitrage condition and provides a regression equation where both the monetary policy expectations and the risk premia can be measured. The one-month forward interest rates extracted from the Libor yield curve is shown to have a greater prediction power of the future monetary policy path compared to the other money market rates analysed, and in particular Eonia futures and forward rates extracted from German treasury bills.

In the second part of the paper, Libor forward rates have been used to study the evolution of market expectations with regard to the monetary policy of the European Central Bank. Regressions with different rolling windows have been performed in order to understand how the parameters of the equation derived in the first part of the paper change. Results on monthly data show that after the period 20002001 the risk premium embedded in money market rates has gradually decreased, and the forecasting error of forward rates has diminished. This shows that the market participants have undergone a learning process, and stable parameters witnessed in the last few years of the sample suggest that the market is now pricing the ECB’s monetary policy more effectively.

# APPENDIX 2

## Modelling the Time-Varying Risk Premium by Using the Kalman Filter: the Euro Money Market Case

FABIO FILIPOZZI

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Volume 1 (2011), no. 9. Poland: Lodz University Press.

# 8

# Modelling the Time-Varying Risk Premium by Using the Kalman Filter: the Euro Money Market Case

***Fabio Filipozzi****

## 8.1. Introduction

Central banks and financial market participants use money market rates in order to measure the expectations of the future course of monetary policy. This is relevant for central banks in order to understand what market participants are expecting from them in terms of monetary policy-decisions, and how much they are able to communicate their view to the market.

The expectations concerning monetary policy are an important part of the decision-making set of financial market participants, because the future path of interest rates influences the return of each financial asset class.

The expectations are usually extracted from traded money markets instruments, like Euribor futures or forward rate agreements (see e.g. Bernoth and von Hagen 2004). This is related to the testing of the expectations hypothesis because the prices of these instruments are driven both by expectations and risk premia. Tests on the expectations hypothesis should help distinguish and measure the expectations and the risk premia, which form the prices of money market instruments. Early attempts to study the expectations hypothesis and the term structure of interest rates (in particular forward rates) have suggested that the expectations hypothesis, or some modified version of it, holds (Cox, *at al.* 1981; Campbell and Schiller 1991). Using the VAR modelling strategy, Evans and

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Marshall (1998) find that nominal interest rate changes are driven by macroeconomic shocks, which confirms the link between the term structure of interest rates and the business cycle. In this strand of literature, Krueger and Kuttner (1996) and Evans (1998) bring the FED fund futures rates in the picture as instruments for making monetary policy forecasts. Evans (1998) finds that FED fund futures perform better than the traditional Taylor rules.

Since then, FED fund futures have been the main instruments used in the US for the analysis of monetary policy expectations. Different methods have been employed to extract the expectations of future interest rates from these and other financial instrument prices (Sack 2004; Durham 2003; Gürkaynak *et al.* 2007). The generally accepted evidence in the forecasts of future short-term rates is that the expectations extracted from financial instruments must be corrected by a risk premium, which is time-varying and countercyclical (Piazzesi and Swanson 2008). This conclusion has been tested lately also for Europe's case by Ferrero and Nobili (2008), with results more mixed than in the US case.

In this chapter Europe's case is studied by using forward rates extracted from Euribor rates. In order to model time-varying risk premium the Kalman filter technique is used. The Kalman filter technique has been recently applied also by Gravelle and Morley (2005) in studying the Canadian term structure of interest rates. They reject the expectations hypothesis and find that the risk premium is time-varying. The possibility of studying the time variation of the risk premium is the main advantage of this modelling strategy, and it will be applied also in this paper to Europe's case.

After setting the theoretical framework in Section 8.2, Section 8.3 briefly describes the data used. Section 8.4 outlines the empirical results, comparing the results of the traditional single equation estimations and the estimations obtained by using the Kalman filter. I particularly concentrate on an analysis of the dynamics and components of the risk premium. Section 8.5 concludes.

## 8.2. Theoretical Framework

The most widely used way to test the expectations hypothesis has taken the following form (Gürkaynak *et al.* 2007):

$$ {}_{m}ON_{m,n} = \alpha + \beta \cdot {}_{t}fwd_{m,n} + \varepsilon_t \,. \tag{8.1} $$

*ON* represents the overnight rate, priced at time *m* (subscript on the left side of each variable), and has settlement date at time *m* and maturity date at time *n* (subscripts on the right side of each variable); *fwd* is the forward rate. If the expectations hypothesis holds, then $\alpha$ should be equal to zero and $\beta$ equal to one. A modified version of equation (8.1) will be used in the first estimations:

$$({}_{m}S_{m,n} - {}_{t}S_{t,t+1}) = \alpha + \beta({}_{t}fwd_{m,n} - {}_{t}S_{t,t+1}) + \varepsilon_t \,. \tag{8.2}$$

Given that the short-term rate is represented here not by overnight rates, but by one-month Euribor (as will be explained in the next section), *ON* is substituted by *S* (short-term rate). Moreover, in empirical applications often both the short-term rates and forward rates are corrected for the level in order to avoid the problem of cointegration between the left and the right side of the equation (as explained e.g. by Gürkaynak *et al.* 2007).

Early tests (conducted regressing equation (8.2) using OLS) has usually rejected the expectations hypothesis (Fama and Bliss 1987; Bekaert *et al.* 1997). The main reason for this failure has been attributed to the risk premium $\alpha$. $\alpha$ is different from zero, negative (compensation for the uncertainty), increasing with the distance of the forward rate (the more distant in the future is the forecast, the more uncertain is the result of the forecast) and also time-varying. The business cycle has been outlined as the main reason for variation of the term premium, and in equation (8.2) an exogenous variable linked to the economic cycle has been added (e.g. Piazzesi and Swanson 2008 use the change in nonfarm employment for the US case). The strategy employed in this chapter is different from the ones of previous contributions. Namely, without taking any a priori explanation of the determinants of the risk premium changes through time, the relation between the term premium and forward rates is modelled and estimated with the Kalman filter technique.

The basic idea is to build a linear dynamic system, where the evolution of one variable (in this case the short-term rate) is governed by an exogenous variable (in this case the forward rates) and also by an unobservable "state" variable (risk premium $\alpha$). The Kalman filter is used to update the mean and variance of the state variable at each step. The general model is designed as follows:

$$({}_{m}S_{m,n} - {}_{t}S_{t,t+1}) = \alpha_t + \beta({}_{t}fwd_{m,n} - {}_{t}S_{t,t+1}) + \varepsilon_t \,, \tag{8.3}$$

$$\alpha_{t+1} = \delta_1 + \delta_2 \alpha_t + \upsilon_t \,, \tag{8.4}$$

(8.3) is the signal equation and (8.4) the state equation. Here the simplest specification is used, assuming random walk behaviour for the state variable ($\delta_1$ is equal to zero and $\delta_2$ to one).

## 8.3. Data

In order to conduct an empirical analysis using equations (8.2), (8.3) and (8.4), I need a realized short-term rate and futures or forwards on these rates. In research on the European money market usually futures on the three-month Euribor are used, mainly because of their liquidity (Bernoth and von Hagen 2004, Ferrero and Nobili 2008). In the US, monthly data are used instead, as there exists a well developed and highly liquid market of monthly futures on FED fund rates. In Europe a similar instrument was launched in 2004, with Eonia as the underlying rate, but its low liquidity and short history makes this instrument not yet optimal for the empirical application used in this chapter.

In order to have both good quality data and monthly observations, the approach chosen in what follows is to extract forward rates from the Euribor spot curve, using end of the month data. This also allows making use of a reasonably long sample, from the beginning of 1999 to June 2008.

Also an economic indicator is used in the empirical analysis. In the US it is often the employment data that are used as contemporaneous business cycle indicators (Piazzesi and Swanson 2008). For the euro area, employment data can not be considered good contemporaneous business cycle indicators because of the more rigid structure of the euro area labour market compared with the US market. For this reason, confidence indicators have been used instead. Both the GDP growth collected by Consensus Forecast and the euro area economic confidence indicator compiled by the European Commission have been considered, and both show the ability to capture the business cycle in Europe in the sample analyzed here. The second indicator has been chosen.

## 8.4. Empirical Results

### 8.4.1. Classic approach

The test of the expectations hypothesis is conducted by regressing equation (8.2) with OLS (Gürkaynak *et al.* 2007). As elaborated above, in order to have the expectations hypothesis confirmed $\alpha$ coefficients should not be different from zero and $\beta$ coefficients should not be statistically different from one.

The regression is performed for the first nine forwards, and the results are reported on the left side of Table A1 (see Appendix). The values of $\alpha$ are increasing with the increase of the distance of the forward. This is in line with what has been found in previous literature (Gürkaynak *et al.* 2007). $\beta$ values are near one for the mid-range forwards, much lower for the shorter and higher for the longer forwards. However, the most important thing to note is that DW shows presence of autocorrelation in the residuals for all the forward rates, excluding the first one. This means that the difference between projected short-term rates by forward rates and their realization has a systematic part that is not captured by equation (8.2), making estimated coefficients' values biased. Equation (8.2) simultaneously measures both the expectations hypothesis ($\beta$) and the two different components of the difference between expected and realized short-term rates, i.e. risk premium ($\alpha$) and error in forecast ($\varepsilon$). The problem with this specification is that the risk premium is measured as a term premium (fixed and dependent only on the distance of the forecast horizon) and it does not take into account other risk factors. The most typical is the risk premium linked to economic conditions. In this way all the varying components of the risk premium remain within the error term, which results to be autocorrelated. In order to test the degree of autocorrelation in the residuals, LM tests have been conducted for all the nine forwards, and the results are reported in Table A2 (see Appendix). With the exception of the first forward, for all the other forwards the residuals are autocorrelated of order one. This means that one way to get the systematic part of the error term into the equation is to add an autoregressive term on the right side:

$$\begin{aligned}({}_{m}S_{m,n} - {}_{t}S_{t,t+1}) &= \alpha + \beta({}_{t}fwd_{m,n} - {}_{t}S_{t,t+1}) + \\ &+ \gamma({}_{m-1}S_{m,n} - {}_{t-1}S_{t,t+1}) + \varepsilon_t.\end{aligned} \tag{8.5}$$

This basically means that short-term rates are sticky and at the same time the model specified in equation (8.2) is not able to capture this stickiness. Stickiness in short-term rates is a very well-proved phenomenon and it is linked to the willingness of the central bank to smooth the changes in monetary policy (Ross 2002; Rudebusch 2002).

The right side of Table A1 reports the results of regression (8.5). The first lag variable coefficient $\gamma$ is indeed significant (except again for the first forward), and DW shows that the residuals are not autocorrelated. $\alpha$ (with the exception of the first and the second forward) is not significantly different from zero. This is partly explained by the fact that now the changes in the short-term rate are mostly explained by the autoregressive term, and therefore the risk premium loses its explanatory power on the short-term rate. This means that I need a different modelling strategy to capture the risk premium. $\beta$ is well below one in the specification with the first lag term. This puzzle is more difficult to explain intuitively. Basically, taking away the sticky part of the short-term rate movement, the market participants fall short of realized rates on forming expectations. They expect rates to remain close to the actual one, i.e. they expect a lower rate when the realized rate is higher than the actual one, and vice versa. This puzzle could be created by the fact that in these regressions I am not able to include the risk premium ($\alpha$ is not significant). All in all, this analysis shows that I need a different kind of modelling strategy if I want to measure both the risk premium and $\beta$.

### 8.4.2. Business Cycle

One way to improve the quality of the estimation is to exploit one common result of the previous analyzes, namely the dependence of expectations' errors on the economic cycle. Campbell and Schiller (1991) and Piazzesi and Swanson (2008) have found that excess return in fixed income instruments and in FED fund futures is predictable, and it is positive when the business cycle is negative, and vice versa. In particular Piazzesi and Swanson (2008) use an employment indicator as the contemporaneous business cycle signal. As explained above in Section 8.3, for the euro area the economic confidence indicator collected by the European Commission is used.

The economic variable is added to equation (8.2):

$$({}_mS_{m,n} - {}_tS_{t,t+1}) = \alpha + \beta({}_t fwd_{m,n} - {}_tS_{t,t+1}) + \lambda ECO_m + \varepsilon_t. \tag{8.6}$$

The results of the regressions are reported on the left side of Table A3 (see Appendix). The economic variable added to the regression is always significant, confirming that in estimating the risk premium the effect of the business cycle must be taken into account. The signs are as expected (when the cycle is positive, the realized short-term rate is higher than the expected one) and the coefficient's value increases with the distance of the forward (when the margin error in the forecast is higher, evidently). $\beta$ is not changing much in size, i.e. $\beta$ remains lower than one.

The most important thing to note is that bringing the business cycle in the picture does not help to solve the problem of the autocorrelation of the residuals. This means that one part of the equation (8.1) remains unexplained. The usual suspect is the part of risk premium not explained by the business cycle. As before, an autoregressive term is added to equation (8.6):

$$\begin{aligned}({}_mS_{m,n} - {}_tS_{t,t+1}) &= \alpha + \beta({}_t fwd_{m,n} - {}_tS_{t,t+1}) + \lambda ECO_m + \\ &+ \gamma({}_{m-1}S_{m,n} - {}_{t-1}S_{t,t+1}) + \varepsilon_t.\end{aligned} \tag{8.7}$$

The results on the right side of Table A3 show that, while both the economic indicators and the autoregressive terms are significant, $\beta$ remains significantly lower than one and $\alpha$ is not significant (with the exception of the first and the second forwards). In the next section a different modeling strategy is used in order to analyze the mentioned puzzles.

### 8.4.3. Kalman Filter

A state space representation is used to model the time-varying risk premium. The estimations have been conducted, taking the simplest form of equations (8.3) and (8.4):

$$({}_mS_{m,n} - {}_tS_{t,t+1}) = \alpha_t + \beta({}_tfwd_{m,n} - {}_tS_{t,t+1}) + \varepsilon_t, \quad (8.8)$$

$$\alpha_{t+1} = \alpha_t + \mu_t. \quad (8.9)$$

The risk premium ($\alpha$) is the state variable for each forward. Its evolution is estimated by the filter, and it drives the signal equation that is defined in the same way as equation (8.3).

The results are reported in Table A4 (see Appendix). The system did not converge for the sixth, eighth and ninth forward rate. Modelling the risk premium with the Kalman filter does not dramatically change the values of $\beta$, which remain far below the expected value of one. Their values are between 0.5 and 0.7, as for the estimation of OLS equation with the autoregressive term.

The analysis of the risk premium offers more interesting results. Table A4 reports the main statistics of the estimated risk premium, and Figure A1 (see Appendix) depicts their evolution (smoothed). Allowing the risk premium to vary and leaving its behavior largely unspecified (its evolution is governed by statistics, no economic factor pinpoints it) results in its average size quite similar across the forward spectrum (the average for all forwards is around five basis points), again very similar to the estimation done using OLS. The advantage of using the Kalman filter technique is that I can observe how the risk premium evolves through time. As expected, Figure A1 shows that the risk premium for the very near forwards is quite stable.

More distant forwards indicate more volatility in the risk premium: the more distant the forward, the higher the volatility. The link between the risk premium as modeled here and the business cycle is confirmed by Figure A2 (see Appendix). The figure shows that the risk premium estimated for the fourth forward rate and the dynamics of the European economic confidence index are correlated.

In order to distinguish the effects on the forecast errors due to the business cycle and other risk factors, the signal equation has been specified as equation (8.6). The estimate model used is therefore:

$$({}_mS_{m,n} - {}_tS_{t,t+1}) = \alpha_t + \beta({}_tfwd_{m,n} - {}_tS_{t,t+1}) + \lambda ECO_m + \varepsilon_t, \qquad (8.10)$$

$$\alpha_{t+1} = \alpha_t + \mu_t. \qquad (8.11)$$

The Kalman filter estimation was repeated for all nine forward rates. Models converged in all nine cases; the results are reported in Table A5 (see Appendix).

The economic confidence coefficients were significant for all nine estimations, confirming that this is one relevant piece of information in explaining the formation of expectations. With the exception of the first forward, both λ and *β* remain unchanged, whereas *β* is again well below 1.

The effect of including the business cycle variable in the model is clear from Figure A3. *α* estimated in the last model is less correlated with both the *α* estimated without economic confidence variable and the variable itself. Moreover, its volatility is less pronounced than in the first case, showing that the term premium is still time-varying but not as volatile as the risk premium linked to the business cycle.

Comparing the behaviour of the two risk premiums measured here (*α* and the business cycle), I can see that both are increasing, on average for the first two forwards, and after that their average size remains stable across the different forwards rates (*α* around 10 basis points). The interpretation usually given to *α* is that of the term premium, which in theory should be increasing with the distance of the forward (see Piazzesi and Swanson 2008; Sack 2004). The model designed here allows to specify this concept. In particular, while *α* remains constant on average, its volatility still increases with the distance of the forwards. This aspect cannot be captured when the term premium is modeled as a constant.

## 8.5. Conclusion

The contribution of the chapter to the research on testing the expectations hypothesis mainly concerns the application of the Kalman filter methodology on European data. This methodology allows the explicit inclusion of the dynamics of the risk premium in the model, showing that it is, indeed, correlated with the business cycle. When the model is corrected for the business cycle, the risk premium becomes less volatile. Furthermore, another important consequence of the modelling strategy chosen in the paper is that the model maintains its validity also in relation to the last year of the sample, when the crisis hit financial markets.

Two open questions remain. On the one hand, when the model is adjusted for the business cycle, the risk premium still does not increase with the distance of the forward as expected, meaning that the term premium is not captured by the model. This is mitigated by the fact that the volatility of the risk premium increases with the distance of the forward. On the other hand, the values of $\beta$ remain well below one, suggesting that either the expectations hypothesis does not hold, or the model should be specified differently.

One way to test these two puzzles would be to specify the state equation of the model differently. Furthermore, applying the model to other short-term instruments (Eonia futures) or other countries (the US in particular) could help to illuminate the reasons behind these puzzles.

## Appendix

Table A1: OLS regression for EH test

| Forward | $\alpha$ | $\beta$ | $R^2$ | DW | $\alpha$ | $\beta$ | $\gamma$ | $R^2$ | DW |
|---|---|---|---|---|---|---|---|---|---|
| 1 | –0.039 | 0.661 | 0.434 | 1.671 | –0.040 | 0.679 | 0.100 | 0.434 | 1.848 |
| | (–2.866) | (9.357) | | | (–2.713) | (9.445) | (1.046) | | |
| 2 | –0.070 | 0.760 | 0.489 | 1.081 | –0.065 | 0.684 | 0.452 | 0.584 | 1.765 |
| | (–3.649) | (10.443) | | | (–2.171) | (8.402) | (5.231) | | |
| 3 | –0.081 | 1.015 | 0.661 | 0.914 | –0.044 | 0.662 | 0.709 | 0.788 | 1.936 |
| | (–4.153) | (14.861) | | | (–0.878) | (8.811) | (10.157) | | |
| 4 | –0.110 | 1.156 | 0.691 | 0.825 | –0.052 | 0.712 | 0.768 | 0.828 | 1.972 |
| | (–4.688) | (15.910) | | | (–0.740) | (8.293) | (11.910) | | |
| 5 | –0.142 | 1.263 | 0.679 | 0.640 | –0.070 | 0.742 | 0.819 | 0.855 | 1.950 |
| | (–4.919) | (15.480) | | | (–0.704) | (7.167) | (14.145) | | |
| 6 | –0.169 | 1.339 | 0.650 | 0.521 | –0.026 | 0.581 | 0.893 | 0.889 | 1.777 |
| | (–4.823) | (14.508) | | | (–0.152) | (5.518) | (20.165) | | |
| 7 | –0.210 | 1.359 | 0.626 | 0.444 | –0.002 | 0.557 | 0.904 | 0.893 | 1.961 |
| | (–5.018) | (13.780) | | | (–0.011) | (4.594) | (21.260) | | |
| 8 | –0.231 | 1.289 | 0.568 | 0.321 | 0.022 | 0.459 | 0.937 | 0.920 | 1.840 |
| | (–4.604) | (12.235) | | | (0.071) | (4.504) | (27.381) | | |
| 9 | –0.284 | 1.353 | 0.516 | 0.297 | 0.042 | 0.328 | 0.953 | 0.930 | 1.786 |
| | (–4.719) | (11.014) | | | (0.098) | (3.218) | (32.431) | | |

Note: The left side reports coefficients' values for the estimation of equation (8.2) and the right side for equation (8.5) with AR(1) coefficient. Standard errors remain below coefficients' values.

Table A2: LM test for equation (8.2)

| | *fwd1* | *fwd2* | *fwd3* | *fwd4* | *fwd5* | *fwd6* | *fwd7* | *fwd8* | *fwd9* |
|---|---|---|---|---|---|---|---|---|---|
| LM Stat | 1.608 | 24.488 | 35.813 | 41.597 | 54.305 | 64.114 | 70.377 | 82.496 | 86.677 |
| Prob | (0.448) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| resid(–1) | 0.121 | 0.519 | 0.521 | 0.576 | 0.694 | 0.774 | 0.780 | 0.788 | 0.718 |
| Prob | (0.214) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| resid(–2) | –0.020 | –0.137 | 0.106 | 0.088 | 0.023 | –0.003 | 0.030 | 0.102 | 0.209 |
| Prob | (0.835) | (0.162) | (0.267) | (0.372) | (0.809) | (0.973) | (0.762) | (0.293) | (0.029) |

Table A3: OLS regression for EH test, with AR(1) coefficient

| fwd | $\alpha$ | $\beta$ | $\lambda$ | $R^2$ | DW | $\alpha$ | $\beta$ | $\lambda$ | $\gamma$ | $R^2$ | DW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | –0.042 | 0.593 | 0.046 | 0.472 | 0.463 | –0.038 | 0.569 | 0.050 | 0.023 | 0.466 | 2.017 |
| | (–3.214) | (8.069) | (2.661) | | | (–2.899) | (7.905) | (2.936) | (0.253) | | |
| 2 | –0.071 | 0.596 | 0.104 | 0.565 | 0.557 | –0.069 | 0.593 | 0.112 | 0.386 | 0.624 | 1.851 |
| | (–3.990) | (7.670) | (4.282) | | | (–2.676) | (7.381) | (3.377) | (4.394) | | |
| 3 | –0.081 | 0.799 | 0.121 | 0.710 | 0.705 | –0.059 | 0.617 | 0.162 | 0.625 | 0.812 | 2.029 |
| | (–4.484) | (9.805) | (4.232) | | | (–1.575) | (8.429) | (3.539) | (8.152) | | |
| 4 | –0.108 | 0.881 | 0.165 | 0.746 | 0.741 | –0.077 | 0.668 | 0.224 | 0.668 | 0.849 | 2.052 |
| | (–5.021) | (10.029) | (4.780) | | | (–1.606) | (8.102) | (3.954) | (9.008) | | |
| 5 | –0.136 | 0.912 | 0.232 | 0.754 | 0.750 | –0.101 | 0.723 | 0.271 | 0.697 | 0.871 | 2.057 |
| | (–5.329) | (9.647) | (5.729) | | | (–1.729) | (7.317) | (4.055) | (9.845) | | |
| 6 | –0.159 | 0.910 | 0.307 | 0.750 | 0.746 | –0.090 | 0.576 | 0.365 | 0.788 | 0.901 | 1.885 |
| | (–5.305) | (8.909) | (6.588) | | | (–1.081) | (5.574) | (4.406) | (13.083) | | |
| 7 | –0.191 | 0.906 | 0.368 | 0.745 | 0.740 | –0.075 | 0.545 | 0.352 | 0.816 | 0.899 | 2.035 |
| | (–5.451) | (8.696) | (7.085) | | | (–0.676) | (4.376) | (3.455) | (13.644) | | |
| 8 | –0.210 | 0.811 | 0.463 | 0.734 | 0.729 | –0.044 | 0.442 | 0.355 | 0.884 | 0.925 | 1.980 |
| | (–5.262) | (7.976) | (8.213) | | | (–0.267) | (4.263) | (3.215) | (18.891) | | |
| 9 | –0.258 | 0.857 | 0.550 | 0.736 | 0.731 | –0.009 | 0.311 | 0.375 | 0.918 | 0.934 | 1.991 |
| | (–5.729) | (8.137) | (9.521) | | | (–0.037) | (3.048) | (3.165) | (23.475) | | |

Note: The left side reports coefficients' values for equation (8.6) and the right side for equation (8.7) with AR(1) coefficient. Standard errors remain below coefficients' values.

Table A4: Statistics on $\alpha$ and $\beta$ when no economic variable is included in the signal equation

| Forwards | *fwd1* | *fwd2* | *fwd3* | *fwd4* | *fwd5* | *fwd6* | *fwd7* |
|---|---|---|---|---|---|---|---|
| $\beta$ | | | | | | | |
| Value | 0.70 | 0.66 | 0.61 | 0.64 | 0.67 | na | 0.52 |
| Std. err. | 0.058 | 0.081 | 0.067 | 0.099 | 0.091 | | 0.112 |
| $\alpha$ | | | | | | | |
| Mean | -0.04 | -0.06 | -0.04 | -0.05 | -0.06 | na | -0.05 |
| Median | -0.03 | -0.04 | -0.01 | -0.03 | -0.07 | na | -0.10 |
| Maximum | 0.01 | 0.18 | 0.55 | 0.60 | 0.69 | na | 0.98 |
| Minimum | -0.17 | -0.30 | -0.67 | -0.82 | -0.90 | na | -1.23 |
| Std. dev. | 0.04 | 0.10 | 0.21 | 0.26 | 0.33 | na | 0.51 |

Table A5: Statistics on $\alpha$ and $\beta$ when the business cycle variable is included in the signal equation

| Forwards | *fwd1* | *fwd2* | *fwd3* | *fwd4* | *fwd5* | *fwd6* | *fwd7* | *fwd8* | *fwd9* |
|---|---|---|---|---|---|---|---|---|---|
| $\beta$ | | | | | | | | | |
| Value | 0.65 | 0.61 | 0.59 | 0.63 | 0.65 | 0.53 | 0.48 | 0.41 | 0.29 |
| Std. err. | 0.057 | 0.071 | 0.071 | 0.105 | 0.084 | 0.099 | 0.106 | 0.084 | 0.097 |
| Eco | | | | | | | | | |
| Value | 0.08 | 0.19 | 0.25 | 0.32 | 0.31 | 0.30 | 0.28 | 0.28 | 0.32 |
| Std. err. | 0.019 | 0.033 | 0.061 | 0.074 | 0.066 | 0.101 | 0.114 | 0.114 | 0.123 |
| $\alpha$ | | | | | | | | | |
| Mean | –0.05 | –0.09 | –0.08 | –0.11 | –0.11 | –0.10 | –0.09 | –0.09 | –0.07 |
| Median | –0.05 | –0.08 | –0.06 | –0.06 | –0.07 | –0.02 | –0.03 | –0.02 | 0.02 |
| Maximum | 0.00 | 0.03 | 0.24 | 0.23 | 0.26 | 0.52 | 0.61 | 0.87 | 1.08 |
| Minimum | –0.15 | –0.32 | –0.53 | –0.70 | –0.93 | –1.09 | –1.02 | –1.15 | –1.21 |
| Std. dev. | 0.05 | 0.10 | 0.17 | 0.20 | 0.23 | 0.32 | 0.38 | 0.46 | 0.54 |

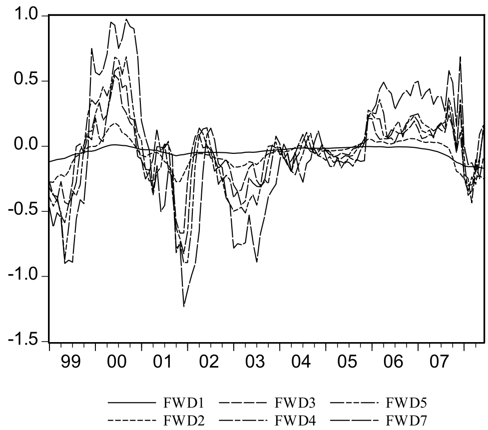


Fig. A1: Time-varying risk premium, no ECO
Note: Smoothed state estimates for all forward rates from the model specified by equations (8.8) and (8.9)


Fig. A2: Estimated risk premium and ECO

Note: EU economic confidence (solid line, LHS) and the risk premium for the fourth forward rate estimated without the ECO variable (smoothed state estimate from the model specified by equations (8.8) and (8.9))


Fig. A3: Estimated risk premium and ECO

Note: EU economic confidence (ECO_CONF_EUD, solid line, LHS), the risk premium for the fourth forward rate estimated without the ECO variable (FWD4, smoothed state estimate from the model specified by equations (8.8) and (8.9), RHS) and the risk premium for the fourth forward rate estimated with the ECO variable (FWD4ECO, smoothed state estimate from the model specified by equations (8.8) and (8.9), RHS)

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# APPENDIX 3

## Covered Interest Parity and the Global Financial Crisis in Four Central and Eastern European Countries

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# Covered Interest Parity and the Global Financial Crisis in Four Central and Eastern European Countries

FABIO FILIPOZZI AND KARSTEN STAEHR

ABSTRACT: *This paper examines the empirical validity of the covered interest parity (CIP) hypothesis in the Czech Republic, Hungary, Poland and Romania. Before the global financial crisis the CIP was mostly satisfied for the first three countries but not for Romania. During and after the crisis, deviations from the CIP have been substantial in all cases but with large differences across the countries. Estimations tie the observed pattern to developments in both global and country-specific risks. In the case of the Czech Republic, increased global risks led to a lower risk premium, indicating that Czech assets functioned as a "safe haven". In Hungary and Poland, increased global risks led to higher risk premiums, suggesting a flight to quality out of Hungarian and Polish assets. Finally, for Romania the deviations from the CIP were unrelated to developments in global or local financial risks, reflecting a repressed financial system.*

The access to forward exchange implies that investors can invest in domestically denominated assets as well as in foreign denominated assets and through forward exchange contracts hedge or cover all exchange rate exposure. Market efficiency would entail that the price formation of forward exchange leads to the same return from the two investment possibilities. Covered interest parity (CIP) posits that the return from investment in assets denominated in domestic currency must equal the return from investment in assets denominated in foreign currency, given that all currency exposure is hedged through a forward or swap contract. The argument is that otherwise there would be possibilities of riskless arbitrage profits as the exchange rate exposure is covered.

This paper examines to which extent the price formation of forward exchange in four major CEE economies, the Czech Republic, Hungary, Poland and Romania, lend support to the CIP condition during the period 2004-2011. All the countries had floating exchange rates during the sample period and saw increasing integration into European economic and financial structures. The main point of investigation is to which extent the price formation changed in connection with the global financial crisis and whether the empirical relation between the variables of the CIP changed. The analysis provides information on the efficiency of financial markets in CEE countries, which is important for the ability of agents to use financial instruments to carry out risk management and intertemporal reallocation. The analysis also sheds light on the effects of the global financial crisis on financial pricing far from the epicentre of the crisis and, hence, provides information of possible contagion effects.

The theory underlying the covered interest parity is based on the assumption that arbitrage equalises the returns from investing in domestic and foreign assets (actually, domestically and foreign denominated assets), cf. Levi (2005, Ch. 7). At time $t$ an investor seeks to invest one domestic currency unit for a holding period of $h$ years, $h > 0$, and considers whether to invest in a domestic or in a foreign asset. Investment in the domestic asset earns the annual interest rate $i_{t,h}$. Investment in the foreign asset at the interest rate $i^*_{t,h}$ entails buying foreign currency at the spot exchange rate $S_t$ and hedging the exposure by selling forward the foreign gross return at the forward exchange rate $F_{t,h}$. The covered foreign exchange position implies that both alternatives, in theory, are riskless, and arbitrage therefore entails that the gross returns from the domestically and foreign denominated assets must be identical.

$$(1+i_{t,h})^h = (1+i^*_{t,h})^h \frac{F_{t,h}}{S_t} \tag{1}$$

This is the covered interest parity condition. If the interest rates are relatively small, the CIP condition can be expressed as the following approximation:

$$\frac{F_{t,h} - S_t}{hS_t} = i_{t,h} - i^*_{t,h} \tag{2}$$

The left-hand side of eq. (2) is the annualised forward premium or capital gain, which the investor attains if the forward rate differs from the spot rate. The right-hand side is the spread between the domestic and foreign interest rates. A positive forward premium entails a positive capital gain for an investor who buys a foreign denominated asset; this is only compatible with the CIP if the domestic interest rate is higher than the foreign one.

In practice the CIP will typically not hold precisely due to transaction costs, different risks of domestic and foreign assets, and liquidity constraints. Deviations from the CIP for the h-year holding period, $D_{t,h}$, can be computed as the annualised forward premium minus the interest rate spread:

$$D_{t,h} = \frac{F_{t,h} - S_t}{hS_t} - (i_{t,h} - i^*_{t,h}) \qquad (3)$$

If $D_{t,h}$ differs non-negligibly from zero, the CIP does not hold. Deviations can emerge because investors are unable or unwilling to exploit arbitrage opportunities. Capital controls, capital requirements and other constraints on capital flows can make arbitrage trades infeasible. Reductions in the absolute value of $D_{t,h}$ can therefore be seen as a sign of increased international financial integration (Clinton 1988, Crowder 1995).

In spite of the exchange rate exposure being covered, investment in domestic and foreign assets may still entail differences in counter-party and transaction risks as well as liquidity exposure. A positive deviation, $D_{t,h} > 0$, implies that the return from investment in foreign assets exceeds the return from investment in domestic assets, which may occur if investors perceive that investment in foreign assets entails greater risks than investment in domestic assets and/or if foreign assets are seen as less liquid than domestic assets. A negative deviation, $D_{t,h} < 0$, could emerge in a situation where domestic assets are assessed to be more risky or less liquid than foreign assets.

It follows that changes in risks or liquidity conditions may affect the deviation from the CIP. Market instability may lead to a "flight to quality" to markets seen as relatively safe and liquid ("safe havens"), which could increase the deviation in safe and liquid markets and lower it in risky and illiquid markets.

Numerous studies have examined the empirical validity of the CIP condition, typically by examining measures of deviation from the CIP such as the one in eq. (3). The general conclusion is that the condition holds well as long as financial markets are deep and not affected by major turbulence or disruption. Clinton (1988) considers five major currencies against the US dollar and finds that the deviation from the CIP is typically within a range of ± 0.06 percentage points and ascribes such level of deviation to transaction costs that render low-margin arbitrage trades unprofitable.

Dooley and Isard (1980) provide an early study of reasons for deviations from the CIP in the DEM/USD market. They find that deviations can partly be explained by the introduction of capital controls or the expectation of such policy measures. Taylor (1989) documents that deviations from the CIP in the GBP/USD market often occurred during market turbulence caused by events such as the devaluation of the GBP in 1967 and the floating in 1972, but political events on both sides of the Atlantic have also played a role.

A number of studies have examined deviations from the CIP in the period around the global financial crisis, which manifested itself in the bailout of Bear Sterns in March 2008 and the bankruptcy of Lehman Brothers in September 2008.

Baba and Packer (2009) consider the dollar/euro market and find that very large deviations from the CIP occurred already in the middle of 2007 and that the deviations became quite persistent from the middle of 2008. They link the deviations to different developments of counterparty risks in Europe and the USA. Intervention from the European Central Bank seems to have stabilised the markets although deviations from the CIP persisted throughout the sample period. Jones (2009) also concludes that increased riskiness of the US banking and money markets was behind the emergence of deviations from the CIP in the middle of 2007. Griffoli and Ranaldo (2010) provide a very detailed study of deviations from the CIP on the dollar/euro market. They find persistent deviations and conclude that arbitrage broke down because market participants had problems obtaining dollar funding.

Studies of the empirical validity of the covered interest parity in countries from Central and Eastern Europe are relatively scarce and in all cases focus on the effects of economic or financial integration. Mansori (2003) argues that estimations of the CIP for the Czech Republic, Hungary and Poland show many similarities to estimations of the CIP for Western European countries. Hermann and Jochem (2007) find that the removal of capital controls in the period before 2002 reduced deviations from the CIP for four CEE countries. Ferreira (2011) compares financial integration in Western European countries and the Czech Republic, Hungary and Poland, using, inter alia, tests of the CIP. For the Czech Republic the CIP condition cannot be rejected for holding periods of 6 and 12 months, while for Hungary and Poland the CIP condition is consistently rejected. The data sample ends in 2004, which may explain the finding of limited financial integration.

This paper is to our knowledge the first to analyse deviations from the covered interest parity in CEE countries in the period surrounding the global financial crisis. The analysis progresses in two steps. First, the paper documents the size and timing of deviations from the CIP in each of the four sample countries. Second, possible causes of the CIP deviations are investigated in regression analyses in which proxies of global and local market risk are explanatory variables.

The rest of the paper is organised as follows. The next section provides a short description of the data used. The following section documents and discusses deviations from the CIP, in part through figures of forward premiums and interest rate spreads. The subsequent section explains deviations from the CIP using proxies of global and local risk components. The finally section summarises the paper.

## Data

This section provides an overview of the dataset used in the empirical analyses. The sample comprises four major CEE economies, namely the Czech Republic, Hungary, Poland and Romania. All data are monthly (end of the month value). The endpoint of the sample at the end of 2011 is common to all series, but the starting date differs across the countries, depending on data availability. The differences do not affect the comparisons of results between countries since all estimations cover the relatively stable years before the global financial crisis as well as the period after the crisis. The four countries all had floating exchange rates during this period, although Hungary used different corridors for its exchange rate until 2008.

Based on Bloomberg data, the forward premium and the interest rate spread is calculated for each of the four countries. The reference area is taken to be the euro area; the exchange rates are in units of local currency per euro and the interest rate spreads of the local interbank offered interest rate are against the Euribor rate. The analyses are undertaken for investment horizons of three months, implying that the returns from the currency exposure and the interest rate differential are both calculated for a 3-month holding period. This horizon has been chosen because the 3-month money market is one of the most liquid segments of the market.

Deviations from the CIP are explained by two variables capturing the riskiness of investment in different markets. The first variable is the VIX index, the volatility of US equities calculated from options on the S&P500 index over the next month. The variable is a measure of the market pricing of expected stock market volatility and is often taken as a proxy for short-term risks in global financial markets. A higher value indicates increased perceived risks.

The other variable is the Credit Default Swap (CDS) spread of five-year government bonds for each of the four countries. A Credit Default Swap allows an investor to hedge against the risk of default of a specific asset. The spread or fee paid is a measure of the market pricing of the default risk; an increase in the spread implies a higher perceived riskiness of the reference asset. We take the CDS spread as a proxy of local or country-specific financial market risk. A high CDS spread signals a high risk of government default which will lead to turbulence in domestic financial markets; financial market turbulence typically also affects CDS spreads as the government's financial outlook deteriorates. The VIX index and the CDS spread are also used in the studies by Griffoli and Ranaldo (2010) and Skinner and Mason (2011), seeking to explain deviations from the CIP.

The problem of using VIX as a proxy of global risks and CDS as a proxy of local risks is that the two variables are highly correlated with a correlation coefficient around 0.7 for each of the four sample countries. The high degree of correlation reflects that financial risks co-vary across countries as global risks spill over to local or country-specific markets. The correlation of the two measures of pricing of risks makes it is difficult to identify the separate effects of global and local risks. Given the size and global impact of the countries in the sample, global risks are likely to have affected local risks, while causality in the other direction is unlikely.

Following this reasoning we seek to remove the global component, VIX, from the measure of local risks, CDS. The variable VIX is regressed on the variable CDS for each of the four countries separately and for the corresponding sample period. The residual is labelled CDSU, cf. eq. (4) below. The constant and the slope coefficient b are estimated using OLS.

$$CDS = Constant + b \cdot VIX + CDSU \quad (4)$$

The coefficient of determination is around 0.6-0.7, and the estimated slope coefficients are positive for all four countries and statistically significant for three of them, but not for Hungary. The residual CDSU contains the orthogonal component, i.e. the variation in CDS that cannot be explained by global developments. The variable CDSU is thus a measure of the idiosyncratic risks, i.e. the risks that stem from the individual country.

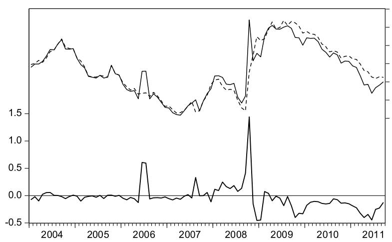
The development of the CDSU variables is generally intuitive. Before the global financial crisis the volatility of the residuals is fairly low for all the four countries. After the Lehman Brothers default, differences across the countries emerge. For the Czech Republic the volatility of CDSU is still low, while it increases for the other countries, in particular for Romania and Hungary. In other words, the differences between the countries become more pronounced after the outbreak of the crisis.

Tests of the time series properties of the data series are not reported to save space; the tests are available from the corresponding author upon request. In general the forward premium and the interest rate spreads are stationary variables, although the results vary somewhat depending on the time sample. For Poland the deviation from the CIP, i.e. the difference between the forward premium and the interest rate spread, the unit root hypothesis is only rejected at the margin. Unsurprisingly, the time series properties of the two risk variables, VIX and CDSU, also depend on the specific sample used for the test.

## Deviations from covered interest parity

This section presents empirical evidence on the fulfilment of the covered interest parity condition for the four sample countries, the Czech Republic, Hungary, Poland, and Romania. Figure 1 shows the annualised 3-month forward premium and the corresponding 3-month interest rate spread (upper part) as well as the deviation from the CIP (lower part).[1] The scale differs across the four plots.

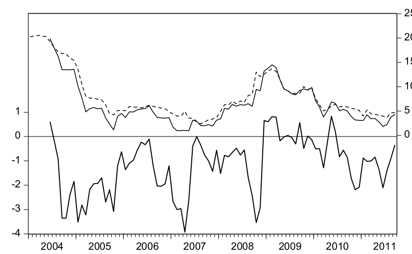
[1] The deviation from the CIP, shown in the lower part of each plot, corresponds to $D_{t,h}$ in eq. (3) with $h = 1/4$.




(a) Czech Republic


(b) Hungary


(c) Poland




(d) Romania

*Figure 1. Annualised 3-month forward premium and interest rate spread, percent. Deviation from the CIP, percentage points. Monthly data, 2004:1-2011:12*
*Legend: The forward premium (solid) and the interest rate spread (dashed) are shown in the upper part of each plot, the deviation from the CIP in the lower part.*

Prior to the outbreak of the global financial crisis, the Czech Republic, Hungary and Poland had deviations from the CIP that were small and fluctuated around zero. This reflects relatively deep financial markets that were integrated into Western European markets (Zoli 2007). In the case of Romania the pricing of forward exchange was essentially disconnected from the interest rate spread; the deviations from the CIP were very large, highly variable and almost consistently below zero. The latter result suggests that investors attached a substantial risk and liquidity premium to assets denominated in the Romanian currency (RON). Romania joined the European Union only in 2007, and financial indicators generally show modest financial depth due to macroeconomic instability and governance and regulatory issues (Zoli 2007).

Turning to the period around the outbreak of the global financial crisis, the four countries exhibit very diverging developments. For the Czech Republic the deviation from the CIP had a modest positive tendency already in the middle of 2007 when financial markets in the USA and Europe came under increasing strain. Investors saw investment in the Czech currency (CZK) as entailing little risk, arguably as a "safe haven" currency. In the Czech Republic the immediate effect of the crisis was an upward spike in the deviation from the CIP, confirming the role of the koruna as the currency of choice during uncertain times. In the following period the deviations were small although larger than prior to the global financial crisis and with a negative tendency in 2011.[2]

In Hungary the outbreak of the global financial crisis led to large negative deviations from the CIP as investors fled exposure to the Hungarian currency (HUF). The negative deviation was relatively short-lived, mainly thanks to the intervention by the Hungarian Central Bank in the forward exchange swap market (Mak and Pales 2009). Between September 2008 and February 2009 the Central Bank introduced five different instruments to ensure liquidity in the swap market. With these measures the Hungarian Central Bank became the counterparty of foreign exchange swap with local banks, which could not otherwise find other counterparties willing to take on HUF exposure. The swap transactions entailed different pairs of currencies (EUR, CHF versus HUF) and different maturities (from overnight to 6 months). It is noticeable that the deviation from the CIP increased in 2010-2011, possibly due to increased risks stemming from persistent fiscal problems in Hungary.

In Poland the global financial crisis brought about large negative deviations from the CIP. After the default of Lehman Brothers, the Polish Central Bank launched a "confidence pact", aimed to guarantee the local banking sector liquidity in both the Polish currency (PLN) and in foreign currencies (NBP 2010, 2011). The latter was achieved through foreign exchange swaps against USD, EUR and CHF with weekly and monthly maturity. The demand for swap transactions with the Polish Central Bank decreased substantially in the last quarter of 2009 and the transactions were ceased in the spring of 2010.[3] In contrast to developments in Hungary, the deviation from the CIP fell from 2009 to 2011, signalling a gradual return to normality.

[2] The relatively stable developments in the Czech Republic after the global financial crisis are also confirmed by the fact that the Czech Central Bank did not intervene in foreign exchange markets. The only measure taken was a liquidity-providing repo (with government bonds as collateral), which had the objective of supporting the government bond market (CNB 2009).

[3] The range of maturities covered by NBP instruments never involved swaps above the one-month maturity, differently from the interventions of the Hungarian Central Bank, which had a maximum maturity of six months.

In Romania, the outbreak of the global financial crisis led to a very large negative deviation from the CIP which lasted half a year. The approach of the Central Bank of Romania was different from the one applied by the central banks of Hungary and Poland; no explicit foreign exchange swap instrument was set up, probably because the main risk identified was the solvency of the local banks. The Vienna initiative meant, however, that the nine biggest foreign banks committed themselves to maintain their exposure to Romania and strengthen the capitalisation of their affiliates (NBR 2009, 2010).

The conclusion from Figure 1 and the discussion above is that developments in the relation between the forward premium and the interest rate spread differed substantially across the four countries. In the relatively calm years prior to the global financial crisis, the CIP held relatively well in the three most advanced countries, which is a finding in line with earlier results in Mansori (2003), Hermann and Jochem (2007) and Ferreira (2011). The CIP did not hold for Romania, which is related to the more gradual economic and financial integration process in the country.

When the crisis hit, the CIP condition generally ceased to hold while at the differentiation across the countries became more pronounced. The Czech Republic exhibited features resembling a safe haven at least during the early stages of the crisis. Hungary and Poland exhibited developments more characteristic of emerging market economies as the deviation from the CIP increased markedly and systematically, even after intervention by the central banks. Finally, Romania is a particular case as the CIP did not receive empirical support, neither before nor after the outbreak of the global financial crisis.

**Explaining deviations from the covered interest parity**

The analysis in the previous section shows a clear change in the deviations from the CIP around the outbreak of the global financial crisis for at least three of the four sample countries. In this section we assess to which extent the deviations from the CIP can be tied to measures of risks. The global financial crisis affected risks in financial markets across the world and it may thus be a source of contagion to forward exchange markets in the CEE countries. Skinner and Mason (2011) find that measures of risk generally have substantial explanatory power on deviations from the CIP in a number of emerging-market economies outside CEE. We examine the importance of, respectively, global risks and idiosyncratic country-specific or local risks.

The estimations are undertaken separately for each country. The estimation sample period is January 2004 to September 2011 except for the Czech Republic and Romania for which the sample period starts later due to data availability. The dependent variable is DEV which is the deviation from CIP computed in eq. (3) and shown in Figure 1. (Indices for time and holding period are suppressed.) Beside the variables for global and country-specific risks, the interest rate spread is included as a control variable in case interest rate differentials do not feed into the forward premium one-to-one.[4]

The three explanatory variables are demeaned (using their mean within the estimation samples for the individual countries). This allows us to interpret the estimated constant as the average risk premium not captured by the three explanatory variables. The demeaned interest rate spread is labelled SPREAD', the demeaned global risk variable is VIX' and the demeaned idiosyncratic risk variable (found in eq. (4)) is CDSU'. To facilitate the discussion of the economic significance of the estimation results, Table 1 shows the standard deviations of the three explanatory variables for each country.

*Table 1: Standard deviation of explanatory variables*

| | VIX′ | CDSU′ | SPREAD′ | Sample |
|---|---|---|---|---|
| **Czech Republic** | 10.57 | 0.38 | 0.83 | 2006:5-2011:9 |
| **Hungary** | 10.06 | 0.98 | 2.03 | 2004:1-2011:9 |
| **Poland** | 10.06 | 0.49 | 1.26 | 2004:1-2011:9 |
| **Romania** | 10.28 | 0.87 | 3.91 | 2004:6-2011:9 |

The cross-country differences in the standard deviation of the global risk variable VIX' only stem from the different sample periods. The CDSU' variable reflects country-specific risks and the standard deviation is highest for Hungary and Romania, reflecting a more unstable environment in these two countries. The variance of the spread variable SPREAD' also differs across the countries; Hungary and Romania show the greatest variation.

The equation to be estimated is shown in eq. (5), where $\varepsilon$ is an error term. The constant and the three slope coefficients, i.e. $\beta$, $\gamma$ and $\delta$, are estimated using OLS.

$$\text{DEV} = \text{Constant} + \beta\cdot\text{SPREAD}' + \gamma\cdot\text{VIX}' + \delta\cdot\text{CDSU}' + \varepsilon \quad (5)$$

[4] We also experimented with the Exchange Market Pressure (EMP) index from Filipozzi & Harkmann (2010) as a proxy of exchange rate risks, but the EMP index generally has little explanatory power (estimation results not shown).

The results are reported in Table 2. The results are first discussed for the four sample countries separately and then compared across the countries.

*Table 2: Results of OLS estimations of deviation from the CIP*

| | Constant | VIX′ | CDSU′ | SPREAD′ | $R^2$ | Sample |
|---|---|---|---|---|---|---|
| **Czech Republic** | -0.042 | 0.009* | -0.255** | -0.107** | 0.360 | 2006:5-2011:9 |
| | (0.031) | (0.005) | (0.118) | (0.048) | | |
| **Hungary** | -0.257*** | -0.027*** | -0.184*** | 0.008 | 0.427 | 2004:1-2011:9 |
| | (0.056) | (0.009) | (0.066) | (0.028) | | |
| **Poland** | -0.292*** | -0.018*** | -0.327*** | -0.038 | 0.499 | 2004:1-2011:9 |
| | (0.042) | (0.005) | (0.094) | (0.027) | | |
| **Romania** | -1.188*** | 0.037 | 0.372 | -0.024 | 0.178 | 2004:6-2011:9 |
| | (0.172) | (0.024) | (0.225) | (0.052) | | |

*Notes:* Newey-West standard errors are shown in brackets. Superscripts ***, **, * denote that the coefficient estimate is statistically different from 0 at the 1%, 5% and 10% level of significance, respectively.

For the Czech Republic, global risks, as captured by the VIX' variable, have a positive impact on the deviation from the CIP, implying a lower risk premium when local risks increase. The estimated coefficient is, however, relatively small and only marginally significant. Local risks, as captured by the CDSU' variable, have a negative impact on the deviation from the CIP, suggesting a higher risk premium when local risks increase; an increase in CDSU' by one standard deviation leads to a reduction of DEV by 0.1%-point. The coefficient of the interest rate spread is negative and statistically different from zero, which in contrast to the prediction of the covered interest parity condition. As a robustness check, we restricted the coefficient of the spread variable to be zero as theory predicts, but in qualitative terms the other estimated coefficients remain unchanged (not shown). Finally, the constant is very small and statistically insignificant, i.e. there is no autonomous time-invariant risk premium.

For Hungary, the estimated coefficients of both the global and the local risk variables are negative and statistically significant. The quantitative importance of the two effects is relatively similar; an increase of one standard deviation in VIX' reduces DEV by 0.3%-points, while a similar increase in CDSU' reduces DEV by 0.2%-points. The constant term is statistically significant and negative, suggesting a country-specific risk premium.

For Poland, the estimation results resemble those for Hungary. Both global and local risks have a negative effect on the deviation from the CIP. An increase of one standard deviation in VIX' diminishes DEV by 0.2%-points, while an increase of one standard deviation in CDSU' diminishes DEV by around 0.3%-points. The constant is negative and of the same magnitude as in the case of Hungary.

For Romania, the main result is that none of the coefficients of the risk proxies attain statistically significant coefficients. This is related to the extreme volatility of DEV. Experiments in which the sample was shortened to start in 2008 or later resulted in estimated coefficients that are very unstable and generally not statistically significant. The estimated constant is negative and around -1.2, which suggests a much higher time-invariant risk premium than for Hungary and Poland.

Overall, the results show striking differences across the countries. The Czech Republic stands out as a country for which global risks are of little importance (or even associated with a lower risk premium), local risks seem to increase the risk premium, and the constant risk component is negligible. Hungary and Poland share many characteristics as the deviation from the CIP increases both when global and country-specific risks increase. The first result suggests that the countries are susceptible to flight to quality as risks in global markets increase. There are also small constant risk premiums in both cases. Romania stands out as deviations from the CIP are extremely large and apparently unrelated to both global and local risk factors. Furthermore, there is a large constant risk premium.

The robustness of the results has been checked in a number of ways. First, eq. (5) has been estimated for all countries using the common sample 2006:5-2011:9. Poland is the only country for which the estimation results change for the shorter sample; although the coefficients of VIX' and CDSU' are not statistically significant anymore, the signs and approximate size are retained. Second, we included the lagged dependent variable in the estimations. The lagged dependent variable is statistically insignificant in the case of the Czech Republic, while it is significant and with a positive sign in the three other cases. While many coefficients lose their statistical significance with the inclusion of the lagged dependent variable, their signs generally remain. Finally, we removed some outliers, in particular around the outbreak of the global financial crisis. As would be expected the removal of such observations with high leverage affects the statistical significance and sometimes also the size of the estimated coefficients, but the qualitative results largely remain.

## Conclusions

This paper analyses the empirical validity of the covered interest rate condition in four major CEE countries with floating exchange systems. The main focus is on the impact of the global financial crisis and the possible causal links from the crisis to deviations from the CIP.

In the period before the global financial crisis, the CIP is largely satisfied for the three more advanced countries in the sample, but not for Romania which has seen relatively sluggish financial development. After the outbreak of the crisis, the CIP does not hold for any of the four sample countries but there are substantial differences across the countries. For the Czech Republic the deviation from the CIP is generally small and even negative at times. For Hungary and Poland the deviation from the CIP is larger, but while it gradually decreased in 2009-2011 for Poland, it increased for Hungary. Finally, for Romania the deviation from the CIP is very large, thus being in line with the period before the crisis.

Interestingly, the deviations from the CIP closely correspond to the interventions in foreign exchange markets undertaken by the central banks after the global financial crisis. The Czech central bank did not deem it necessary to intervene, as market-based arbitrage continued to function reasonably well. The Hungarian and Polish central banks both entered the foreign exchange swap markets to counteract the effects of the limited private liquidity. The Romanian central bank did not undertake any direct measures as forward exchange markets never played a major role, as also reflected in the large deviations from the CIP already before the crisis.

Econometric analysis lends further support to the conclusions above. The deviations from the CIP can be linked to both global and idiosyncratic local risks, but the pattern differs across the countries. For the Czech Republic, global risks that do not spread to the local risk measure appear to reduce the risk premium, for Hungary and Poland both global and idiosyncratic local risks lead to higher risk premiums and for Romania the deviations from the CIP do not depend on the risk factors in the model.

In the pre-crisis period there were clear differences between, on the one hand, the three economically more advanced countries in the sample, i.e. the Czech Republic, Hungary and Poland and, on the other hand, the least developed country, Romania. The econometric analysis suggests that the differences are partly due to the low degree of financial integration and the perceived riskiness of investment in Romania. With the outbreak of the global financial crisis the covered interest parity condition generally ceases to hold, but at the same time differentiation across the three more advanced countries increases. The Czech Republic exhibits features of an advanced economy or even a safe haven, while Hungary and Poland are more characteristic of emerging market economies, where increased riskiness and reduced liquidity make investors flee the countries. Finally, Romania appears to be little affected by the increased risks during the crisis due to the limited development and integration of its financial markets.

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# APPENDIX 4

## Uncovered Interest Parity in Central and Eastern Europe: convergence and the global financial crisis

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# UNCOVERED INTEREST PARITY IN CENTRAL AND EASTERN EUROPE: CONVERGENCE AND THE GLOBAL FINANCIAL CRISIS[*]

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*Abstract:* This paper presents tests of uncovered interest parity in Croatia, the Czech Republic, Hungary, Poland and Romania; all countries in Central and Eastern Europe with floating exchange rates. Data are monthly and the trading horizon is three months. The estimations show that the UIP hypothesis is rejected for the full sample from 1999 to 2011 for all five countries. A number of reasons for the rejection were investigated. Rolling regressions show that standard versions of the UIP essentially lose all explanatory power in 2008-10, which was a period in which the global financial crisis led to instability in currency and interest markets in Central and Eastern Europe. Two indicators of global risk aversion were also found to enter significantly in the many UIP estimations. Finally, the size of the interest rates spread also seems to be of importance, at least for Poland and Romania.

*Keywords:* UIP, financial integration, global financial crisis, Central and Eastern Europe

*JEL classification:* E43, F36, G01, G15

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"*Uncovered interest rate parity remains a key assumption in international economics despite the massive body of empirical evidence against the hypothesis.*"

A. Alexius (2001, p. 505)

# 1. Introduction

This paper presents the results of econometric analyses testing the uncovered interest parity (UIP) hypothesis on data from Poland, the Czech Republic, Hungary, Romania and Croatia. The data sample starts in 1999 or shortly afterwards and ends in September 2011, and as such spans a period in which the countries experienced both rapid economic and financial integration and also the fallout from the global financial crisis. The UIP hypothesis is tested for a trading horizon of three months using monthly data. The five countries in the sample are the main countries in Central and Eastern Europe having floating or essentially floating exchange rate regimes during the sample period.[1] Poland, the Czech Republic and Hungary joined the European Union in May 2004 and Romania in January 2007, while Croatia was in the final stages of membership negotiations at the time of writing in August 2011.

The hypothesis of uncovered interest parity rests on the idea that arbitrage leads to equalisation of the return on assets or liabilities in the domestic currency and the expected return on comparable assets or liabilities in a foreign currency. Testing the UIP hypothesis may thus provide information as to whether the exchange and interest markets under consideration function so that all the gains from trade are exploited, i.e. whether the markets are efficient. In practice, however, divergence between domestic and expected foreign returns may also be due to issues such as transaction costs, different risk profiles and non-symmetric tax treatments.

This paper presents tests of the UIP hypothesis for Croatia, the Czech Republic, Hungary, Poland and Romania. Section 2 provides a survey of empirical studies of the UIP hypothesis with a particular focus on studies dealing with countries in Central and Eastern Europe (CEE). There are only a very limited number of studies that examine the UIP hypothesis for Central and East European countries, particularly studies which use data covering the EU accession and the global financial crisis. The CEE countries liberalised their capital markets and removed their remaining exchange rate restrictions before joining the EU (European Commission 2010a). Many of the countries experienced substantial capital inflows in the years immediately before and after accession to the EU, just to see a reversal of the flows in 2008-09 following the global financial crisis (Jevcak et al. 2011). It is a largely un-researched question whether these abrupt changes in capital flows have affected the relationship between exchange rates and interest rates in the CEE countries.

[1] The study excludes countries with fixed exchanges and countries that adopted the euro during the sample period.

Testing the UIP hypothesis for the CEE countries is also important because households and firms in many countries in the region have borrowed extensively in foreign currencies, mostly the euro and the Swiss franc (Rosenberg & Tirpak 2008). In essence borrowers expect that borrowing in a foreign currency is cheaper than domestic currency borrowing, meaning they have bet that the UIP will not hold within the horizon of the loan contract. Speculators without an underlying motive of borrowing or saving have also taken positions, carry trade, in the currencies of the CEE countries. Rosenberg & Tirpak (2008) and Brzoza-Brzezina et al. (2010) find that the interest differential between domestic and foreign rates is an important determinant of borrowing and saving in foreign currencies in the CEE countries.[2]

This paper seeks to contribute to the empirical literature on the UIP by investigating its empirical validity in the main CEE countries that have a floating exchange rate. The paper tests the UIP hypothesis using individual regressions for each of the five CEE countries. As typically found in the literature, the UIP holds better for some countries than for others and better in some periods than in others. The paper investigates factors that may explain the variation across countries and across time, linking the findings to the different stages of convergence attained in the countries and to the global financial crisis that unfolded in 2007-2009.

The rest of the paper is organised as follows: Section 2 discusses the theoretical foundation of the UIP hypothesis. Section 3 surveys a number of empirical studies with a particular emphasis on the CEE countries. Section 4 documents the data and shows the results of unit root tests. Section 5 presents the baseline estimations using the full sample available. Section 6 contains the estimations when structural change is identified using rolling windows. Section 7 considers whether there are non-linear effects. Section 8 shows the results when different proxies of external determinants of the risk premium are included. Finally, Section 9 summarises the results.

## 2. The theory of uncovered interest parity

The theory underlying the Uncovered Interest Parity is fairly simple as it builds on the assumption of arbitrage equalising expected returns in different markets (Levi 2005, Ch. 8).

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2 Batini & Dowling (2011) use a UIP framework to decompose exchange rate movements between major currencies and the US dollar into shocks stemming from US monetary policy and other sources. The sharp depreciation of most of the sample currencies against the US dollar during the global financial crisis cannot be attributed to changes in the interest rate spread, but rather to changes in the risk premia. The subsequent appreciation of many of the currencies may partly reflect the carry trade exploiting low US interest rates and higher interest rates in other countries. None of the CEE countries are included in the sample.

Consider the investment decision of an investor who at time $t$ seeks to invest a sum for a period of m time units. Assuming that the interest rate is constant and equal to $i_{t,m}$ for the entire investment horizon, the gross return from investing domestically is $1+i_{t,m}$ per time unit leading to $(1+i_{t,m})^m$ compounded during the $m$ periods of the investment. The sum can alternatively be exchanged at the spot exchange rate $S_t$ and invested abroad at the interest rate $i^*_{t,m}$. The foreign denominated gross return after $m$ periods is $(1+i_{t,m})^m/S_t$ and this sum can be exchanged into domestic currency at the exchange rate $S_{t+m}$.

In practice the exchange rate m periods ahead is unknown, so the investor will have to form expectations for this exchange rate. The variable $S^e_{t+m}$ denotes the expectation in period $t$ for the exchange rate in period $t+m$. A risk-neutral investor would be indifferent as to whether to invest in the domestically denominated asset or in the foreign denominated asset if the expected returns are identical, i.e. if uncovered interest parity holds:

$$(1+i_{t,m})^m = (1+i^*_{t,m})^m \frac{S^e_{t+m}}{S_t} \tag{1}$$

This condition is usually log-linearised. We adopt the notation $\Delta_m \log S^e_{t+m} = \log S^e_{t+m} - \log S_t$, which is approximately the relative change in the exchange rate over the m-period horizon of the investment. The variable $\Delta_m \log S^e_{t+m}$ is positive if the investor expects that the domestic currency will depreciate from period $t$ to period $t + m$ and negative if the investor expects that the domestic currency will appreciate. Using this notation eq. (1) becomes:

$$\frac{\Delta_m \log S^e_{t+m}}{m} = \log(1+i_{t,m}) - \log(1+i^*_{t,m}) \tag{2}$$

Using the approximations $i_{t,m} \approx \log(1+i_{t,m})$ and $i^*_{t,m} \approx (1+i^*_{t,m})$ and lowercase $s_t$ to denote the logarithm of the exchange rate, i.e. $s_t = \log(S_t)$ and $s^e_{t+m} = \log(S^e_{t+m})$, the version of the UIP in eq. (2) can be rewritten as:

$$\frac{\Delta_m s^e_{t+m}}{m} = i_{t,m} - i^*_{t,m} \tag{3}$$

The left-hand side is the annualised average expected capital gain from the foreign currency investment. The right hand side is the spread between the domestic and foreign interest rates. The upshot is that a positive spread is consistent with the UIP hypothesis only if the spot rate is expected to depreciate in the way given in eq. (3), i.e. investment in the foreign denominated asset will only take place if the positive interest spread is compensated for by a corresponding capital gain.[3]

Eq. (3) can be tested empirically if a measure of the expected spot exchange rate $m$ periods ahead is available, for instance from surveys or market data. A more common methodology, however, is based on the assumption of rational expectations, i.e. $\Delta_m s^e_{t+m}/m = \Delta_m s_{t+m}/m + \varepsilon_{t+m}$, where $E_t[\varepsilon_{t+m}] = 0$, i.e. the mathematical expectation of $\varepsilon_{t+m}$ is zero, conditional on information in period $t$. This empirical version of the UIP is:

$$\frac{\Delta_m s_{t+m}}{m} = i_{t,m} - i^*_{t,m} + \varepsilon_{t+m} \tag{4}$$

A simple empirical methodology for a test of the UIP hypothesis entails estimation of the following standard UIP regression model:

$$\frac{\Delta_m s_{t+m}}{m} = \alpha + \beta(i_{t,m} - i^*_{t,m}) + \varepsilon_{t+m} \tag{5}$$

Eq. (5) is the model used in most estimations in the paper. The UIP corresponds to the joint null hypothesis that the constant $\alpha = 0$, the slope coefficient $\beta = 1$ and $E_t[\varepsilon_{t+m}] = 0$; the UIP hypothesis cannot be rejected if none of these conditions can be rejected.[4] Three comments are appropriate:

First, the assumption that $E_t[\varepsilon_{t+m}] = 0$ implies that the residuals are serially uncorrelated if the investment horizon coincides with the sampling frequency. If, however, the investment horizon exceeds the investment frequency (as would be the case with, for instance, monthly data and a quarterly investment horizon), overlapping data emerge and the residual will be subject to serial correlation of order $m - 1$ even if $E_t[\varepsilon_{t+m}] = 0$ is satisfied for the investment horizon (Baillie & Bollerslev 2000).

Second, the test implies essentially a joint test of several hypotheses, including the hypothesis that arbitrage equalises the expected currency gain and the interest rate differential and the hypothesis that investors have rational expectations (Alper et al. 2009). If $\alpha = 0$ and $\beta = 1$ cannot be rejected (in a model with non-serially correlated residuals), it is reasonable to assume that both hypotheses are satisfied. Rejection implies that the UIP does not hold, but the underlying reason (such as

[3] The domestic interest rate that is consistent with UIP follows directly from Eq. (3), i.e. $i_{t,m} = i^*_{t,m} + \Delta_m s^e_{t+m}/m$ .

[4] Fama (1984) suggests a narrower test of the UIP hypothesis, essentially testing whether the forward rate is an unbiased estimator of the future exchange rate. The Fama regression entails that the forward premium is regressed on the future exchange rate change and a slope coefficient of one is interpreted as confirmation of the efficient market hypothesis.

absence of arbitrage trades or non-rational expectations) cannot be identified right away.

Third, the test entails the estimation of one coefficient of the interest spread $i_{t,m} - i^*_{t,m}$, not separate coefficients for each of the interest rates. The implicit assumption is that the investors react only to the interest rate spread, i.e. in similarly sized but opposing ways to each of the two interest rates (Mehl & Cappiello 2007). In practice, the assumption is convenient as it typically implies that the interest spread $i_{t,m} - i^*_{t,m}$ is stationary, but this may not be the case for each interest rate considered individually.

The theoretical model in eq. (3) and the empirical model in eq. (5) are based on the assumption that the investors are risk-neutral and do not require a risk premium to hold one currency or the other. This assumption is unrealistic in practice insofar as investors are risk averse. A constant risk premium can be included by allowing the constant $\alpha$ to differ from zero.[5] This assumption might be too restrictive if the risk premium is non-constant, but it would then be necessary to model the risk premium. The presence of a risk premium – and in particular a non-constant risk-premium – does not contradict the UIP hypothesis per se, but it complicates the empirical testing as it requires that the risk premium can be identified empirically.

Beyond the presence of a risk premium, it is possible to point out a number of factors which would entail that eq. (3) would not hold (Levi 2005, Ch. 8):

- Financial markets may not be fully integrated because of regulation, institutional barriers or undeveloped trading possibilities (lack of instruments). In this case, the trades needed to arbitrage different expected returns may not be available.
- Illiquidity or thin markets may lead to market inefficiency as prices may not reflect available information. Illiquidity creates more risks and complicates arbitrage trades, but this may not play a major role in currency markets with large turnovers.
- Transaction costs may make it unprofitable to execute trades that exploit small deviations from the UIP.
- Information costs may be high, in part because information is needed for expectations about exchange rate movements to be formed.
- Investors in exchange and interest markets may not have fully rational expectations. Investors may use mechanical or momentum-based trading strategies, essentially disregarding the available information.
- Liquidity preference may favour investment in domestic currency assets, as investment in foreign currency assets may be more difficult to wind down if there is a sudden need for liquidity in the domestic currency.

[5] If the exchange rate is expected to remain constant ($\Delta_m s^e_{t+m} / m = 0$) and $\alpha > 0$, the domestic interest rate $i_{t,m}$ must exceed the foreign currency interest $i^*_{t,m}$ in order for UIP to hold.

- The asymmetric tax treatment of interest returns and returns from capital gains (here stemming from exchange rate changes) may mean that the strict UIP hypothesis which does not take account of taxation would not hold.

## 3. Empirical studies

The uncovered interest parity hypothesis has been tested empirically for a long time, but better financial data have continuously expanded the possibilities for testing. We will briefly discuss the results of studies using datasets covering developed economies, emerging market economies and countries in Central and Eastern Europe.

Meese & Rogoff (1983) is an influential early study showing that the interest rate spread has essentially no predictive power for the future exchange rate movements of the US dollar when evaluated on data from the 1970s.

A range of empirical studies have subsequently examined the UIP hypothesis using different currency and time samples and different econometric methods. Froot & Thaler (1990) survey 75 published estimates and conclude that the strict version of the UIP hypothesis is rejected in almost all cases. Similar conclusions have been reached in other subsequent survey papers (e.g. Engel 1996, Alexius 2001). The consistent finding that the estimated slope coefficient is far below one and often negative has been labelled the forward premium anomaly (Froot & Thaler 1990, Booth & Longworth 1986, Olmo & Pilbeam 2011).

Most studies are based on data with investment horizons of one month, three months or six months as such data are readily available. Studies suggest, however, that the UIP may hold better at longer investment horizons. Chinn & Meredith (2004) study the empirical validity of the UIP hypothesis for the currencies of the G7 countries using a sample from 1983 to 2000. For short investment horizons, the UIP is rejected in all cases, but when the UIP regression is estimated using 5 or 10 year horizons, the slope coefficient is always positive and in many cases not statistically different from one.[6] Qualitatively similar results are obtained by Alexius (2001) and Mehl & Cappiello (2007) although the UIP hypothesis is still rejected for some countries.

The time sample also seems to be of importance, which is unsurprising given that financial markets and regulatory schemes change over time. Lothiana & Wu (2011) use a sample of 200 years and consider the UIP hypothesis between the

[6] The finding that the UIP hypothesis generally holds better for long investment horizons than for short horizons can be related to the *peso problem* (Froot & Thaler 1990). In this context, the peso problem implies that adjustments of the exchange rate to the UIP may occur in discrete and infrequent steps of substantial magnitude.

dollar and sterling and between the franc and sterling. They find that the slope estimate $\beta$ typically is positive although far from one until 1980, but then turns negative for most periods after that. It is argued that the limited support for the UIP hypothesis is the result of expectations that ex-post are wrong for extended periods of time. Flood & Rose (2002) reach different conclusions using data from the 1990s and a broad sample of high-income and emerging economies. Estimation of standard UIP regressions leads to the conclusion that the hypothesis received more support from their data from the 1990s than from earlier data, although the overall conclusion is still negative as spelled out in the title: "Uncovered interest parity in crisis".

Baillie & Bollerslev (2000) suggest that the forward premium anomaly can, at least partly, be explained by the different time series properties of the variables in the standard UIP regression. The relative exchange rate change ($\Delta_m s_{t+m}/m$) is close to a random walk (at least at relatively high frequencies), while the interest rate spread ($i_{t,m}-i^*_{t,m}$) typically exhibits substantial persistence (but not a unit root). Baillie & Bollerslev (2000) simulate data based on these characteristics and show that the resulting slope, although centred around one, exhibits a very high variance. The upshot is that estimations with relatively few observations are likely to produce coefficient estimates that are sensitive to sample changes and that may differ significantly from one even if the UIP is in fact satisfied.

It is typically found that the UIP holds better for cases where the interest rate spread is substantial and less well for cases where the interest rate spread is small. Mehl & Cappiello (2007) find that UIP relations estimated for some high-income and emerging market economies exhibit non-linearities. They estimate a smooth transition regression implying different marginal effects of the interest rate spread when the interest rate spread is small and when it is large. The upshot is that the standard linear model mixes the effects of different regimes. Using data for selected European currencies, Lothiana & Wu (2011) find more support for the UIP hypothesis in periods in which the interest rate spread is large. This result seems intuitively reasonable as factors such as risks and transaction costs may not warrant arbitrage trading if the returns from such trades are limited (Froot & Thaler 1990).

Alper et al. (2009) survey the literature on UIP testing in emerging market economies. On the one hand, the high trend inflation observed in many emerging markets facilitates the forecasting of exchange rate developments and therefore makes it more likely that the UIP hypothesis does hold. On the other hand, structural breaks and uncertainties are likely to be more pronounced in emerging markets, which would suggest that the UIP does not hold. Empirical studies confirm that UIP estimations frequently exhibit different properties for emerging markets and for high-income economies. Alper et al. (2009, p. 123) conclude that "…identifying and modelling structural breaks provide room for improvement for further research on the UIP condition for [emerging markets]". Bansal & Dahlquist (2000) provide an explicit comparison of results for high-income and emerging market economies and conclude that the UIP is more likely to hold for emerging markets than for high-income economies. Different per capita GNP, average inflation and inflation volatility are factors that may explain the different results.

Only a small number of studies have examined the empirical validity of the UIP hypothesis for countries in Central and Eastern Europe. Brasili & Sitzia (2003) estimate panel models based on CEE data in which future exchange rate changes are explained by the interest rate spread and a range of other factors that may be considered proxies of the risk premium. The spread is not statistically significant in a specification in which it enters linearly, but a non-linear transformation of the spread attains statistical significance, suggesting that non-linearities play an important role. Ho & Ariff (2009) also use a panel explaining the future exchange rate change with many variables along with the interest rate spread. A range of specifications all produce positive and statistically significant coefficients to the interest rate spread for the sample of Eastern European countries, but the coefficients vary substantially across different specifications. The use of panel data in these two studies precludes the estimation of country-specific coefficients of the interest rate spread.

Mansori (2003) compares results for the Czech Republic, Hungary and Poland from 1994 to 2002 with results for a number of West European countries. There is more support for the UIP hypothesis for the three East European countries, especially the Czech Republic and Hungary, than for the West European countries. The results for the CEE countries are however very sensitive to changes in the time sample, possibly as a result of the convergence processes underway during the period analysed. Horobet et al. (2009, 2010) estimate standard UIP regressions for eight countries, including four from Central and Eastern Europe using monthly data from 2006 to 2009. The estimated slope coefficients are positive in all cases, but neither economically nor statistically different from zero. This result seems to hold whether or not exchange market volatility is taken into account.

## 4. Data and unit root tests

This section provides an overview of the dataset and the main features of the series for the five sample countries, Croatia, the Czech Republic, Hungary, Poland and Romania. The samples vary across the five countries but generally span a bit more than a decade, starting in 1999 and ending in September 2011. The five countries all had floating exchange rates during this period, although Poland formally used managed devaluations until April 2000 and Hungary used different corridors until 2008.[7]

The analyses are undertaken for positions with a 3-month horizon, implying that the returns from the currency exposure and the interest rate differential are both calculated for a 3-month holding period. As discussed in the literature survey in Section 3, the results may vary with the investment horizon, but the 3-month horizon has been chosen because the 3-month money market is one of the most liquid segments of the market.

The five countries saw increased integration with Western Europe, and in particular with the euro area, during the sample period. The reference area is therefore taken to be the euro area: the exchange rates are in units of local currency per euro and the interest rate spreads of the local interest rate are against the Euribor rate. It is noticeable that the countries considered here were at different stages of their processes of convergence with Western Europe during the sample period.[8]

Most of the estimations are based on only two variables, cf. eq. (5).[9] The variable FX_CHG is the percentage change of the spot exchange rate over a 3-month period, where the exchange rate denotes units of local currency per euro at the end of month. A positive value of FX_CHG indicates a depreciation of the local currency against the euro over the 3-month period; a negative value indicates an appreciation. The variable INT_SP is the annualised interest spread between a 3-month domestic currency deposit and the 3-month Euribor.

The available sample of data varies across the countries. For Croatia, the series on the nominal exchange rate starts in November 1999, implying that the 3-month FX_CHG variable starts in February 2000. For Poland, the local 3-month interest rate is available from the beginning of 2001. Table 1 reports summary statistics of the exchange rate changes and the interest rate spreads for the five sample countries.

[7] The Hungarian bands changed frequently before they were finally removed in February 2008. Until May 2001, the managed devaluation was based on a "daily rate of devaluation" against, in 1999, a basket (30 percent USD, 70 percent EUR) and, thereafter, the euro. The band around the central rate of the devaluation path was +/– 2.25 percent. From May to October 2001 the band around the central rate was increased to +/– 15 percent. From October 2001 the central parity was fixed at 276.1 HUF/EUR and in June 2003 to 282.36 HUF/EUR, while the band remained at +/– 15 percent.

[8] For an overview of the stages of convergence, see the European Commission (2010a, 2010b). Different indicators can be used to assess the degree of convergence of the CEE countries with Western Europe. European Commission (2010a, 2010b) asserts that the convergence process in Romania and Croatia has been slower than that in the other three CEE countries in our sample.

[9] The variables are calculated based on Ecowin source data.

*Table 1: Descriptive statistics for 3-month exchange rate change and 3-month interest rate spread*

| **FX_CHG** | **Mean** | **Median** | **Max.** | **Min.** | **Std. Dev.** | **Obs.** |
|---|---|---|---|---|---|---|
| Croatia | -0.20 | -0.51 | 17.09 | -20.97 | 6.46 | 140 |
| Czech Republic | -2.94 | -4.24 | 60.48 | -23.00 | 12.15 | 153 |
| Hungary | 1.99 | 2.04 | 63.03 | -47.54 | 18.54 | 153 |
| Poland | 2.39 | -0.97 | 98.36 | -37.77 | 25.06 | 129 |
| Romania | 9.26 | 6.90 | 76.87 | -32.82 | 21.12 | 153 |

| **INT_SP** | **Mean** | **Median** | **Max.** | **Min.** | **Std. Dev.** | **Obs.** |
|---|---|---|---|---|---|---|
| Croatia | 3.30 | 2.74 | 11.05 | -0.05 | 2.50 | 140 |
| Czech Republic | 0.36 | 0.15 | 5.04 | -1.35 | 1.25 | 153 |
| Hungary | 6.19 | 5.71 | 12.97 | 2.66 | 2.52 | 153 |
| Poland | 3.70 | 3.27 | 13.03 | 0.66 | 2.62 | 129 |
| Romania | 22.75 | 13.00 | 145.07 | 2.38 | 26.58 | 153 |

Figure 1 depicts the nominal exchange rate of each Eastern European country against the euro from the beginning of 1999 and until December 2011. The first thing to notice is that the exchange rate dynamics vary considerably across the five sample countries. The currencies of Croatia and the Czech Republic have tended to appreciate against the euro, while the currency of Romania has tended to depreciate. The currencies of Hungary and Poland have been relatively stable with exchange rates fluctuating around a relatively constant level.

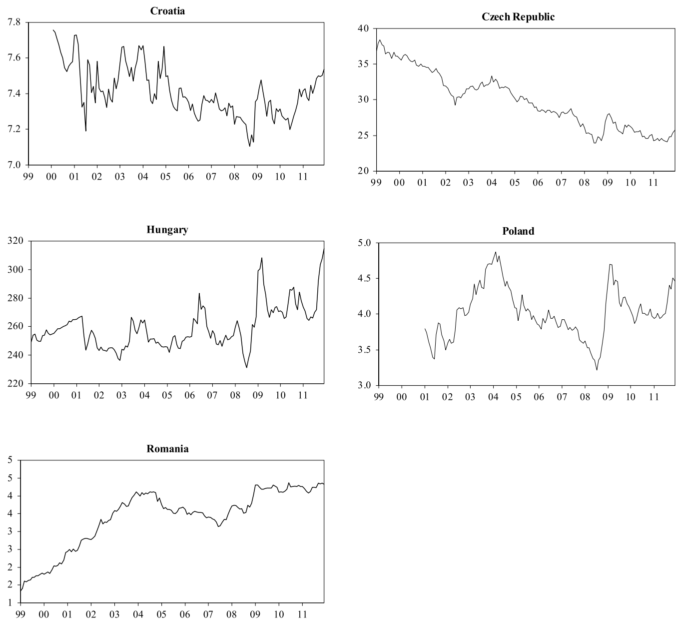


*Figure 1: Nominal exchange rate of local currency against euro*

The different exchange rate development across the sample countries is the result of many factors. The process of integration into EU structures, and the associated confidence effects, has affected the exchange rate dynamics in the Central and Eastern European countries. The speed of and commitment to integration has differed across the countries.[10] The main message for our analyses is that there is no "Central and Eastern European block" with closely co-moving exchange rates; the exchange rate developments are fundamentally different across the five sample countries.

Figure 2 depicts the 3-month annualised change of the exchange rate against the euro. The series are very volatile, which suggests that, for the UIP to hold, the

[10] The Romanian case is noticeable because the period from 2003 to 2005 represents a political and economic regime switch. During this period Romania joined the Council of Europe and the WTO, and became an associated member of the European Union. These steps were part of the process of stabilising the political and economic situation in the country, and helped to increase the confidence of financial markets in the Romanian economy (European Commission 2010a).

interest rate differential between the country and the euro area would also have to be volatile.

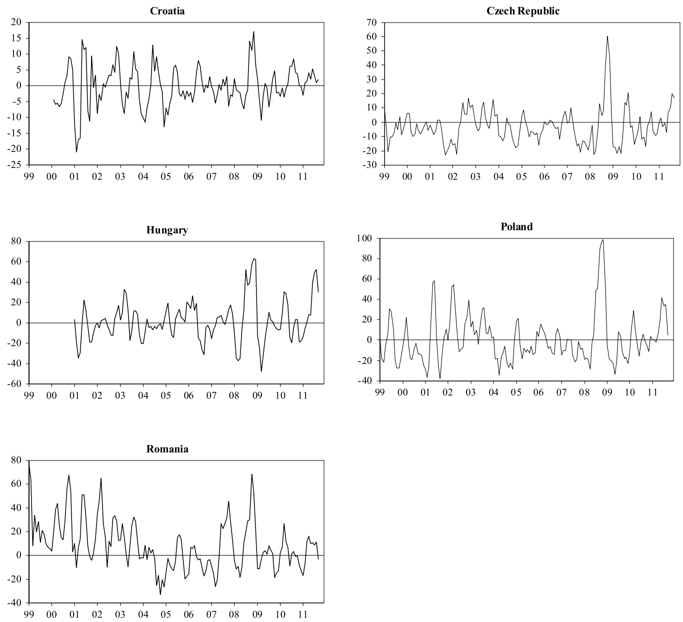


*Figure 2: Annualised changes of local currency versus euro over 3-month period, %*

Figure 3 reports the spread between the local 3-month interbank interest rate and the 3-month Euribor. The volatility of the interest rates spread is much smaller than the volatility of the foreign exchange rate changes on the same horizon.

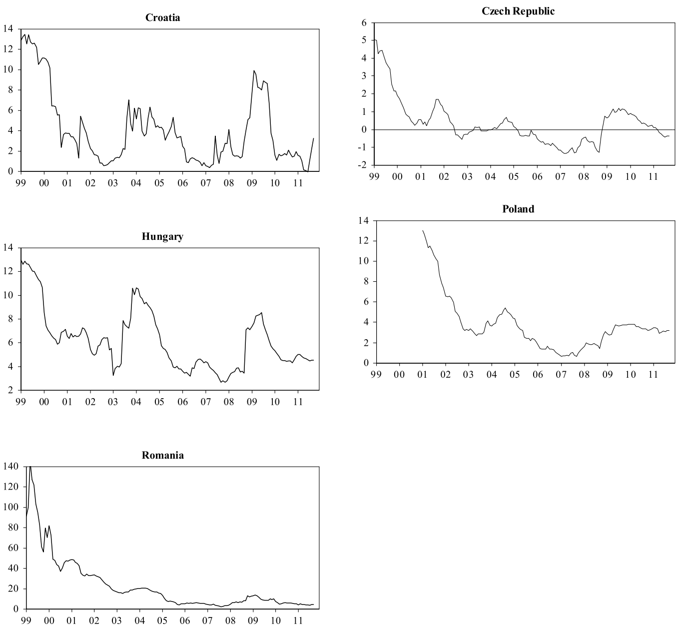


*Figure 3: Annualised interest rate spreads on 3-month deposits, %*

The time series properties of the exchange rate changes and the interest rate spreads have been examined by means of Augmented Dickey-Fuller tests. Given that the variables are either changes in percentage terms (for currency pairs) or spreads (interest rates), the test is performed at the level of the variables and an intercept, but no time trend, is included in the estimations. The number of lags used is chosen by means of the Schwartz selection criterion. The results are reported in Table 2. The hypothesis of a unit root can be rejected in all cases; the series are I(0) for all five sample countries.

*Table 2: Augmented Dickey-Fuller unit root tests*

| **FX_CHG** | **1% C.V.** | **5% C.V.** | **10% C.V.** | **Statistic** | **Prob.** | **Process** |
|---|---|---|---|---|---|---|
| Croatia | -3.479 | -2.883 | -2.578 | -7.831 | 0.000 | I(0) |
| Czech Republic | -3.475 | -2.881 | -2.577 | -5.225 | 0.000 | I(0) |
| Hungary | -3.475 | -2.881 | -2.577 | -6.969 | 0.000 | I(0) |
| Poland | -3.482 | -2.884 | -2.579 | -5.161 | 0.000 | I(0) |
| Romania | -3.475 | -2.881 | -2.577 | -4.495 | 0.000 | I(0) |
| **INT_SP** | **1% C.V.** | **5% C.V.** | **10% C.V.** | **Statistic** | **Prob.** | **Process** |
| Croatia | -3.477 | -2.882 | -2.578 | -3.476 | 0.010 | I(0) |
| Czech Republic | -3.474 | -2.880 | -2.577 | -3.767 | 0.004 | I(0) |
| Hungary | -3.473 | -2.880 | -2.577 | -2.745 | 0.069 | I(0) |
| Poland | -3.482 | -2.884 | -2.579 | -4.352 | 0.001 | I(0) |
| Romania | -3.477 | -2.882 | -2.578 | -3.963 | 0.002 | I(0) |

*Note:* C.V. denotes critical value.

## 5. Uncovered interest parity

We start by rewriting eq. (5) using our empirical notation in which a bracket after the variable name is used to indicate a time shift (in month) of the variable:

$$FX\_CHG(3) = \alpha + \beta \cdot INT\_SP + \varepsilon(3) \qquad (6)$$

Eq. (6) is estimated for each country individually using OLS. The results are reported in Table 3. The choice of a 3-month investment horizon but monthly data leads to first- and second order-autocorrelation of the residuals. We therefore report Newey-West robust standard errors. The strict version of the UIP holds if $\alpha = 0$ and $\beta = 1$ and the residuals do not exhibit serial correlation of the third or a higher order. The table reports the F-statistics for the Wald test of the joint hypothesis $\alpha =$

0 and $\beta = 1$. Examination of the residuals reveals the existence of autocorrelation of first and sometimes second order, but never of higher orders.

The estimation results reveal that the coefficients of determination, $R^2$, of all the regressions are extremely low. This is not surprising in light of Figures 2 and 3 and is found in all tests of the UIP hypothesis (Flood 1996). The foreign exchange return is much more volatile than the interest rate spread, which limits the ability of the interest rate spread to explain the foreign exchange change.

*Table 3: UIP estimation results (OLS)*

| | $\hat{\alpha}$ | $\hat{\beta}$ | F-stat | $R^2$ | Sample | Obs. |
|---|---|---|---|---|---|---|
| **Croatia** | 1.401<br>(0.888) | $-0.486^{**}$<br>(0.210) | 31.660<br>[0.000] | 0.035 | 2000:02-2011:09 | 140 |
| **Czech Republic** | -2.447<br>(1.718) | -1.380<br>(0.972) | 9.492<br>[0.000] | 0.020 | 1999:01-2011:09 | 153 |
| **Hungary** | $9.546^{*}$<br>(5.706) | $-1.220^{*}$<br>(0.711) | 10.120<br>[0.000] | 0.028 | 1999:01-2011:09 | 153 |
| **Poland** | 3.658<br>(6.479) | -0.342<br>(1.319) | 0.642<br>[0.528] | 0.001 | 2001:01-2011:09 | 123 |
| **Romania** | 2.023<br>(3.290) | $0.308^{***}$<br>(0.087) | 47.944<br>[0.000] | 0.148 | 1999:01-2011:09 | 153 |

*Note:* Newey-West standard errors are shown in round brackets. Superscripts $^{***}$, $^{**}$, $^{*}$ denote that the coefficient estimate is statistically different from 0 at the 1, 5 and 10% level of significance respectively. The null hypothesis of the F-test is that $\alpha = 0$ and $\beta = 1$; the *p*-value is shown in square brackets.

The estimated slope coefficients in Table 3 are different from 1 at the 1% level of significance for all five sample countries. For all countries except Romania, the coefficients are also negative, which is in accordance with the forward premium anomaly found in many other studies (cf. Section 3). For Romania, the estimated coefficient is positive and significantly different from zero (but also significantly different from one). This would be consistent with the finding that the UIP hypothesis is more likely to hold when the interest rates spread is large (Froot & Thaler 1990, Mehl & Cappiello 2007, Lothiana & Wu 2011). It follows from Figure 3 that the spread between the Romanian 3-months interest rate and the 3-months Euribor rate was in the double digits until 2005 and also afterwards remained much higher than for the other sample countries. The large interest spread reflects that Romania has experienced a more prolonged convergence process the other sample countries.

The estimated constant terms are, with the exception of the Czech Republic, positive, but statistically significantly different from 0 only for one country. As already noted, this coefficient should indicate the presence of either a risk premium or barriers to entry. While it is probable that barriers to entry or other parts of the regulatory landscape do not change very often, previous research and anecdotal evidence (again, from the recent financial crisis) indicates that the risk premium varies across time and economic cycles, and therefore to model them as a constant would be to impose a tight constraint on the model.[11]

The F-statistics reported in Table 3 shows that Poland is the only country for which the null hypothesis cannot be rejected. The Polish case is predicated by the fact that the standard errors of the two coefficient estimates are very high for this country. For all other countries in the sample, the joint hypothesis that $\alpha$ and $\beta$ take values in accordance with the UIP is rejected.

## 6. Uncovered interest parity across time

The test of the UIP in Section 5 is undertaken on the entire available time sample from the turn of the century to September 2011. The recent global financial crisis has, however, provoked very sharp reactions in inter alia foreign exchange and interest markets. Eastern European countries largely escaped the first part of the crisis (the "sub-prime" phase from summer 2007), but the default of Lehman Brothers in September 2008 affected the region greatly. This is also shown by Figures 1 and 3, in which sudden depreciations of the currencies against the euro and a jump in the spreads between local interest rates and the Euribor are evident.

In order to shed further light on the impact on the UIP of the global financial crisis, and more generally to shed light on the time dimension, we undertake rolling windows estimations with samples of monthly observations for five years. The estimations are based on eq. (6), i.e. the simple linear version of the UIP. Figure 4

[11] The residuals generally exhibit some heteroskedasticity. To assess the impact, we estimated eq. (6) using a GARCH specification. Although the GARCH coefficients are statistically significant in many cases, the effects on the estimated $\alpha$ and $\beta$ and the explanatory power of the regressions are modest.

shows the coefficient of determination, while Figures 5 and 6 show the estimated constants and slope coefficients for the five countries. For all three figures, the date reported on the horizontal axis indicates the end of the sample.

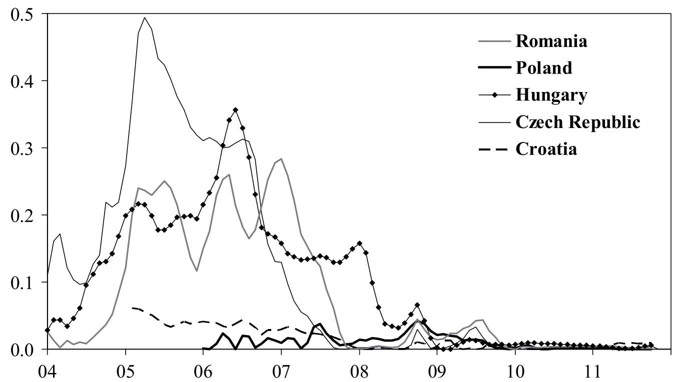


*Figure 4: Coefficient of determination, 5-year rolling windows*

Figure 4 reveals that the explanatory power of the regressions is always very low for Poland and Croatia, but relatively high before the crisis for the three other countries. This could be an indication that Poland and Croatia may have been more "closed" or insulated from external influences than the other three countries in the sample (Jevcak et al. 2011). Moreover, when the windows consist largely of the period around the global financial crisis, the simple UIP specification (without crisis indicators and with fixed coefficients) basically has no explanatory power for the five sample countries.

Further insights into developments before and after the global financial crisis hit the region can be gained from Figures 5 and 6. The coefficient estimate and +/– 2 times the Newey-West standard errors are depicted in each figure. The estimated constants and slopes for all the sample countries display extreme variation. This could be due to the relatively short span of the sample (five years for each rolling regression), or to an inherent instability in the relation between interest rate spreads and currency returns (Baillie & Bollerslev 2000).

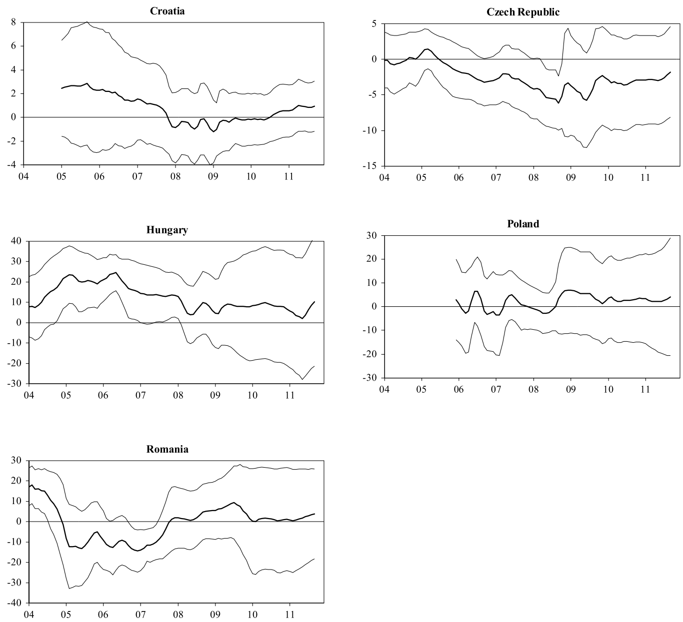


*Figure 5: Estimated constants, 5-year rolling windows*

The UIP specifications exhibit some explanatory power for the Czech Republic, Hungary and Romania in the pre-crisis period. For the Czech Republic the constant was close to zero and the slope was negative. The absolute value of the slope estimate is extremely large when the period 2000-2001 is included in the sample; this was a period in which the Czech koruna appreciated rapidly. For Hungary the slope estimate is also negative (below -1), while the constant is positive. For Romania the slope is positive and the constant is negative. Moreover, the slope is close to one for all of the period before 2007 but turned negative later. This suggests that the UIP was satisfied in the transition period when the interest spread was very high, but not in later periods when the spread was reduced.

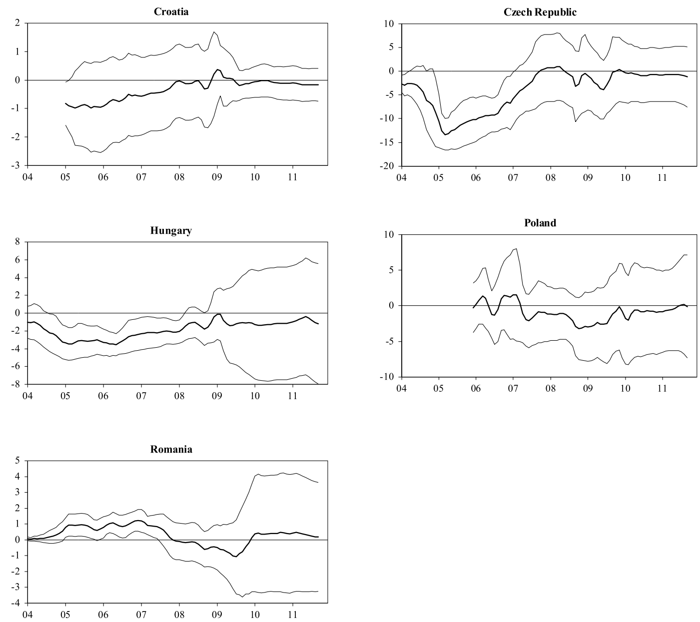


*Figure 6: Estimated slope coefficients, 5-year rolling windows*

The conclusion from the estimations in Sections 5 and 6 is that the UIP has limited empirical validity in the sample of CEE countries. Still, there are noticeable differences across the sample countries and across different time samples. The rest of the paper examines a number of possible reasons for these findings. Transaction costs may limit arbitrage when the interest rate spread is small (Section 7) and the risk premium may be time-varying (Section 8).

## 7. Non-linearities

The size of the interest rate spread may affect whether or not the UIP hypothesis is supported. Transaction and information costs are likely to keep investors from exploiting deviations from the UIP when the interest rate spread is small, but not when the spread is high (Froot & Thaler 1990). The conjecture has some empirical support (Mehl & Cappiella 2007, Lothiana & Wu 2011).

The extreme volatility of the FX_CHG variable has made us pursue a simple and robust way to model the presence of different regimes for different levels of interest rate spreads. We separate the interest spread into two series. Taking the average spread over the sample for each country, two series of interest rate spreads are computed: the variable INT_SP_LO equals the spread when the spread is lower than the average, and zero otherwise; the variable INT_SP_HI equals the spread when the spread is higher than the average, and zero otherwise. Both spread variables are included in the UIP specification:

$$FX\_CHG(3) = \alpha + \beta^{LO} \cdot INT\_SP\_LO + \beta^{HI} \cdot INT\_SP\_HI + \varepsilon(3) \qquad (7)$$

The results of the regressions are reported in Table 4. The results are as expected for Poland and Romania; the slope coefficients for high interest rate spreads are in both cases positive and statistically different from zero, while the coefficients for low spreads are statistically insignificant. The results are inconclusive for the other three countries; the slope coefficients of the high interest rate spreads are negative and the coefficients are generally estimated imprecisely. Overall, Table 4 provides some support to the hypothesis that the UIP should hold better when the interest rate spread is large than when it is low, at least for Poland and Romania.

We have also implemented two other specifications of the non-linear relation from the interest spread to the foreign exchange rate change (results not shown). One approach was the smooth transition model of Granger & Teräsvirta (1993), but we generally had problems estimating the non-linear relation. Another approach was to use a Taylor order approximation up to the third order of the Granger & Teräsvirta model and then to estimate coefficients to all the included powers. In many cases the estimated coefficients attained implausible sign and size and the $R^2$ of the regressions did not change from the base case (results not shown). In conclusion, non-linearities seem to play only a minor role for the UIP estimations, i.e. transaction and information costs are unlikely to be behind the weak support of the UIP for the CEE countries.

*Table 4: UIP estimation results, high and low interest rate spread variables*

| | $\hat{\alpha}$ | $\hat{\beta}^{LO}$ | $\hat{\beta}^{HI}$ | F-stat | $R^2$ | Sample | Obs. |
|---|---|---|---|---|---|---|---|
| **Croatia** | 2.181 | -0.969 | $-0.553^{**}$ | 21.459 | 0.041 | 2000:02-2011:09 | 140 |
| | (1.355) | (0.729) | (0.225) | [0.000] | | | |
| **Czech Republic** | -1.905 | 0.107 | $-1.743^{*}$ | 6.195 | 0.023 | 1999:01-2011:09 | 153 |
| | (1.680) | (3.328) | (0.955) | [0.000] | | | |
| **Hungary** | 8.979 | -1.073 | -1.163 | 7.543 | 0.028 | 1999:01-2011:09 | 153 |
| | (9.084) | (1.894) | (0.934) | [0.000] | | | |
| **Poland** | 1.445 | 0.221 | 0.464 | 4.936 | 0.080 | 2001:01-2011:09 | 129 |
| | (5.111) | (0.497) | (0.221) | [0.002] | | | |
| **Romania** | 5.790 | -0.113 | $0.266^{***}$ | 34.744 | 0.156 | 1999:01-2011:09 | 153 |
| | (4.523) | (0.462) | (0.089) | [0.000] | | | |

*Notes:* OLS estimation. Newey-West standard errors are shown in round brackets. Superscripts $^{***}$, $^{**}$, $^{*}$ denote that the coefficient estimate is statistically different from 0 at the 1, 5 and 10% level of significance respectively. The null hypothesis of the F-test is that $\alpha$ = 0, $\beta^{LO}$ = 1and $\beta^{HI}$ = 1; the *p*-value is shown in square brackets.

## 8. Risk aversion and financial instability

A possible explanation for the low explanatory power of the UIP estimations is that the risk premium is in fact not constant. We include different proxies of the risk premium.

We start by including the VIX index as a proxy of the risk premium. The VIX index is an implied volatility index calculated from option prices on the S&P500 equity index and is often seen as a main indicator of risk aversion in global financial markets. A higher value of the VIX index is tantamount to larger financial uncertainty. We include VIX as an additional explanatory factor in the empirical UIP specification:

$$\text{FX\_CHG}(3) = \alpha + \beta \cdot \text{INT\_SP} + \gamma \cdot \text{VIX} + \varepsilon(3) \quad (8)$$

The results are reported in Table 5. While the $R^2$ of the estimations do not improve markedly, the coefficient of VIX is positive for all the countries and also statistically significant for Croatia and Romania. More financial instability in global financial markets puts ceteris paribus depreciation pressure on the local currency. The slope coefficients stay largely unchanged, while the constants change sign for three countries, becoming (with the exception of Hungary) negative, but mostly not significant. This suggests that when global risk aversion is taken into account, the time-invariant remaining part captured by the constant loses its explanatory power.

*Table 5: UIP estimation results, including VIX*

| | $\hat{\alpha}$ | $\hat{\beta}$ | $\hat{\gamma}$ | **F-stat** | $R^2$ | **Sample** | **Obs.** |
|---|---|---|---|---|---|---|---|
| **Croatia** | -2.125<br>(1.912) | $-0.65^{***}$<br>(0.230) | $0.185^{**}$<br>(0.094) | 25.946<br>[0.000] | 0.096 | 2000:02-<br>2011:09 | 140 |
| **Czech Republic** | $-13.048^{**}$<br>(6.133) | $-2.176^{*}$<br>(1.232) | 0.488<br>(0.320) | 3.746<br>[0.026] | 0.131 | 1999:01-<br>2011:09 | 153 |
| **Hungary** | 2.585<br>(8.785) | $-1.439^{*}$<br>(0.757) | 0.373<br>(0.430) | 5.580<br>[0.005] | 0.056 | 1999:01-<br>2011:09 | 153 |
| **Poland** | -11.250<br>(9.412) | -0.755<br>(1.488) | 0.748<br>(0.614) | 1.156<br>[0.318] | 0.075 | 2001:01-<br>2011:09 | 129 |
| **Romania** | $-11.151^{*}$<br>(6.385) | $0.271^{***}$<br>(0.082) | $0.639^{**}$<br>(0.294) | 40.687<br>[0.000] | 0.210 | 1999:01-<br>2011:09 | 153 |

*Notes:* OLS estimation. Newey-West standard errors are shown in round brackets. Superscripts $^{***}$, $^{**}$, $^{*}$ denote that the coefficient estimate is statistically different from 0 at the 1, 5 and 10% level of significance respectively. The null hypothesis of the F-test is that $\alpha = 0$ and $\beta = 1$; the $p$-value is shown in square brackets.

An alternative measure of risk aversion, less global and more linked to European foreign exchange markets, may be based on other currency pairs in the region. As a rough measure of the external risk aversion affecting currency markets in Europe, we use the 3-month return of the Swedish krona against the euro. Sweden had a floating exchange rate throughout the sample period and the exchange rate is likely be affected by currency market pressures. The estimated equation is the following, where SWE_FX_CHG denotes the annualised 3-month depreciation of the Swedish krona against the euro:

$$\text{FX\_CHG}(3) = \alpha + \beta \cdot \text{INT\_SP} + \delta \cdot \text{SWE\_FX\_CHG}(3) + \varepsilon(3) \qquad (9)$$

The results are reported in Table 6. The $R^2$ are higher and the coefficients of the Swedish krona return are always statistically significant (with the exception of the results for Croatia) and have positive signs. It seems that including the currency pressure on the Swedish krona gives the same overall result as was given when the VIX variable were included, but in an arguably stronger way. Unlike in the equation with VIX, the constants become insignificant, with the exception of the one for the Czech Republic, where the constant is still significant and negative.

*Table 6: UIP estimation results, including change in Swedish krona foreign exchange rate*

| | $\hat{\alpha}$ | $\hat{\beta}$ | $\hat{\delta}$ | **F-stat** | $R^2$ | **Sample** | **Obs.** |
|---|---|---|---|---|---|---|---|
| **Croatia** | 1.239 | -0.462$^{*}$ | 0.094 | 30.880 | 0.064 | 2000:02-2011:09 | 140 |
| | (0.915) | (0.221) | (0.071) | [0.000] | | | |
| **Czech Republic** | -3.005$^{**}$ | 0.147 | 0.484$^{***}$ | 5.042 | 0.211 | 1999:01-2011:09 | 153 |
| | (1.449) | (0.846) | (0.173) | [0.008] | | | |
| **Hungary** | 6.714 | -0.787 | 0.601$^{***}$ | 6.992 | 0.161 | 1999:01-2011:09 | 153 |
| | (5.655) | (0.754) | (0.211) | [0.001] | | | |
| **Poland** | 3.317 | -0.304 | 1.199$^{***}$ | 0.736 | 0.310 | 2001:01-2011:09 | 129 |
| | (5.075) | (1.168) | (0.312) | [0.481] | | | |
| **Romania** | 1.679 | 0.324$^{***}$ | 0.807$^{***}$ | 77.248 | 0.334 | 1999:01-2011:09 | 153 |
| | (2.758) | (0.068) | (0.129) | [0.000] | | | |

*Notes:* OLS estimation. Newey-West standard errors are shown in round brackets. Superscripts $^{***}$, $^{**}$, $^{*}$ denote that the coefficient estimate is statistically different from 0 at the 1, 5 and 10% level of significance respectively. The null hypothesis of the F-test is that $\alpha = 0$ and $\beta = 1$; the $p$-value is shown in square brackets.

Concluding this section, the two indicators of risk aversion in international financial markets seem to exhibit substantial explanatory power. The estimated coefficients attain the expected sign and are statistically significant in many cases. The addition of these risk aversion measures, however, does not change the conclusions about the estimated slope coefficient, but has, as expected, an impact on the constant term, which becomes statistically insignificant.[12]

## 9. Summary

This paper presented the results of empirical tests of uncovered interest parity in Croatia, the Czech Republic, Hungary, Poland and Romania during the first decade of the 21st century. The objective was to examine whether the UIP would obtain empirical support in this particular sample, and to ascertain to which extent the convergence process and the global financial crisis have affected the UIP relation.

We proceeded from simple estimations of the link between the return on 3-month exposure to local currencies against the euro and the spread between local interest rates and Euribor. The stability of the estimated parameters was analysed using rolling windows. The analysis examined the importance of a number of issues that may affect the results. Estimations took into account the possibility of different regimes depending on the size of the interest rate spread. Various indicators of risk and risk aversion were included, chiefly to capture the effect of the global financial crisis. The main results are summarised below.

The basic model used to test the UIP in the CEE countries gave a result in line with most of the previous literature, namely that the UIP relation cannot be supported in general. The forward premium anomaly is confirmed in the present sample of Central and Eastern European countries; the estimated slope coefficient is negative in all cases except Romania.

Rolling window regressions showed that the coefficient estimates generally are unstable and depend on the choice of sample. The rolling regressions also cast some light on the effect of global financial crisis on the UIP relations in the five CEE countries. At least for the Czech Republic, Hungary and Romania, there is a clear change after the crisis as the explanatory power of the UIP regressions drops dramatically after 2007.

Transaction and information costs do not seem to affect the UIP estimations in ways which can be clearly discerned through the inclusion of non-linearities in the UIP relation. It is clear, however, that the importance of the interest rate spread varies between low and high interest rate spread regimes, but the picture is not uniform across the sample countries. For Poland and Romania, the slope coefficient is positive when the interest rate spread is large, although the estimate is still statistically different from one.

[12] For the Czech Republic, Hungary and Poland we tried to use the Exchange Market Pressure (EMP) index in Filipozzi & Harkmann (2010). The coefficients of the EMP index were not statistically significant (not reported).

There is substantial evidence suggesting that the risk premium is not constant. Both the global volatility index VIX and the movements in the Swedish exchange rate seem to exhibit substantial explanatory power although not symmetrically across all five countries. This suggests that global risk factors have considerable impact on the liquidity of financial markets and the arbitrage processes underlying the UIP in the five countries from Central and Eastern Europe.

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# APPENDIX 5

## The Financial Crisis in Central and Eastern Europe: the Measures and Determinants of the Exchange Market Pressure Index and the Money Market Pressure Index

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# The Financial Crisis in Central and Eastern Europe: the Measures and Determinants of the Exchange Market Pressure Index and the Money Market Pressure Index

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## Abstract

This paper discusses how the global financial crisis has affected the formation of exchange rates and interest rates in three major Central and Eastern European countries: Poland, the Czech Republic and Hungary. Two main channels of the transmission of the crisis are considered: the exchange rate channel, measured by the exchange market pressure index (EMP), and the interest rate channel, measured by the money market pressure index (IMP). Two key results are achieved by using panel regressions. First, during the recent crisis the interest rate channel was controlled by authorities, who left the exchange rate to be the absorber of the imbalances created before the crisis. Second, even though the crisis transmitted through to the banking sector, monetary and external imbalances contributed to the vulnerability of the countries analysed here. The government sector seems to have had a minor role in creating the conditions for the crisis, while it played a central role in taming the effects of the crisis.

JEL classification codes: F30, G01, E44
Keywords: currency crisis, exchange rates, exchange market pressure index, money market pressure index, financial crisis, CEE

## 1. Introduction

After a period of strong expansion of economies across the world, in 2007 a crisis burst out in the real estate sector of the United States. With the collapse of Lehman Brothers in 2008 the crisis soon became global. Initially, it primarily affected the advanced economies of the United States and Western Europe, but the spillover of the crisis was unexpectedly powerful and, among others, also affected Poland, the Czech Republic and Hungary – members of the European Union waiting for accession to the euro-zone. The financial crisis has been equally exciting as it has been complicated, the relationships between money and exchange markets and the crisis are relevant for research.

The objective of this paper is to discuss how the global financial crisis has affected the exchange and money markets in three major Central and Eastern European countries: Poland, the Czech Republic and Hungary. More specifically, the paper addresses four questions:

- Did the crisis hit the three major CEE countries in the same way?
- Which roles have the exchange rate and interest channels played in the transmission of the financial crisis to Poland, the Czech Republic and Hungary?
- Which factors have created the preconditions for the crisis and which ones have evolved simultaneously with the crisis?
- Which role has the authorities taken?



The paper examines two main channels of transmission of the financial crisis to Central and Eastern Europe. The first one is the exchange rate channel. The approach for measurement is the exchange market pressure index (EMP), developed by Girton and Roper (1977) initially and later by Eichengreen et al. (1996), which consists of changes in exchange rates, changes in interest rates and changes in international reserves.

The second one is the interest rate channel of money markets. Central banks reacted to the crisis with active monetary policy measures, which resulted in several interest rate cuts to historically low levels. However, interbank interest rates seemed to skyrocket, possibly "neutralising" central banks' efforts to combat the crisis. In order to consider the effect of interest rates changes on the three countries in question, the analysis of the money market pressure index (IMP), developed by Hagen and Ho (2007), is conducted in parallel with the EMP analysis.

Given that the crisis is characterised by illiquidity, it is assumed that central banks intervened mostly in money markets and the banking sector while leaving the exchange market aside. Thus, we expect the EMP to show a more distinct behavior, as the IMP is strongly controlled by central banks.

Monthly data for Poland, the Czech Republic and Hungary are used to study the dynamics of exchange and money market pressure indices in these countries. Later, the EMP and IMP indices are subsequently regressed on several different explanatory variables to understand the impact that both external and internal factors had on the indices, and accordingly their role in the effects and development of the crisis.

By using the EMP and IMP indices, it is possible to define a binary dependent variable, showing the real moments of the crisis. We use this approach for logit analysis. The main novelty of the current research stands in the contemporaneous consideration of the EMP and IMP, and in the focus on Eastern European countries. To the authors' knowledge, this is also the first attempt to study the influence of the recent crisis on the exchange and money markets in the CEE during 2001–2009. Furthermore, we try to distinguish between the different variables and to group them into those causing vulnerability and those reacting to the crisis.

The rest of the article is structured as follows. Section 2 gives an overview about the theoretical literature on which the empirical analysis is built. Section 3 covers the problems related to the construction of the Exchange Market and money market pressure indices. In Section 4, the data and approach for the calculation of indices are described. Section 5 is dedicated to the empirical analysis of the constructed indices. Section 6 concludes.

## 2. Review of Theoretical Literature

Part of the theory of crises in the financial world looks at whether crises are exceptional events or not, while trying to identify why they happen. In general, there are two opposing views about the occurrence of crises. One states that crises in general are very random events that happen independently of any real changes in the economy, so that the occurrence of a crisis can not be influenced or caused by anything specific and crises exist of themselves. The other view is that financial crises are a natural part of the business cycle and are caused by changes in the real economy (Gorton, 1988; Allen and Gale, 1998).

This divergence of views also applies to the financial and foreign exchange markets during periods of distress. Currency crises in general can be defined as a rapid and extreme change in the exchange rate, which may happen because of a speculative attack on a country's currency that could result in devaluation. Several different approaches, often referred to as generations of models, have tried to explain why the crises occur, and these will be discussed in the next sections.



The recent turmoil in financial markets has once again made the crises the object of several studies. The theories explaining the currency crises, broadened also for the financial crises, can be divided into three groups or three generations of models.

According to the first-generation models, originally developed by Krugman (1979) and Flood and Garber (1984), a financial crisis can be foreseen as it is only a result of bad policy combinations that lead to a deterioration of fundamentals. Though the first-generation models mainly dealt with crises that originated in the currency markets, they could also be applied to financial markets. The models explain crises as a consequence of the inability of governments to run a strict fiscal policy as excessive money creation to finance a deficit creates excessive devaluation pressure on the currency.

As a result, money growth is not compatible with a currency peg as market participants realise that there is a contradiction in the fundamentals, and they try to convert the currency to a foreign one, thus creating more downward pressure as the supply of domestic currency increases. In order to support the peg, the central bank is forced to buy domestic currency and use up its foreign reserves or to increase its interest rates. The real actual crisis itself occurs when mass selling of the domestic currency starts.

Overall, according to the first-generation models, crises are connected with weak fundamentals; such as budget deficits, current and trade account deficits, a fall in international reserves and an excessive real money supply (Belke and Setzer, 2004; Vaugirard, 2007).

The second-generation models explain crises as a consequence of the expectations of investors and a change in market sentiment in the presence of multiple equilibria. The models also consider the possible trade-offs between different policy decisions. These models, originally credited to Obstfeld (1994; 1996), suggest that expectations are self-fulfilling, meaning that if investors believe that there will be a crisis then there will indeed be a crisis. This will happen mainly because investors change their behaviour according to their beliefs. Therefore, according to the second-generation models crises are possible even with strong fundamentals (Belke and Setzer, 2004; Vaugirard, 2007; Flood and Marion, 1998).

Second-generation models also help to explain the reasons why crises tend to spread across borders. If there is a crisis in one country, it increases the likelihood of a crisis in another country. In general, the crises could occur contemporaneously because of a common shock that influences, for example, a particular region. The crisis could spread across the borders between close trade partners. This may happen because the problems in one country may affect the other through a fall in exports and prices. The spillover may be also caused by changes in beliefs and sentiment and thus caused by self-fulfilling expectations (Eichengreen et al., 1996).

The third-generation models emphasise the importance of financial institutions and the banking sector in creating crises alongside structural flaws and policy inconsistencies, and also stress the importance of macroeconomic fundamentals and expectations. Krugman (1998) was one of the first to discuss the role played by moral hazard and bubbles in the financial world in creating crises, following the Asian crisis of 1997. However, the third-generation models differ between authors and there is no clear consensus about the issue among authors.



One approach explains crises as a consequence of the moral hazard that accompanies over-borrowing by banks in an environment of financial liberalisation without prudential supervision. A crisis occurs when the imbalances in the financial sector trigger capital flight or liquidity problems in the markets (Krugman, 1998; Corsetti et al., 1998; Poeck at al., 2007).

In addition, banks that have currency mismatch in their balance sheet are exposed to credit and liquidity risks. Banks could face moral hazard as they lend money out at higher rates than those they paid to raise it. Risky investments are financed by the higher rates, and ultimately this causes asset price bubbles, lifting the prices of risky assets and making the banks seem sounder than they actually are. It is believed that a crisis occurs when the bubble bursts and then the processes go into reverse. The prices of risky assets fall and therefore the banks become insolvent. The fall in asset prices causes capital flight, which can become a mass flight that results in more pressure on the currency than can be defended against by the central bank. Moral hazard is an important feature of these models, as foreign investors are unable to identify the true risks faced by the banks. In general, banking sector weakness, foreign capital exposure and the level of domestic credit growth are believed to be the crisis indicators, or even triggers (Kaminsky and Reinhart, 1998, 1999; Burnside et al., 1999, 2001, 2007; Sarno and Taylor, 2002; McKinnon and Pill, 1996).

Third-generation models have sometimes also covered the contagion of financial crises, looking at crises that spread across borders excessively without any fundamental reason. The spread of a crisis due to herd-like behaviour and excess panic is like an avalanche that cannot be stopped.

These models also discuss the importance of interest rates in the economy. According to first generation models, increasing the interest rates should help to protect the peg by increasing the demand for the domestic currency. The third-generation models argue that increasing the interest rates results in a lack of funding alternatives for the private sector and thus pushes down investments and output. It has now been seen that it is not only the central bank interest rate that influences a crisis, but also the interbank rates.

Even though the early works on crises dealt mainly with currency crises, different types of crisis have occurred during the past. It is clear today that these types of crisis are not independent of one another. One type could easily transform into another and thus create more distress. It could be argued that the recent crisis combines different types of crises. In addition, the models were originally meant to explain the theory behind the fixed exchange rate, but they could apply equally to floating exchange rate arrangements. Overall, it can be said that the main factors connected with crises are banking sector fragilities, extensive and uncontrolled credit growth, and poor macroeconomic conditions.

It is clear why it is so difficult to define a crisis in a way that makes it possible to measure it. The following section gives an overview of one method that should help to define, characterise, analyse, and measure crises in both foreign exchange and money markets.

## 3. Financial Crises Indices

### 3.1. Construction of the Exchange Market Pressure Index

In order to analyse the severity of a crisis and the influence that various factors have on it, a definition of crisis is needed that could be used in empirical analysis. To identify periods of crisis, an index could be built that reflects the changes.



The exchange market pressure index was first developed by Girton and Roper (1977) as they studied the changes in the exchange rate for Canada. Their index helps to identify currency crises as moments when an exchange rate is under pressure or even under speculative attack.

The Girton-Roper model includes movements in the exchange rate and international reserves in their work. Weymark (1995, 1998) also offered an approach for small open economies starting from the same point. They suggest that money market disequilibrium is caused by excess demand for foreign currency and the need for rebalancing by depreciation of the exchange rate or by changes in international reserves.

The basic exchange market pressure index can be extracted (Bird and Mandilaras, 2006):

$$EMP_t = \alpha \Delta e_t - \beta \Delta r_t + \gamma \Delta i_t \ , \qquad (1)$$

where; $e_t$ is the exchange rate at time $t$; $i_t$ is the short-term interest rate at time $t$; and $r_t$ is the level of reserve assets at time $t$.

There is no consensus on the weights $\alpha$, $\beta$, $\gamma$ of each component. In several studies it has been suggested that the variables should be equally weighted so that the sum of weights equals zero. In other studies, it has been suggested that the components should be corrected for volatility.

To study contagion in the exchange market, Eichengreen et al. (1996) use a differently constructed composite index. The index is calculated by changes in exchange rates, interest rate differentials and changes in the reserve assets in country *i* at time *t*. In their study, all the data has been measured against German data, but the anchor country could also be other than Germany. In addition, the authors suggest adjusting the index variables for volatility.

This can be expressed as (Dungey et al., 2004; Haile and Pozo, 2008):

$$EMP_{i,t} = \alpha\Delta e_{i,t} + \beta(i_{i,t} - i_{0,t}) + \gamma(\Delta r_{i,t} - \Delta r_{0,t}) \ , \tag{2}$$

where; $e_{i,t}$ is the exchange rate for country $i$ at time $t$; $i_{i,t}$ is the short-term interest rate for country $i$ at time $t$; $r_{i,t}$ is the level of reserve assets for country $i$ at time $t$; and $\alpha$, $\beta$, $\gamma$ are the weights of the variance of each component: for example $\alpha = 1/\ \sigma_e$ where $\sigma_e$ is the standard deviation of exchange rate changes. Subscript 0 stands for the anchor country variables.

These construction forms are the basic indices that have been used in the studies. However, the literature also suggests several other forms. The existence of several approaches seems to suggest that the results gained for the EMP might differ. In addition, it may mean that index choice needs to depend on the features of the individual country; such as, whether it is a developed or developing country, and whether it has free capital movement and a floating or fixed exchange rate. That is why this article also gives other options. Another version offered by Eichengreen et al. (1995, 1996) and Pontines and Siregar (2008) is:

$$EMP_{i,t} = \frac{1}{\sigma_e}\frac{\Delta e_{i,t}}{e_{i,t}} - \frac{1}{\sigma_r}\left(\frac{\Delta rm_{i,t}}{rm_{i,t}} - \frac{\Delta rm_{0,t}}{rm_{0,t}}\right) + \frac{1}{\sigma_i}\left(\Delta(i_{i,t} - i_{0,t})\right) \ , \tag{3}$$



where; $e_{i,t}$ is the units of country $i$'s currency per anchor country's currency in period $t$; $\sigma_e$ is the standard deviation of the relative change in the exchange rate; $rm_{i,t}$ is the ratio of gross foreign reserves to money stock for country $i$ in period $t$; $rm_{0,t}$ is the ratio of gross foreign reserves to money stock for the anchor country in period $t$; $\sigma_r$ is the standard deviation of the difference between the relative changes in the ratio of foreign reserves and the money base in country $i$ and the anchor country; $i_{i,t}$ is the nominal interest rate for country $i$ in period $t$; $i_{0,t}$ is the nominal interest rate for the anchor country in period $t$; and $\sigma_i$ is the standard deviation of the nominal interest rate differential between country $i$ and the anchor country.

As can be seen from this, the main question seems to be the weighting of each variable. It is easy to understand that during turbulent times the volatilities or changes in the variables are also higher than in tranquil times. The increased volatilities may result in the overestimation of some variables and may thus result in an estimation bias for the EMP. That is why various authors have tried to adjust the index.

The EMP index can be used to define the moments when there is a crisis in a country. For researchers, the EMP offers further interest because it allows a crisis to be defined as a binary variable and therefore helps in conducting probability based tests.

A country is believed to be in crisis if the index value is higher than an extreme threshold that is often set at 1.5 or more standard deviations of the index. In this case, we can find the depreciation of the exchange rate (Eichengreen et al., 1996):

$$crisis_{i,t} = 1 \text{ if } EMP_{i,t} > \mu_{EMP} + 1.5\sigma_{EMP} \ , \tag{4}$$
$$\text{otherwise, } crisis_{i,t} = 0 \ ,$$

where; $\mu_{EMP}$ is the sample mean and $\sigma_{EMP}$ the sample standard deviation.

If the EMP index is made into a binary variable, it could be used to test how different variables affect the probability of the country being in crisis. Furthermore, it also permits testing for whether the probability of a crisis happening is affected by a crisis elsewhere. If it increases the probability, the null hypothesis needs to be rejected and there is evidence of contagion. To test the pair, a binary probit model is used (Eichengreen et al., 1996).

In this way the EMP index helps researchers to define crisis moments more objectively and thus lowers the level of subjectivity. The construction of the EMP index depends on the exchange rate regime and the weighting scheme selected for each index component that the researcher decides to use.

### 3.2. Construction of the Money Market Pressure Index

The previous sections covered the problems of identifying currency crises. However, the nature of recent crises has been much more connected to financial markets. The problem remains that there are no good objective proxies for defining the period of crisis.

In order to capture crises that are defined by excessive demand for liquidity in the market, Hagen and Ho (2007) constructed the money market pressure index. The index is based on the idea that a money market crisis can be measured by both the quantity of excess liquidity available for the banking system, or the lack of liquidity in the system, and the price of the liquidity.

The index follows the exchange market pressure index model in many ways. More precisely, they define a banking crisis as an unusually high demand for liquidity in money markets.

The market is in equilibrium if the demand for reserves is equal to the supply. Depending on the target of the central bank, the disequilibrium could be solved by changing the supply of reserves or by changing the interest rate. If the banks need to increase their liquidity due to losses of assets or due to bank runs, the demand for reserves increases and there is a shift of the demand curve to the right. The new equilibrium, if the supply remains constant, will have a higher interbank rate. If the central bank aims to control the interest rates, the supply needs to increase. This could be done through open market operations or through discount window lending (Hagen and Ho, 2007).



Therefore, the crisis creates a liquidity shortage, and deposit money banks try to get additional reserves from the interbank market or from central banks. In a simplified way the IMP could then be expressed as (Hagen and Ho, 2007):

$$IMP = \Delta f + \Delta i^r \,, \qquad (5)$$

where $\Delta f$ is the ratio of central bank funds to bank deposits[1]; and $\Delta i^r$ is the money market rate in real terms.

It is clear that the volatilities of each component could have a serious impact on the index and therefore an adjustment of the components' standard deviations is suggested by changing the index into a weighted sum:

$$IMP = \frac{\Delta f}{\sigma_f} + \frac{\Delta i^r}{\sigma_{i^r}} \,, \qquad (6)$$

[1] The central bank funds to bank deposits ratio is defined as loans from monetary authorities to deposit money banks divided by the total deposits of non-banks with deposit money banks, or total credit support from the monetary authority divided by total bank deposits (Hagen and Ho, 2007)

where; $\sigma_f$ and $\sigma_{i^r}$ stand for the standard deviation of the central bank funds/bank deposits ratio and real money market rate respectively.

Following Eichengreen et al. (1996), the IMP could also be transformed into a binary variable showing the crisis:

$$crisis_{i,t} = 1 \text{ if } IMP_{i,t} > \mu_{IMP} + 1.5\sigma_{IMP} \ , \qquad (7)$$
$$\text{otherwise, } crisis_{i,t} = 0 \ ,$$

where $\mu_{IMP}$ is the sample mean and $\sigma_{IMP}$ the sample standard deviation.

Following this logic, a crisis can be observed in an objective way. With the help of IMP, it is possible to test whether the crisis that is believed to have started at the end of 2007 could also be witnessed in the IMP dynamics.

## 4. The EMP and IMP in Central Europe

Although the current crisis does not seem to have ended yet, the period is worth closer observation and study. The current crisis is defined by increased volatility and a great drawdown in stock markets. However, the exchange market and money market changes need to be studied as well.



We study the dynamics of these two indices for Hungary, the Czech Republic and Poland. It is expected that the crisis observations calculated using the EMP and IMP indices for the countries studied are not randomly distributed, making it possible to define several crisis moments with the EMP and IMP for the period 2007-2009. The next sections discuss the approach which has been used in this paper to construct our dependent variables for the EMP and IMP.

### 4.1. Data

Data is taken from the CD-Rom version of the International Monetary Fund's statistics (IFS, 2009). We have used monthly data from 2001M2 through to 2009M9. All the countries had free floating or managed floating exchange rate regimes during the observation period. It is important to stress that our data on countries have time series of different lengths. It has been especially difficult to find the required data for Poland.

Several problems occurred during the data gathering process. We used monthly data in order to increase the number of observations, and because the changes in the exchange market and money market were quite fast, which would have been concealed if we had used quarterly or annual data. However, some data are not available for as long a period as might be wished. The list of variables is included in the Appendices, and the majority of variables are transformed into 12-month changes.

Another problem is that the choice of interest rate could be crucial for this kind of analysis, and it is known that the central banks tried to soften the impact of the recent crisis by lowering official rates. However, the interbank rates have often moved in the opposite direction, so here, we have used the money market interest rates where available, taken from the interbank market.

## 4.2. The EMP Index

For our study here, we calculate the variable EMP as follows:

$$EMP_{i,t} = \alpha \Delta \ln e_{i,t} + \beta \Delta \ln I_{i,t} - \gamma \Delta \ln r_{i,t} \quad , \qquad (8)$$

where $e$ denotes the price of a USD in country $i$'s currency at time $t$; $I$ denotes country $i$'s money market rate at time $t$; $r$ denotes country $i$'s international reserves in USD at time $t$; Δln stands for change in the natural logarithm of the variables.

$\alpha$, $\beta$, $\gamma$ are weights that are inverses of the standard deviations of the corresponding variable:

$$\alpha = \frac{1}{\sigma_{\Delta \ln e_{i,t}}} \ ; \ \beta = \frac{1}{\sigma_{\Delta \ln I_{i,t}}} \ ; \ \gamma = \frac{1}{\sigma_{\Delta \ln r_{i,t}}} \ .$$

This approach follows the forms used by Jayaraman and Choong (2008) and Bird and Mandilaras (2006); the weights are calculated similarly in Eichengreen et al. (1996).

There are several reasons for this approach. One is that by using this form, we have been able to ensure that the EMP and IMP are calculated in the same manner. On top of this, although several studies have excluded interest rates, we believe that changes in the money market interest rate played an important role in the recent crisis, if not a leading role, and thus should be included in the analysis. Furthermore, one of the underlying models developed by Weymark (1995) excluded interest rates from the analysis on the grounds that there is perfect capital mobility and substitutability between countries. It is arguable whether this is true for the countries studied in this paper. That is why our approach is based more on the Girton-Roper model (1977) and has more similarities with the works of Eichengreen et al. (1996), Bird and Mandilaras (2006); Jayaraman and Choong (2008).



As has been seen already, different scaling schemes are suggested in the literature. We acknowledge the problems connected with the choice of scaling factors, but still prefer the simple scaling factor used in Eichengreen et al. (1996).

Bertoli et al. (2006) point out that different variables and different aggregation methods can lead to different levels of EMP, and therefore the results of the analysis depends substantially on the method used in the construction of the indexes. In order to minimise the potential distortion coming form this source, we decided to use data from one source, (even if this means accepting a shorter sample for Poland), and also to adopt the most standard aggregation approach. As pointed out by Bertoli et al. (2006), the problem arising from indexes construction are relevant when countries investigated have different structure from the OECD one (for which the index was constructed) and/or there are structural changes on the economies in the sample considered. The three CEE countries analysed here have not suffered major structural changes during the sample period, and are also similar to each other; therefore different assumptions would not lead to substantially different results.

This framework should fit better for countries that are more prone to speculative attacks, and we find that this is the case for these three countries. The data have shown that the three countries under investigation here had already experienced some pressure before 2008. Thus the rates of increase in the money market rates increase in the exchange rate expressing depreciation of the exchange rate, and fall in international reserves would all increase in the EMP value.

## 4.3. The IMP Index

In the construction of the IMP index, two different determinants of the banking crisis are highlighted. The first is based on the amount of excess liquidity and the second on the price of liquidity. During the last financial crisis, both dimensions have had a role in the surge, dynamic and solution of the problem, and therefore the choice of the right variables in constructing the index is extremely important. In order to understand which variables could potentially be able to capture the behaviour of money markets and the banking system, the financial stability reports of the three central banks have been analysed.

From the discussion in Section 3.2, the IMP index (variable *IMP)* used in our paper is the combination of changes in the ratio of central banks funds to bank deposits, and of money market interest rates, weighted by their standard deviations:

$$IMP_{i,t} = \frac{\Delta \ln f_{i,t}}{\sigma_{\Delta \ln f_{i,t}}} + \frac{\Delta \ln I_{i,t}}{\sigma_{\Delta \ln I_{i,t}}} \tag{9}$$

Where *f* denotes the ratio of central bank funds to bank deposits for country *i* at time *t*; *I* denotes country *i*'s money market rate at time *t*; Δln stands for the change in the natural logarithm.

As has been seen, we have also used the interbank rate in the IMP construction, as we believe it has played a crucial role during the recent crisis.



The quantity of liquidity is tricky to measure. Not only are the interbank money markets different in the three countries, but also the open market operations and the role of the forex exchange market (both spot and forward) are different.

## 4.4. Dynamics of Indices

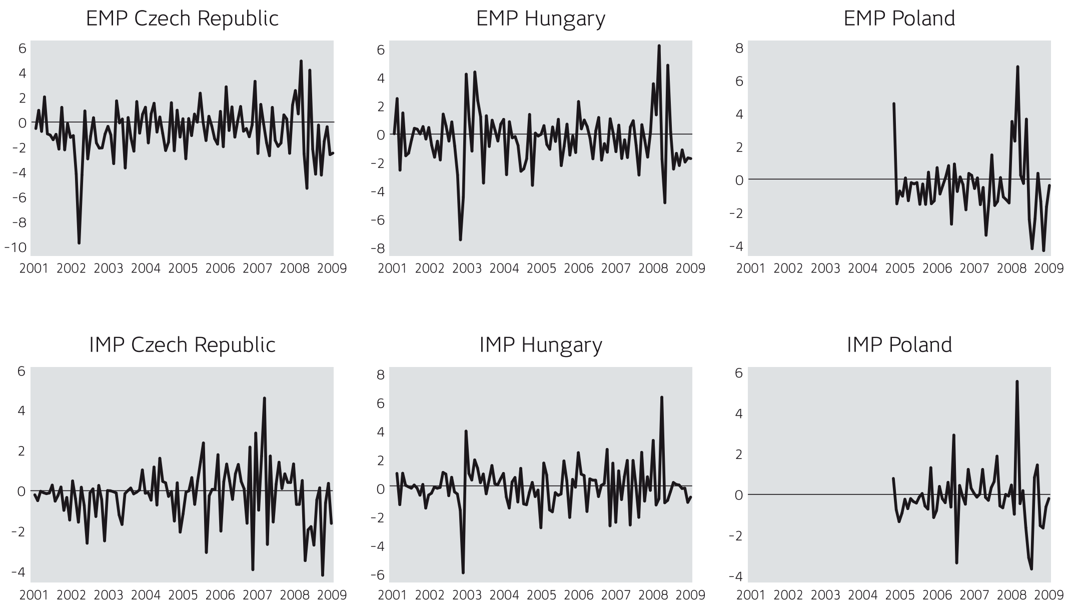
The top half of Figure 1 depicts the *EMP* variables and the bottom half the *IMP* variables for the three countries for the period between 2001 and 2009. Figure 3 shows the annual changes in the same indicators for the same countries (*EMP12* and *IMP12*) and for a slightly shorter sample period, as the first year's observations are missing. As explained above, the sample is much shorter for Poland.

A quick glance shows that between summer 2007 and autumn 2008 both variables reach their peak for the sample considered here, and this is true for all the countries and both indicators. The timing of the arrival of the crisis is different for the three countries, but none of them remains untouched.

Looking more closely, it is possible to see that the jump in the value of the indicators is bigger for Poland and Hungary than it is for the Czech Republic. This is particularly clear for the EMP indicator. This suggests that pressure on the exchange rate of the Czech Koruna has been lower than the pressure on the other two currencies. This hypothesis can also be verified by analysing the monthly and annual changes in the nominal exchange rates of the three currencies. During the sample used here, the Koruna has experienced less sizeable depreciation than have the other two currencies. Taking a depreciation of 3% in a month as a threshold, the Koruna has suffered strong monthly depreciation on six occasions, and only once before the recent crisis, in July 2002. The Hungarian Forint has also weakened six times, but in three different periods (2003, 2006 and 2008-9), and the Polish Zloty 17 times, with an example occurring in every year between 2002 and 2009, with the exception of 2007[2].

The bottom part of Figure 1 describes the interest rate channel involvement in the transmission of the crisis for the three countries. A difference between the countries that may be noticed is that while Hungary and Poland are hit in September 2008, at the same time as the Lehman Brothers default, for the Czech Republic the IMP peaked earlier, in the second half of 2007 during the first wave of the turbulence in the financial markets in connection with the sub-prime problem.

**Figure 1.** EMP and IMP for the Czech Republic, Hungary and Poland




*Source:* Authors' calculations



One possible explanation for this difference lies in the different interest rates and banking sector structures of the three countries. In the Czech Republic both official interest rates, set by the central bank, and the interbank money market were very low in 2007 before the first wave of the crisis. At the start of the crisis they quickly reacted by increasing rates in summer 2007, while Hungary and Poland already had high interest rates; as they were less linked to the Western European interest rate environment. The second wave of the crisis had more influence on the banking sector, which was more exposed to external financing in Poland and Hungary than in the Czech Republic. The Polish and Hungarian central banks had to intervene to help their local banking sectors, expanding the central bank balance sheets, which have a direct impact on the measurement of the IMP. The intervention in the Czech Republic was not so heavy, given a much healthier situation in the banking sector (CNB, 2009).

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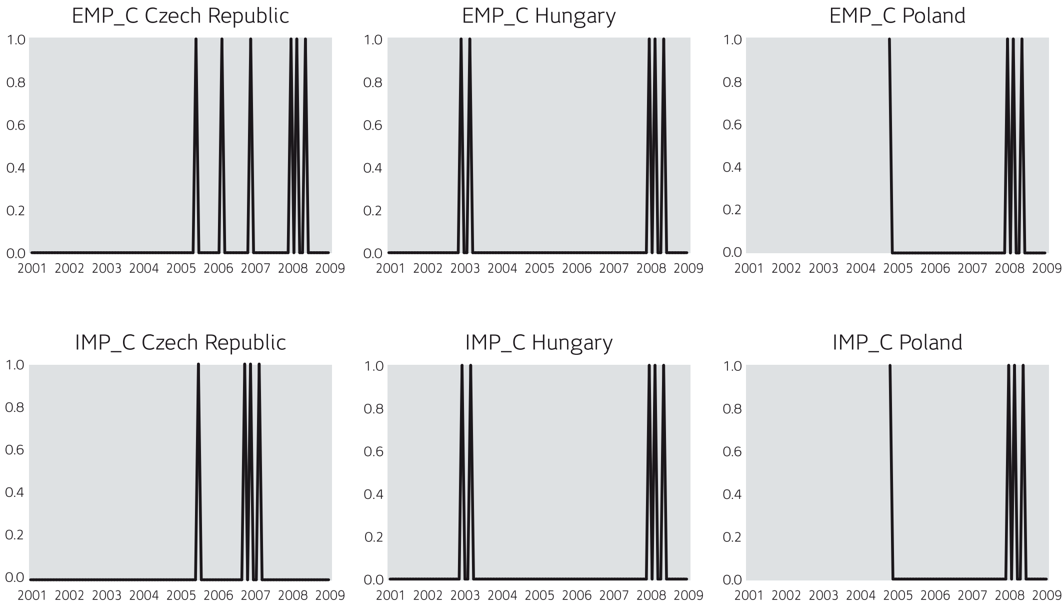
[2] A similar message comes considering monthly year-over-year changes: the Koruna had only two months with year-over-year depreciation of more than 10%, both of them in 2009, while the Forint had 14 months with such a depreciation, in 2003, 2006 and during the recent crisis, while the Zloty had 26 months, in 2003, 2004 and during the recent crisis.

Another method has been used to assess the importance of the change in the IMP and EMP indicators. It is possible to measure a threshold above which the value of the indicator becomes significant, so that values above the threshold signal increasing pressure. Those moments are given a value of one, while observations below the threshold are given a value of zero (see Eichengreen et al. 1996 for details). In this way, the binary series of pressure/no pressure can be built (variables *EMP_C* and *IMP_C*). The graphs for these series are presented in Figure 2. These graphs confirm that both indicators show that the crisis affected the three countries in 2008, the only exception being the IMP for the Czech Republic, where the pressure appears in 2007, but not in 2008.

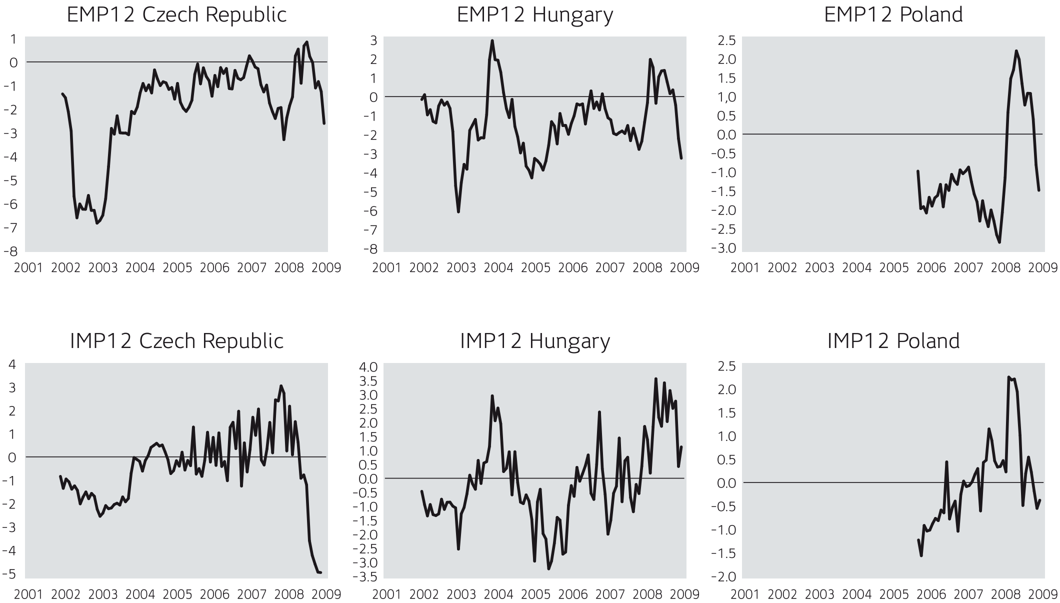
Figure 2. EMP and IMP for the Czech Republic, Hungary and Poland




*Source:* Authors' calculations

From the presentation in Figure 3 of the *EMP12* and *IMP12* indices, it can be seen that these indicators are stickier than their correspondents for monthly changes. Again, there is an important difference between the Czech Republic on one side and Poland and Hungary on the other. Here, the build up in the pressure measured by both *EMP12* and *IMP12* is slower for the Czech Republic, while it is quite sharp in 2008 for the other two economies. This is particularly true for the exchange rate channel, where the peak of September 2008 is not much higher than the level of the index in the period 2005-2007, while in Hungary, and even more so in Poland, the difference between the highest point of 2008 and the levels in 2005-2007 is much more pronounced.

Figure 3. EMP12 and IMP12 for the Czech Republic, Hungary and Poland




*Source:* Authors' calculations



It is also noticeable that these indicators show that the pressure on both the Forint and the money market in Hungary is similar in 2008 and in 2003-4, signalling that this market was more subject to external pressure even before the recent financial crisis, in comparison to the Czech Republic. For Poland the data span does not reach out before 2005.

## 5. Empirical Analysis

### 5.1. Variables

Our EMP and IMP indices express the present situation of the exchange and money markets while our explanatory variables show the dynamics of the variables in the past 12 months. We run several tests and regression equations over a set of fundamental variables to explain the changes in the EMP and IMP indices. We have been supported in our choice of variables by the theoretical literature and by empirical studies, and also by the reports of the central banks about financial stability.

We have included several variables to consider the generation of the models dealing with the existence of the crises. These variables can be clustered into four groups as banking sector variables, real economy related variables, fiscal situation variables and external balance variable. An exact description of the variables can be found in Appendix 1, the table of descriptive statistics is presented below. For each variable the "overall" statistics (all three countries, the entire dataset), the "between" statistics (the variation of the means to each individual country across time periods), and the "within" (the variation of the deviation from the respective mean to each individual country) statistics are reported.

Table 1. Descriptive Statistics

| Variable | | Mean | Std.dev | Min | Max | Observations |
|---|---|---|---|---|---|---|
| *EMP* | overall | -0.502 | 1.969 | -9.730 | 6.806 | *N = 263* |
| | between | | 0.204 | -0.719 | -0.332 | *n = 3* |
| | within | | 1.961 | -9.513 | 6.716 | *T-bar = 87.667* |
| *IMP* | overall | -0.135 | 1.402 | -5.950 | 6.067 | *N = 262* |
| | between | | 0.092 | -0.220 | -0.038 | *n = 3* |
| | within | | 1.400 | -6.047 | 5.970 | *T-bar = 87.333* |
| *cpi* | overall | 0.038 | 0.024 | -0.004 | 0.108 | *N = 315* |
| | between | | 0.017 | 0.027 | 0.057 | *n = 3* |
| | within | | 0.020 | 0.003 | 0.088 | *T = 105* |
| *lagm2_res* | overall | -0.015 | 0.174 | -0.492 | 0.494 | *N = 240* |
| | between | | 0.038 | -0.042 | 0.032 | *n = 3* |
| | within | | 0.172 | -0.465 | 0.447 | *T-bar = 80* |
| *stocks* | overall | 0.093 | 0.320 | -0.636 | 0.888 | *N = 315* |
| | between | | 0.069 | 0.030 | 0.166 | *n = 3* |
| | within | | 0.315 | -0.625 | 0.868 | *T = 105* |
| *lagreer* | overall | -0.047 | 3.815 | -10.755 | 13.134 | *N = 312* |
| | between | | 0.021 | -0.072 | -0.033 | *n = 3* |
| | within | | 3.815 | -10.731 | 13.158 | *T = 104* |
| *decl_exp* | overall | 0.108 | 0.130 | -0.250 | 0.458 | *N = 312* |
| | between | | 0.026 | 0.088 | 0.137 | *n = 3* |
| | within | | 0.128 | -0.239 | 0.468 | *T = 104* |
| *bor3m* | overall | 0.419 | 5.270 | -11.638 | 75.667 | *N = 279* |
| | between | | 0.297 | 0.163 | 0.744 | *n = 3* |
| | within | | 5.265 | -11.963 | 75.342 | *T = 93* |
| *banks_for* | overall | 0.162 | 0.418 | -0.357 | 1.898 | *N = 243* |
| | between | | 0.294 | 0.024 | 0.551 | *n = 3* |
| | within | | 0.358 | -0.746 | 1.509 | *T-bar = 81* |
| *dom_cred* | overall | 0.141 | 0.095 | -0.128 | 0.404 | *N = 243* |
| | between | | 0.051 | 0.095 | 0.196 | *n = 3* |
| | within | | 0.086 | -0.082 | 0.349 | *T-bar = 81* |
| *govt_borr* | overall | 0.134 | 0.433 | -0.206 | 2.726 | *N = 243* |
| | between | | 0.116 | 0.022 | 0.253 | *n = 3* |
| | within | | 0.421 | -0.324 | 2.608 | *T-bar = 81* |

*Source:* Authors' calculations



The growth rate of government borrowing (variable *govt_borr*) is a variable that reflects government fiscal policies. The faster the growth rate, the laxer the policy is understood to be. According to the first generation models this may result in pressure in the exchange markets. In Poeck et al. (2007) the variable has been proven to be useful in explaining pressure in the exchange markets.

Three indicators have been included from the banking sector side. Rapid growth in domestic credit (changes in domestic credit, *dom_cred*) leads to booms in financial markets and could theoretically produce imbalances. In Demirgüç-Kunt and Detragiache (1998), the variable has been shown to increase significantly the probability of a crisis.

It is also important whether the private sector credit growth is funded by domestic or foreign capital (Komulainen and Lukkarila, 2003). To capture this mismatch between the banks balance sheets and foreign funding, the ratio of banks foreign liabilities to assets (*banks_for*) has been included in our study. The variable is often connected with the third-generation models of crises as the ratio expresses the vulnerability to sudden withdrawals of foreign capital. The higher the ratio, the higher is the probability of a crisis.

We have also included a variable (*bor3m*) connecting the interbank money market of the three countries under investigation with the euro area money market. The variable measures the difference between the three months local interbank money market rates and the three months Euribor. A higher value of the variable would be a sign of higher tension in the local money markets (compared to the euro area market), therefore a potential increase in our pressure indicators.

The external balance situation of the three countries has been measured through two variables, REER and decline in export. The changes in REER could help in measuring the over and undervaluation of the real exchange rate, as an overvalued exchange rate may lead to devaluation pressure. We have expected the REER to express these imbalances in advance of the crisis shown by the EMP and IMP extreme values, and thus we have used one month lagged values (variable *lagreer*). Similarly to Castell and Dacuycuy (2009), we expect the higher values of REER to increase the values of the indices.



A decline in exports (*decl_exp*) is connected in the literature with the external sector and shows a country's ability to earn foreign currency. Dornbusch et al. (1995) connect the decline in exports with crises as the variable could show that a country has lost its competitiveness. In Radelet and Sachs (1998), the authors argue that the higher the decline, the bigger the problems a country faces in servicing its current account deficit. Castell and Dacuycuy (2009) suggest that a decline might be caused by an overvalued currency and thus a decline in exports could be an important indicator of an upcoming crisis.

In our analysis the economic situation of the countries has been captured by three variables. Inflation (*cpi*), expressed in the consumer price index, is believed to cause higher interest rates that pressure the exchange market. Even though this is often disputed in the literature, the empirical evidence shows that high values for this variable are relevant in explaining the crises (Demirgüç-Kunt and Detragiache, 1998; Eichengreen et al., 1996; Moreno, 1995).

The connection between stock (*stocks*) returns and crises is discussed in many papers. Our main rationale for including the variable was the integration of the foreign exchange markets and financial markets. The changes in the stock markets could help to capture the changes in market sentiments. The market participants may anticipate a crisis in their expectations, meaning that extreme changes in stock returns might help to predict a crisis. Castell and Dacuycuy (2009) have interpreted the relationship between stock returns and crises similarly to our approach. They argue that a decline in asset prices, including stock returns, may be a signal of a loss of confidence in the market, and they also suggest that bubbles in asset prices might precede a crisis. Similarly, asset bubbles connected with high stock returns are shown to precede financial crises in Calomiris and Gorton (1991).

However, as has been seen, the direction of causality between stock returns and crises is not clear. Granger et al. (2000) have found some inconsistent granger causality between the two. Stavárek (2005) did not find any significant relationships between crises and stock returns, while Broome and Morley (2004) showed that stock returns did indeed help to indicate a crisis.

M2/reserve is connected, because as a government borrows the first generation models of crises as M2/reserves growth ratio could express the lax policies of the government. M2/reserves have been found to be a useful indicator for currency crises in several studies and it is expected that the higher ratio increases the EMP/IMP value or the probability of a crisis. We have expected the M2/reserve ratio to express these imbalances in advance of the crisis, and thus we have used one month lagged values (*variable lagm2_res*) (See Calvo and Mendoza, 1996; Demirgüç-Kunt and Detragiache, 1998; Sachs et al., 1996).

The set of variables used here does not imply that other variables could not be included. We did not use, for example, the lending interest rate to deposit rate ratio, in order to avoid over-correlation with the EMP and IMP indices and because of data availability issues. In addition, the possible predictive power of the current account situation has not been included in our analysis, though it has been used in some other studies. We also left out structural variables, even though some country dummies could potentially improve the regression results. The used approach considers the variables as indicators of weakness in the economy. Thus, these variables help to determine the vulnerability but do not show direct cause.



As we are using static analysis, we do admit some problems connected with the approach. We leave aside the question of whether any crisis in the past has any relevance for the occurrence of a crisis in the future, and so the lagged values of the EMP and IMP indices are not included in our analysis.

## 5.2. Model

In this section, we present the empirical modelling approach used to study the relationship between the variables already presented and the indices of the crises. The index method discussed above has been used to identify the crises. The indices defined help to identify the moments of excessive demand for liquidity in the money market and moments of excess pressure on the exchange rate. Even though several references have used only one country, we have committed to panel data.

We use three approaches. First, we use a panel regression to study the relationship between the variables and the indices of crises, concentrating on the random and fixed effects. Second, we control the relationship between the EMP/IMP as a binary variable and variables with non-linear regression analysis as a panel logit. Third, we tried to distinguish between variables that indicate a growing vulnerability of the economies to exchange rate and interest rate crisis, and variables that move contemporaneously with the crisis indicators (signalling either co-movement or reaction to the crisis).

We have used STATA 9 for the empirical study. In order to verify the results, we run several tests. The panel regression and panel logit regressions are preceded by the poolability tests. The model specification is controlled by two approaches; by a one by one regression of variables and by the general to specific procedure. Unlike the majority of other studies, we have chosen to use both these indices as level and as binary variables.

Our regression models for the EMP and IMP indices are hybrids of Poeck at al. (2007);

Jayaraman and Choong (2008); Castell and Dacuycuy (2009); Bird and Mandilaras (2006) and Hagen and Ho (2007) for the IMP, in which we compromise several of the previously discussed variables. We focus our attention on the banking sector, the real economy, fiscal situation variables and the external balance. These may be presented in the following models that express that the indices are connected to the variables:

$$EMP = f\,(cpi,\ lagm2\_res,\ stocks,\ lagreer,\ decl\_exp,\ bor3m,\ banks\_for,\ dom\_cred,\ govt\_borr)$$
$$IMP = f\,(cpi,\ lagm2\_res,\ stocks,\ lagreer,\ decl\_exp,\ bor3m,\ banks\_for,\ dom\_cred,\ govt\_borr) \quad (10)$$

We have also used the non-linear approach in the model for the binary crises indices. We use the index of money market pressure and the exchange market pressure index to identify the threshold values, which are later employed in compiling a binary variable of crisis/ no crisis. Similar methods, sometimes as a probit, have been used in Hagen and Ho (2007); Eichengreen et al. (1996); Bussière (2007); Komulainen and Lukkarila (2003). This can be summed up in the following models:

$$EMP\_C = f\,(cpi,\ lagm2\_res,\ stocks,\ lagreer,\ decl\_exp,\ bor3m,\ banks\_for,\ dom\_cred,\ govt\_borr)$$
$$IMP\_C = f\,(cpi,\ lagm2\_res,\ stocks,\ lagreer,\ decl\_exp,\ bor3m,\ banks\_for,\ dom\_cred,\ govt\_borr) \quad (11)$$

The panel logit models for fixed and random effects have been used. These two approaches, panel regression and binary variable analysis, are the methods most commonly used in the literature. However, there are also critical reviews (see Pontines and Siregar, 2008; Li et al., 2006; Bertoli et al., 2006). In our analysis, we have to consider that the time span is not balanced and is critically short for Poland. Episodes with extremely high vales of the EMP and IMP are good for identifying turbulent periods, but the relationship between the variables is not clear.

In Section 5.4, some of the variables will be lagged by one year. The choice of the variables to lag will be explained in that section. We will run the following panel regression with random effects:

$$EMP = f\,(lag\_cpi\_12,\ lag\_m2\_res\_12,\ stocks,\ lag\_reer\_12,\ lag\_decl\_exp\_12,\ bor3m,\ banks\_for,\ dom\_cred,\ lag\_govt\_borr\_12)$$
$$IMP = f\,(lag\_cpi\_12,\ lag\_m2\_res\_12,\ stocks,\ lag\_reer\_12,\ lag\_decl\_exp\_12,\ bor3m,\ banks\_for,\ dom\_cred,\ lag\_govt\_borr\_12) \quad (12)$$

## 5.3. Regressions Results

Having analysed the poolability of our dataset (see Appendix 3), we may now proceed with the panel regressions. We start with the EMP and IMP indices and then in the later part of this section we look at the binary dependent variables and the probit models.

Table 2 gives the results of the panel regression of the EMP on the left of the table and the IMP on the right of the table for the independent variables described in Section 5.1. The table gives the results of regressions under both hypotheses of fixed and random effects. Given that in theory we do not have any preference between random and fixed effects, we decided to run both the regressions in order to compare the results; this also works for the robustness check. The comparison between the size, sign and significance of the parameters suggest that they are very similar for the two models, suggesting that our estimate for the model specification is robust.

Starting with the EMP regressions, we found that two groups of variables have significant coefficients. The first is the government-borrowing variable, which has a negative sign. In theory, a government with increasing financing needs will use foreign markets to raise money, and this is potentially negative for the domestic currency; so therefore, the sign should be positive. If we look at what happened during the recent crisis, the dynamic has been different. More precisely, the main channel through which the crisis reached the countries under investigation here has been the financial, especially the banking, sector. The size of the fiscal reaction has been relevant; as it came about in order to help banks in difficulties and as a more traditional expansionary policy to sustain aggregate demand. The fiscal interventions have helped to tame the severity of the crisis, thus driving down the EMP indicator; during the recent crisis, the causality has been from crisis to budget deficits, not vice versa. The causality issue will be addressed in Section 5.4. For the IMP, the sign of the government-borrowing coefficient is also negative, even if it is not significant.



Table 2. EMP and IMP Regressions

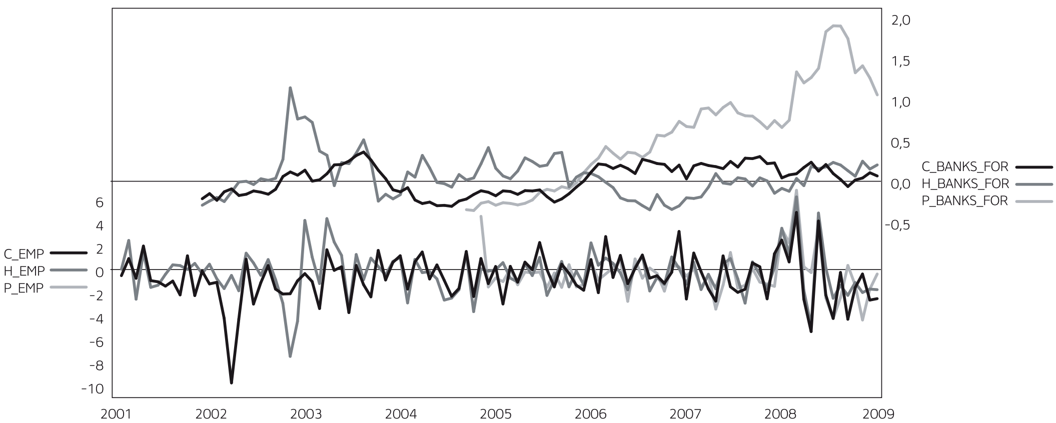
| EMP fixed vs random | | | IMP fixed vs random | | |
|---|---|---|---|---|---|
| | fixed | random | | fixed | random |
| *cpi* | -4.187 | -10.142 | *cpi* | 6.718 | 4.369 |
| | (9.098) | (6.944) | | (7.164) | (5.453) |
| *lagm2_res* | -2.904 *** | -2.678 *** | *lagm2_res* | -0.728 | -0.640 |
| | (0.841) | (0.811) | | (0.662) | (0.637) |
| *stocks* | 0.310 | 0.215 | *stocks* | -0.141 | -0.165 |
| | (0.572) | (0.565) | | (0.450) | (0.444) |
| *lagreer* | -0.064 | -0.086 * | *lagreer* | 0.004 | -0.003 |
| | (0.044) | (0.040) | | (0.035) | (0.031) |
| *decl_exp* | -2.760 | -2.330 | *decl_exp* | 1.378 | 1.488 |
| | (1.449) | (1.403) | | (1.141) | (1.102) |
| *bor3m* | 0.040 | 0.040 | *bor3m* | 0.003 | 0.004 |
| | (0.022) | (0.022) | | (0.017) | (0.017) |
| *banks_for* | -2.161 *** | -1.887 *** | *banks_for* | -0.292 | -0.235 |
| | (0.553) | (0.502) | | (0.435) | (0.394) |
| *dom_cred* | 12.368 *** | 12.053 *** | *dom_cred* | 1.752 | 1.602 |
| | (2.609) | (2.579) | | (2.054) | (2.026) |
| *govt_borr* | -1.093 ** | -1.084 ** | *govt_borr* | -0.253 | -0.238 |
| | (0.350) | (0.347) | | (0.276) | (0.273) |
| *_cons* | -1.500 *** | -1.308 *** | *_cons* | -0.651 | -0.562 |
| | (0.446) | (0.387) | | (0.352) | (0.304) |
| N | 236 | 236 | N | 236 | 236 |
| $R^2$ | 0.19 | | $R^2$ | 0.041 | |

*Note:* * p < 0.05; ** p < 0.01; *** p < 0.001
*Source:* Authors' calculations

The importance of the financial sector in the dynamics of the crisis is confirmed by the significance of the domestic credit variable. Here the sign is positive, as expected: excess growth in borrowing by the private sector can cause a potential threat to the domestic currency and show the potential problems ahead. This is also true for the IMP indicator, even if again the coefficient is not significant.

In addition, another variable linked to the financial sector is significant. The ratio between the foreign liabilities and foreign assets of the banking sector enters the regression with a negative sign. As with government borrowing, here the negative sign indicates that when the crisis finally broke, after a period of stable values of the EMP and a growing level of foreign liabilities relative to assets for the banking sector, banks were suddenly not able to finance themselves in the international markets. The banks switched from the latter financing channel to the local, mainly central bank, channel (NBP, 2009; MNB, 2009). Therefore, the jump in the crisis indicator corresponded to the sharp decrease in the *banks_for* variable. This point is also illustrated in Figure 4. When the crisis hit, the foreign liabilities of banks dropped in the Czech Republic and remained stable in Poland. Only in Hungary did this ratio increase, probably due to the help received by foreign owners of most of the biggest Hungarian banks. Nevertheless, the *banks_for* ratio also started to fall in Hungary in 2009.[3]

Figure 4. EMP and BANKS_FOR for the Czech Republic, Hungary and Poland




*Source:* Authors' calculations



Outside the financial and government sector, only one variable has a statistically significant coefficient. The lag value of the ratio between M2 and reserves has a negative impact on the EMP.

The other variables, those linked to the general economic environment and to the external sector, have coefficients that are not significant. From one side, this could suggest that the pressure on the domestic currencies of the three CEE countries analysed here has come through the financial and public sectors rather than from the general economic environment of the countries. On the other side, the reason of insignificance of economic and external sector variables could be linked to the fact that these variables create preconditions for a crisis, which is built during the time and well before the crisis eruption,

[3] In Figure 4, the capital letters C, H and P stand for Czech Republic, Hungary and Poland respectively.

but have no contemporaneous link with the crisis indicators. This issue will be addressed in the next section.

A separate discussion applies to the IMP indicator. The results of the regressions, reported in the right hand side of Table 2, show that almost all the variables are not significant in indicating the IMP level. A possible explanation for the difference in the results between the two indicators is that the IMP is built on two variables, which behave in a way that is difficult to capture with the explanatory variables employed here. The IMP is constructed on market overnight interest rates, which move in line with central bank reference rates, making them quite sticky, and on the ratio between the liabilities of the banking sector to the central banks and the banking sector deposits, which is always quite sticky.

The manifestation of the crisis in the two components of the IMP is usually through a jump, both in interest rates and in the central bank balance sheet. The variables used on the right hand side of the regression are often 12-month changes or growth rates, with a more gradual dynamic, which can be more helpful in explaining the dynamic of the build up of a financial crisis than its abrupt and sudden emergence. This is more consistent with the idea of the IMP indicator.

Now we turn to the binary variables *EMP_C* and *IMP_C*, which have a value of 1 when the level indicators EMP and IMP are above a certain threshold and 0 below that level. The results of the panel logit regressions are presented in Table 3.



The first thing to notice is that the sign of the coefficients does not change if the binary dependent variables are used. The main difference lies in the significance of the coefficients, in particular for *EMP_C*. Unlike in the regressions using the EMP level, in Table 2, the decline in exports is significant in measuring the probability of a crisis. Here again the sign of the coefficient is affected by the causality problem. The recent financial crisis has had a dramatic impact on the international markets, causing at least a temporary sharp drop in international trade, which is expressed as a sharp decline in the exports of the CEE countries. This means that there is a contemporaneous inverse relation between the crisis and the export dynamic in these countries. As before, the IMP regression does not show the coefficients are significant.

**Table 3.** EMP_C and IMP_C regressions

| EMP_C logit | | | IMP_C logit | | |
|---|---|---|---|---|---|
| | fixed | random | | fixed | random |
| *cpi* | -16.983 | -17.524 | *cpi* | 7.876 | 4.840 |
| *lagm2_res* | -4.918 | -4.429 | *lagm2_res* | -0.990 | -0.824 |
| *stocks* | 0.694 | 0.585 | *stocks* | -1.304 | -1.181 |
| *lagreer* | -0.233 | -0.207 * | *lagreer* | 0.118 | 0.113 |
| *decl_exp* | -16.000 ** | -16.845 *** | *decl_exp* | 0.315 | -0.145 |
| *bor3m* | 0.037 | 0.013 | *bor3m* | -0.045 | -0.055 |
| *banks_for* | -2.683 | -2.908 | *banks_for* | -1.189 | -1.567 |
| *dom_cred* | 28.456 ** | 28.321 * | *dom_cred* | 11.531 | 11.662 |
| *govt_borr* | -3.037 | -3.894 | *govt_borr* | -0.450 | -0.422 |
| *_cons* | | -5.606 *** | *_cons* | | -4.673 *** |

*Note:* * p < 0.05; ** p < 0.01; *** p < 0.001
*Source:* Authors' calculations

### 5.4. Vulnerability versus Direct Effect

One important question that remains unanswered from the estimation of the previous section is how each explanatory variable is related to the market pressure indicators. According to the theory, the general approach used for the majority of studies is that the variables included precede the crisis and therefore help to explain it. However, in this paper, due to the characteristics of the crisis, a difference between the variables used can be made. Some indicate the vulnerability of the economy and the financial sector, which increases the probability of a crisis. Other variables capture the reaction of market participants that is often contemporaneous to the crisis.

In more detail, some variables indicate the emerging weakness of the economy and therefore have a positive relation with the market pressure indices. The influence of these variables is delayed and they enter the analysis with a one year lag. These are typically macroeconomic variables, the changes of which are sticky or that require a long process in order to change.

On the other hand, there are some variables that react in a contemporaneous manner with market pressure indicators, either because they are "price signals" reflecting market sentiment or perception of the actual and future situation of the economy, or because they are under the direct control of economic agents, who can intervene quickly to influence the dynamics of these variables.



This explains our two-group approach where variables are divided into "vulnerability" and "direct impact" variables. The first group includes CPI, M2/reserves, REER and export decline plus government borrowing, which we include in the regression analysis with lagged values. The first two can be read as indicators of growing monetary imbalances, which do not necessarily trigger an immediate reaction in the exchange rates, but increase the probability of the pressure on both the interest rates and the exchange rates. REER and export decline, that is external sector variables signaling the weakening position of a country, seem to have the same lagged effect on the EMP and the IMP. The same implies to the government sector where an increasing debt does not necessarily trigger an immediate reaction in the market but can hinder the confidence of market participants when a high debt level is reached.

The second group includes either "market variables", such as stocks and interest rates (*bor3m*), which describe the market sentiment, or variables that are subject to a sudden stop behavior in case of a crisis, such as domestic credit.  Therefore, these variables should react instantaneously compared to the changes in the EMP and the IMP. In fact, both the ability of local banks to collect financial resources abroad and their capacity to extend credit to domestic clients are, similar to financial variables, also dependent on the perception of economic agents, and can therefore reverse their course quickly.

The results of the panel regression with both lagged vulnerability and contemporaneous direct impact variables are reported in Table 4. The results of the grouped variables approach are similar for the IMP, while they offer some new insight for the EMP. First, as concerns the IMP, the ability and willingness of the authorities to control the interest rate channels seems to be confirmed. Furthermore, the EMP regression supports the distinction between vulnerability and direct impact described above.

Comparing the results of Table 4 and Table 2, it is possible to see that the role of the banking sector in the outbreak of the crisis is confirmed (with both *banks_for* and *dom_cred* remaining significant and with the expected sign).

The role of the government sector in building up the preconditions for a crisis and in attempting to counter the crisis seems clearer now. The effect of government borrowing on the crisis can be twofold. First, as in the previous approaches, increased borrowing enhances the probability of a crisis and is therefore an indicator of vulnerability. On the other hand, it also includes the direct impact, as the government might use expansionary fiscal policies to dampen the effect of a crisis.

The "vulnerability" part of government debt (captured by the coefficient in Table 4) seems to behave as expected (positive, i.e. higher debt indicates higher market pressure), but is not relevant, as its coefficient is not significant. However, the role of a government in helping to counter the direct effect of the crisis appears to be very important, as indicated by the negative and significant coefficient of *govt_borr* variable in Table 2. Therefore, it seems that, at least for the countries analysed here, government behavior has not been a relevant factor in causing the crisis, whereas the expansionary (and debt creating) policies used to counter the crisis have been important and effective.

Table 4. Vulnerability versus Direct Effect Regressions

| | EMP | IMP |
|---|---|---|
| *lag_cpi_12* | -13.8248 | -9.48848 |
| | (7.349) | (5.970) |
| *lag_m2_res_12* | 1.49501 | 0.832092 |
| | (1.067) | (0.867) |
| *stocks* | -0.29801 | -0.08731 |
| | (0.491) | (0.399) |
| *lag_reer_12* | -0.10052 * | 0.005018 |
| | (0.048) | (0.039) |
| *lag_decl_exp_12* | 3.155095 * | -0.22254 |
| | (1.533) | (1.245) |
| *bor3m* | 0.035934 | 0.003445 |
| | (0.022) | (0.018) |
| *banks_for* | -1.73632 *** | -0.53041 |
| | (0.473) | (0.384) |
| *dom_cred* | 9.259401 *** | 2.320623 |
| | (2.488) | (2.022) |
| *lag_govt_borr_12* | 0.296046 | -0.12139 |
| | (0.372) | (0.302) |
| *_cons* | -1.39185 * | 0.084158 |
| | (0.559) | (0.454) |
| N | 207 | 207 |

*Note:* * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$
*Source:* Authors' calculations

The distinction between vulnerability and direct impact is also relevant for the external sector variables. In particular, export decline becomes significant with the expected (positive) sign, if it enters the equation with a 12-month lagged value. The decline in exports signals the deterioration of the international position of the countries, but the reaction of this variable when the pressure is high is not immediate.

Last, the distinction between vulnerability and direct impact helps to better understand the variables of monetary imbalances. CPI maintains the same sign as the regression in Table 2, but this time the coefficient is "almost significant"[4]. *M2_res* variable is now of the expected sign, signaling that monetary imbalances have indeed played a role in the building of preconditions for a crisis.

### 5.5. Discussion of the Robustness

We performed different tests in order to check the robustness of our results (see Appendices 2 and 3). First of all, we performed the Hausman test in order to choose the random versus fixed effect specification of our panel estimation. Even if the test shows a preference for the random effect model, we performed the panel estimation with both specification, and the estimated coefficients have the same signs in both estimation, and their size is also similar, which confirm that our model is robust in respect of the estimation specification.

In order to control for the significance of the coefficients, we corrected the standard errors of the coefficients with the Huber-White method, and, with the exception of *bor3m* (as explained above), the significance of coefficients doesn't change.



We also tried a general to specific and a one-to-one estimation procedure in order to see if the insignificance of some of the coefficients depends on possible multicollinearity with other variables. Also in this case, our original results were confirmed.

Finally, we have calculated the indices over the USD, but the calculation over euro did not change the dynamics of the indices. For further research, many questions have risen. It could be possible to continue to study the results depending on the thresholds and window widths used to identify the calculated EMP and IMP indices.

### 5.6. Discussion of the Results

We conclude this chapter by discussing the main findings of our empirical analysis. The first thing to stress is that the graphical analysis highlights that both the EMP and IMP indices from before 2007 are able to capture the eruption of the global financial crisis in the three CEE countries under investigation here. Both the degree and the timing of the crisis signalled by the indices correspond to the actual emergence of the crisis as reported for example by the analysis of the three countries' central banks.

When the two indices are analysed empirically, the results are not as straightforward as those for the graphical analysis. Firstly, some of the variables used in the empirical analysis turned out to show a significant influence on the exchange market pressure, in particular, domestic credit dynamics and government borrowing, while any link between the money market pressure and the variables employed here seems to be hard to capture. This is more puzzling considering that all the anecdotal evidence suggests that the global financial crisis

[4] Significant at the 10% level.

spread between countries mainly through the banking sector and the interbank money markets.

This puzzle can be explained in our opinion in two ways, the first being more of an economically fundamental reason, the second more of a technical question. From a fundamental point of view, crises find their most evident expression in prices. The three countries analysed here have had a free floating nominal exchange regime[5], during the period under investigation, and therefore crises in these countries have hit the nominal exchange rate immediately, as shown in Figure 5. The figure also shows that the behaviour of the three exchange rates is very similar, making a joint analysis of the three countries easier.

As concerns the IMP index, the interbank interest rate is not controlled directly by the central banks, but is certainly an explicit target of these institutions. The attempt to control this interest rate, which represents the price of short term liquidity, makes the use of this index as a measure of a crisis more complicated. From one side the nature of the interbank markets in general, and of the interaction between the banking sector and the central bank in particular, can differ across countries. In our case, the most explicit example lies in the central banks' monetary policy operations before the crisis. While MNB (Magyar Nemzeti Bank, the central bank of Hungary) usually offered liquidity to the banking sector through monetary policy operations, the other two central banks had almost exclusively withdrawn liquidity from the banking sector before autumn 2008, and turned to liquidity providing operations only at the peak of the crisis. This substantial difference has two main consequences, the first being that aggregating data across the three countries may hinder the explanatory power of the regression of the IMP on the potential explanatory variables.



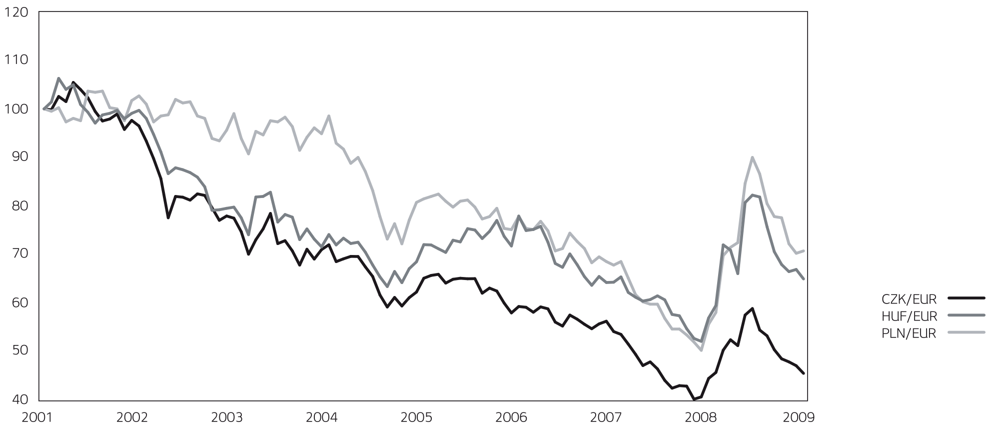
The second, technical, reason for the difference in the empirical analysis between the EMP and IMP is linked to what is explained in the previous paragraph. One of the two components used to build the IMP index is the ratio between CB funding and the deposit size of the banking sector. CB funding was almost not existent in the Czech Republic and Poland before the crisis, while it was always present in Hungary (MNB, 2009; CNB, 2009; NBP, 2009). Also, as explained in chapter 3, the components of the indexes are weighted by their volatility. This means that in the Czech Republic and Poland the CB funding component is underweighted, as it is non-existent for most of the sample, while this is not the case for Hungary. This technical problem can have serious consequences for the construction of the IMP index and therefore also possibly for the results of the empirical analysis. One possible development of our analysis would be a comparison of different weighting schemes for the components of the indexes, but this is outside the scope of our paper.

The difference in the structural liquidity of the banking sectors in the three countries may also be one reason why the money market pressure index used here is difficult to aggregate across countries, and a possible source of insignificance in the pooled regressions. In addition, the possibility of omitted variables should not be overlooked. This is mainly due to the characteristics of recent crises, which involve more panic and less fundamental explanations. As we saw, the existence of crises can also be seen in the exogenous variables used in the analysis, but the arrival of a crisis in the variables is somewhat delayed. A crisis seems to arrive faster in the EMP and IMP indices. Thus, it could be suggested that other

[5] All three countries' central banks have an inflation target as their main policy goal. There was no restriction on the fluctuation of zloty starting from April 2000, while Hungary had an explicit free float regime since 2008, but previously the fluctuation band against the euro was +/-15%, and only once in 2003 Hungary had to intervene in the Forex market at the limit of the band (NBP, 2009; MNB, 2009).

variables are needed to help explain panic triggered crises, rather than the fundamental ones used here.

Figure 5. Hungarian Forint, Polish Zloti and Czech Koruna Nominal Exchange Rate against USD




*Note:* base = 100 in January 2001
*Source:* Authors' calculations; IFS.



## 6. Conclusion

The current paper uses the idea of Girton-Roper (1977) of the exchange market pressure index (EMP) and the money market pressure index (IMP) developed later by Hagen and Ho (2007) to study the relationships between the exchange and money markets and the recent crisis. The analysis focuses on three CEE countries: Poland, the Czech Republic and Hungary. During 2001–2009, financial markets experienced two major shocks: first, the problems emerging from the sub-prime market and later the bankruptcy of Lehman Brothers. These events triggered a reversal of capital flows, a collapse of commodity prices, a loss in confidence, a depreciation of currencies, and a shortage of liquidity.

The EMP index proposes that the exchange market is under pressure if there is excessive demand for foreign reserves during a crisis. This distorts the market equilibrium and the balance should be found through exchange rate depreciation or through other monetary policy measures. The money market pressure index has been developed on the basis of the exchange market pressure index. The IMP index that comprises changes in interest rates and the relationship between central bank funds and bank deposits, suggests that during the crisis, the money market may experience excessive demand for liquidity. The IMP index helps to identify the moments when there is excessive demand for liquidity that causes pressure on the money market. In the IMP, interest rates play an important role as the official rates might move differently from the market rates as seen recently.

Using a similar methodology as Poeck et al. (2007), Jayaraman and Choong (2008), Castell and Dacuycuy (2009), Bird and Mandilaras (2006), and Hagen and Ho (2007), we studied the dynamics of the EMP and IMP during the last nine years and compared their behavior across the three countries. Later, we have used panel regressions over a set of variables regarding the banking sector, the real economy, the fiscal situation and the external balance to study whether the variables help to determine the vulnerability of the economy to a crisis. We have developed this further by dividing the variables according whether they precede the crisis or evolve simultaneously with it.

In addition, the indices have been employed to define binary dependent variables showing the moments of crisis and no crisis. We have also run panel logit models to see how the explanatory variables influence the probability of the occurrence of a crisis. However, not all the needed data was available for all the countries, especially for Poland, the length of time series is critically short, and thus the panel is not balanced.

Concerning the goal of our analysis to study whether the crisis hit the countries in the same way, it can be concluded that the EMP and IMP indices both manage effectively to capture the turbulent periods. In the studied period of 2001–2009, all countries experienced several moments of high EMP values and the timing of these moments was rather similar. Though none of the countries remains untouched, the pressure on the exchange rate of the Czech koruna has been lower than for the other two currencies.

The dynamics of the IMP index varies more across countries. All countries experienced some moments of higher volatility of the IMP. However, the timing of these periods differs considerably among the three countries. Hungary and Poland were hit in September 2008, simultaneously with the bankruptcy of Lehman Brothers, but the IMP for the Czech Republic already peaked in the second half of 2007, during the turbulence in the financial markets that resulted from the problems of the sub-prime market.



The second objective was to understand what roles the exchange rate and interest channels have played in the transmission of the financial crisis to Poland, Czech Republic and Hungary. It is generally assumed that the crisis spread through the interest rate channels. However, the empirical analysis of the IMP index does not have as clear results as in the case of the EMP index. This can be explained by the vast interventions of the central banks in the money markets and banking sector. All studied Eastern European countries experienced the severest shock from the crisis, as they were very dependent on external funding after lending from foreign banks dried out. Thus, the central banks first seem to have decided to focus on that issue.

The central banks started to cut rates to support the economy and also adopted other monetary measures, such as opening the central bank lending channel to support the financial sector. This had an influence on the behavior of the IMP index.

The measures to help the money market may be considered somewhat exceptional; while as countries remained faithful to traditional FX intervention measures over the crisis, such as the drying out of the FX reserves to control the pace of depreciation and exchange rates, probably also driven by the need to help the real economy. Indeed, the crisis did originate from the money market, but spread freely through the exchange rate channel.

Most importantly, we centered our attention on the factors' changes preceding the crisis and those that played a role in the outbreak of the crisis. It is necessary to distinguish between the variables that first characterise the vulnerability, i.e. the way the economy has built up the preconditions for a crisis, and second, indicators that characterise the reaction of market participants. The majority of previous studies have not included this distinction. The ratio of banks foreign liabilities to assets and domestic credit growth have been identified as the relevant determinants of the impact of the crisis on the EMP index. This is true in panel EMP regression as well as in panel logit analysis. The variables related to the general economic environment and to the external sectors are relevant in explaining the creation of preconditions for a crisis, i.e. the vulnerability of the countries considered here.

Government borrowing has a minor role in explaining the vulnerability of the countries, but has a relevant role in the outbreak of the crisis. This suggests that the pressure on the domestic currencies of the three CEE countries in question has mainly emerged from the financial sector (but also the external sector and monetary imbalances), while the public sector has played an important part in the reaction to the crisis.

Moreover, the paper examines the role of the authorities in dampening the effects of the crisis. Results show that during the recent crisis the authorities of the three CEE countries concentrated their efforts to reduce the vulnerability of the financial sector. Due to the increased cost and lack of external financing, the central banks acted as liquidity providers. In other words, the central banks intervened to ensure both the operation and the availability of financing in the banking sector. The policymakers used tools that worked for this aim, more specifically for a fast increase in central bank funding at the early stages of the crisis. Much less attention was paid to the exchange rates, since these also worked in favor of the export sector. Our analysis seems to support the hypothesis that the exchange market acted as an absorber of the crisis. Thus, there are differences between the results gained from the EMP and from the IMP.

Several important questions rose for further research. The dynamics of these indices regarding the exchange and money markets need to be studied for other influencing factors, e.g. what, and in which way, has caused these kinds of patterns. The variables employed in this paper cover most of the potential source of instability for the exchange rate and money markets, but not exhaustively. Exploring the influence of other variables on the EMP and IMP indices could add insight on the dynamics and contagion of crises across countries.



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## Appendix 1. Data Sources

| Indicator | Source | Name in analysis |
|---|---|---|
| IMP and EMP indices | | |
| EMP | Nominal exchange rate – IFS line ae<br>International reserves – IFS line 1 L.d<br>Interest rate – Overnight money market rate. Bloomberg | *EMP* |
| IMP | Ratio of central bank funds to bank deposits – IFS line 24 +line 25+line 26C divided by IFS line 26G<br>Interest rate – Overnight money market rate. Bloomberg | *IMP* |
| EMP 12-month change | | *EMP12* |
| IMP 12-month change | | *IMP12* |
| Binary variable EMP | | *EMP_C* |
| Binary variable IMP | | *IMP_C* |
| Economy | | |
| Consumer price index | IFS line 64 | *cpi*<br>*lag_cpi_12* |
| M2/reserves ratio growth | IFS line 34+ IFS line 35 converted into dollars using line ae divided by IFS line 1 L.d; 1 month lagged | *lagm2_res*<br>*lag_m2_res_12* |
| Stock returns | MSCI local stock markets index levels. Bloomberg | *stocks* |
| External Balance | | |
| REER | IFS line 64; 1 month lagged | *lagreer*<br>*lag_reer_12* |
| Decline in export | IFS line 70 | *decl_exp*<br>*lag_decl_exp_12* |
| Banking | | |
| localBOR3m-Euribor3m | Difference between local official money market rates (Wibor for Poland, Pribor for the Czech Republic, Bubor for Hungary) and Euribor. Bloomberg | *bor3m* |
| Net bank foreign liabilities/assets | IFS line 26c divided by IFS line 21 | *banks_for* |
| Changes in domestic credit | IFS line 32, changes compared to previous period | *dom_cred* |
| Fiscal situation | | |
| Growth rate of government borrowing | IFS line 12a + line 22a | *govt_borr*<br>*lag_govt_borr_12* |

## Appendix 2. Unit Root and Stationary Tests

| | Hungary | Poland | Czech Rep. |
|---|---|---|---|
| EMP | -9.607* | -6.642* | -9.942* |
| IMP | -13.022* | -7.717* | -4.010* |

*Note:* * no unit root at 1% level
*Source:* Authors' calculations

For robust results to be obtained from the analysis for the time series, the series should at least be stationary. If the time series are not stationary, some transformation can be used to make them stationary, such as logarithmic returns or first differences.

The standard unit root test is the augmented Dickey–Fuller Test that we have used here. There are no unit roots at 99% confidence level in the EMP and IMP indices for the countries studied according to the Augmented Dickey–Fuller Test.

## Appendix 3. Poolability Test

| EMP full sample | | | EMP common sample | | | |
|---|---|---|---|---|---|---|
| | Hungary | Czech Rep. | | Hungary | Poland | Czech Rep. |
| *cpi* | -10.850 | -13.835 | *cpi* | 2.811 | -62.308 | -38.503 |
| *lagm2_res* | -6.983 | -4.831 | *lagm2_res* | -6.023 | -5.270 | -16.194 |
| *stocks* | -0.540 | 0.829 | *stocks* | 1.955 | -1.477 | -0.430 |
| *lagreer* | 0.000 | -0.212 | *lagreer* | -0.004 | -0.059 | -0.105 |
| *decl_exp* | -5.912 | -3.957 | *decl_exp* | -6.601 | -7.561 | -6.232 |
| *bor3m* | 0.094 | 0.038 | *bor3m* | 1.968 | -0.051 | 0.048 |
| *banks_for* | -4.644 | -5.251 | *banks_for* | -2.983 | -1.415 | -8.222 |
| *dom_cred* | 25.408 | 17.683 | *dom_cred* | 34.657 | 7.406 | 30.067 |
| *govt_borr* | -10.257 | -1.428 | *govt_borr* | -15.355 | 2.518 | -5.524 |
| *_cons* | -2.690 | -1.688 | *_cons* | -4.704 | 1.155 | -1.228 |
| | Value | *F*-stat (5%) | | | Value | *F*-stat (5%) |
| *F*-test | 1.573 | 1.91 | | | 1.580 | 1.83 |
| **IMP full sample** | | | **IMP common sample** | | | |
| | Hungary | Czech Rep. | | Hungary | Poland | Czech Rep. |
| *cpi* | -6.739 | 11.779 | *cpi* | -9.678 | -23.981 | 12.068 |
| *lagm2_res* | 1.280 | -0.100 | *lagm2_res* | 6.802 | -6.010 | -0.516 |
| *stocks* | -0.405 | 0.670 | *stocks* | -0.838 | 1.184 | 1.228 |
| *lagreer* | 0.023 | -0.011 | *lagreer* | 0.022 | 0.008 | 0.076 |
| *decl_exp* | 1.385 | 3.197 | *decl_exp* | 1.553 | -6.839 | 4.163 |
| *bor3m* | 0.214 | -0.005 | *bor3m* | -0.039 | -0.117 | 0.030 |
| *banks_for* | -0.591 | 1.300 | *banks_for* | 0.002 | 1.635 | 5.897 |
| *dom_cred* | -0.040 | -0.065 | *dom_cred* | -8.429 | -3.398 | -8.224 |
| *govt_borr* | 1.3328 | 0.0219 | *govt_borr* | 0.699 | 1.041 | 0.934 |
| *_cons* | 0.260 | -0.949 | *_cons* | 2.125 | 0.921 | -0.306 |
| | Value | *F*-stat (5%) | | | Value | *F*-stat (5%) |
| *F*-test | 1.042 | 1.910 | | | 1.217 | 1.830 |

*Source:* Authors' calculations

Before regression, we checked for poolability of the dataset. With an unbalanced panel, the method of checking poolability is not straightforward, and in our case it is particularly difficult because, as mentioned above, for Poland the data range is shorter than for the other two countries. Therefore, we decided to conduct two poolability tests, one for the entire sample and considering only the Czech Republic and Hungary, the other considering all the countries but only for the common part of the sample. (Baltagi, 2005; Park, 2009)

The test is conducted by running regressions (1) and (2), and testing whether the coefficient $\alpha_i^j$ can be assumed to not be different from $\alpha_i$. The regressions and test have also been run for the IMP.

$$EMP_t = \alpha_0 + \alpha_i X_{i,t} + \varepsilon_t \quad (1)$$
$$EMP_t^j = \alpha_0^j + \alpha_i^j X_{i,t}^j + \varepsilon_t^j \quad (2)$$

The *X* variables are the ones described in section 5.1, and are the ones used in the panel regression, and we have grouped them into four types of variables. The first group of three variables are for the general economic environment: the 12-month change in the consumer price index (*cpi*), the lagged value of the ratio between M2 and central banks' foreign reserves (*lagm2_res*) and the relevant stock exchange 12-month return (*stocks*).

A second group of variables represents the dynamic of the external sector: the lag value of the difference between the REER and its filtered value (*lagreer*), the 12-month change in exports (*decl_exp*) and the difference between the local 3-month interbank markets rate and the corresponding rate in the Euro area (*bor3m)*. The third group of variables is for indicators of the situation in the banking sector: the ratio between the foreign liabilities and foreign assets of the banking sector (*banks_for*) and the 12-month growth of domestic credit (*dom_cred*). Finally, the government sector is represented by the growth of government borrowing (*govt_borr*).

The results of the tests are reported in the table above. In the table, the values of the coefficients are reported, without the *t*-stat values as we are interested for the moment only in the sign of the coefficient, together with the *F*-statistics, which measure the level of statistical difference between the parameters considered in aggregate and estimated with (1) and (2).

Looking at the *F*-statistics, in all four cases the poolability hypothesis can not be rejected at a 5% confidence level. Comparing the single parameters, the message on poolability is not that straightforward, in particular for the IMP index. In the upper part of the table on the left, the coefficients of regression (1) are reported for the full sample of Hungary and the Czech Republic, and eight out of ten have the same sign.

For the shorter common sample, and with the inclusion of Poland, five coefficients have the same sign for all the three countries, as is shown in the upper right part of the table. This can be because in a shorter sample, which also covers the global financial crisis, the parameters can be less stable than when a longer sample is considered. The results for the full sample for Hungary and the Czech Republic corroborate the hypothesis that in the long run the data are poolable across these three countries for the EMP regression.

The regressions using the IMP are dependent variables that give more mixed results. *F*-statistics indicate again that the series are poolable across countries, with 5% confidence, but the signs are different for most of the coefficients. This can be a signal that while market pressure has come through exchange rates in a very similar way in the three countries, the same can not be said for the money market channel.

# APPENDIX 6. ELULOOKIRJELDUS

1. Isikuandmed

| | |
|---|---|
| Ees- ja perekonnanimi | Fabio Filipozzi |
| Sünniaeg ja -koht | 19.09.1970 Milaano (Itaalia) |
| Kodakondsus | Itaalia |

2. Kontaktandmed

| | |
|---|---|
| Aadress | Estonia pst. 15, Tallinn |
| Telefon | +372 5277859 |
| E-posti aadress | fabio.filipozzi@eestipank.ee |

3. Hariduskäik

| Õppeasutus (nimetus lõpetamise ajal) | Lõpetamise aeg | Haridus (eriala/kraad) |
|---|---|---|
| Tallinna Tehnikaülikool | Eeldatav lõpetamine 2012 august | Rahvamajandus, PhD |
| Bocconi Ülikool | 1995 | MA |
| L. Cremona Keskkool | 1989 | Keskharidus |

4. Keelteoskus (alg-, kesk- või kõrgtase)

| Keel | Tase |
|---|---|
| Itaalia keel | Emakeel |
| Eesti keel | Kõrgtase |
| Inglise Keel | Kõrgtase |

5. Täiendusõpe

| Õppimise aeg | Täiendusõppe läbiviija nimetus |
|---|---|
| 1999-2000 | Master in Economics, Bocconi Ülikool |

6. Teenistukäik

| Töötamise aeg | Tööandja nimetus | Ametikoht |
|---|---|---|
| 2009- | Eesti Pank | Investeerimisallosakonna juhataja |
| 2005- | Tallinna Tehnikaülikool | Tunnitasuline õppejõud |
| 2005-2009 | Swedbank Investeerimisfondid AS | Portfelli haldur, Juhatuse esimees |
| 2004 | Eesti Pank | Portfelli haldur |
| 2000-2003 | Nextra Asset Management | Portfelli haldur |
| 1999-2000 | Eesti Pank | Analüütik |
| 1999 | Arca Fondi Asset Management | Portfelli haldur |
| 1997-1999 | Etra Sim | Back ja middle office spetsialist |

7. Teadustegevus

1) Artiklid rahvusvahelistes ajakirjades või artiklite kogumikes

Filipozzi, F.; Staehr, K. (2012). Covered Interest Parity and the Global Financial Crisis in Four Central and Eastern European Countries. Eastern European Economics (ilmumas, ETIS 1.1)

Filipozzi, Fabio; Staehr, Karsten (2012). Uncovered Interest Parity in Central and Eastern Europe: convergence and the global financial crisis. Discussions on Estonian Economic Policy. Berlin: Berliner Wissenschafts-Verlag (ilmumas, ETIS 1.2)

Filipozzi, F. (2011). Modelling the time-varying risk premium by using the Kalman filter: the Euro money market case. Professor Wladislav Milo (Toim.). FindEcon Monograph Series: Advanced in Financial Market Analysis. Poland: Lodz University Press (ilmunud, ETIS 3.1)

Filipozzi, F.; Harkmann, K. (2010). The Financial Crisis in Central and Eastern Europe: the Measure and Determinants of the Exchange Market Pressure Index and the Money Market Pressure Index. Research in Economics and Business: Central and Eastern Europe, 2. (ilmunud, ETIS 1.2)

Filipozzi, F. (2009). Market-Based Measures of Monetary Policy Expectations and Their Evolution Since the Introduction of the Euro. Economic Notes, 38(3), 137 - 167. (ilmunud, ETIS 1.2)

2) Artiklid konverentsi kogumikes

Filipozzi, F. (2008). Market-based measures of monetary policy expectations and their evolution since the euro introduction. In: Doctoral Summer School 2008: University of Tartu and Tallinn University of Technology Doctoral School in Economics, 2008.

Filipozzi, F. (2006). Macro-finance models of the term structure: a review. In: Eesti Majandusteaduse Seltsi I aastakonverents Pärnu, 20.- 22. jaanuar 2006.

3) Muud artiklid

Filipozzi, F. (2000). Eesti krooni tasakaalukurss, selle dünaamika ja kursikõikumiste mõju. Tallinn: Eesti Pank (Toimetised 2000, 3)

8. Kaitstud lõputööd

| | |
|---|---|
| Magistritöö | Avalik valik, hääletamise reeglid ja rahapoliitika: teooria ja EKP näide.<br>Juhendaja Professor Donato Masciandaro, Bocconi Ülikool 1995 |

9. Teadustöö põhisuunad

Finantsökonoomika, intressiturud, valuutaturud, turgude efektiivsus, rahapoliitika.

# APPENDIX 7. CURRICULUM VITAE

1. Personal data

| | |
|---|---|
| Name | Fabio Filipozzi |
| Date and place of birth | 19.09.1970 Milan (Italy) |
| Nationality | Italian |

2. Contact information

| | |
|---|---|
| Address | Estonia pst. 15, Tallinn |
| Phone | +372 5277859 |
| E-mail | fabio.filipozzi@eestipank.ee |

3. Education

| Educational institution | Graduation year | Education (field of study/degree) |
|---|---|---|
| Tallinna University of Technology | Expected August 2012 | Economics, PhD |
| Bocconi Üniversity | 1995 | Economics, MA |
| L. Cremona Secondary school | 1989 | Secondary education |

4. Language competence/skills (fluent; average, basic skills)

| Language | Level |
|---|---|
| Italian | Mother tongue |
| Estonian | Fluent |
| English | Fluent |

5. Special courses

| Period | Educational or other organisation |
|---|---|
| 1999-2000 | Master in Economics, Bocconi University |

6. Professional employment

| Period | Organization | Position |
|---|---|---|
| 2009- | Bank of Estonia | Head of investment division |
| 2005- | Tallinn University of Technology | Visiting lecturer |
| 2005-2009 | Swedbank Investment Funds AS | Portfolio manager, Chairman of the board |
| 2004 | Bank of Estonia | Portfolio manager |
| 2000-2003 | Nextra Asset Management | Portfolio manager |
| 1999-2000 | Bank of Estonia | Analyst |
| 1999 | Arca Fondi Asset Management | Portfolio manager |
| 1997-1999 | Etra Sim | Back and middle office specialist |

7. Scientific work

1) Articles in international journals or in collection of articles

Filipozzi, F.; Staehr, K. (2012). Covered Interest Parity and the Global Financial Crisis in Four Central and Eastern European Countries. Eastern European Economics (forthcoming, ETIS 1.1)

Filipozzi, Fabio; Staehr, Karsten (2012). Uncovered Interest Parity in Central and Eastern Europe: convergence and the global financial crisis. Discussions on Estonian Economic Policy. Berlin: Berliner Wissenschafts-Verlag (forthcoming, ETIS 1.2)

Filipozzi, F. (2011). Modelling the time-varying risk premium by using the Kalman filter: the Euro money market case. Professor Wladislav Milo (Ed.). FindEcon Monograph Series: Advanced in Financial Market Analysis. Poland: Lodz University Press (published, ETIS 3.1)

Filipozzi, F.; Harkmann, K. (2010). The Financial Crisis in Central and Eastern Europe: the Measure and Determinants of the Exchange Market Pressure Index and the Money Market Pressure Index. Research in Economics and Business: Central and Eastern Europe, 2. (published, ETIS 1.2)

Filipozzi, F. (2009). Market-Based Measures of Monetary Policy Expectations and Their Evolution Since the Introduction of the Euro. Economic Notes, 38(3), 137 - 167. (published, ETIS 1.2)

2) Articles in conference proceedings

Filipozzi, F. (2008). Market-based measures of monetary policy expectations and their evolution since the euro introduction. In: Doctoral Summer School 2008: University of Tartu and Tallinn University of Technology Doctoral School in Economics. , 2008.

Filipozzi, F. (2006). Macro-finance models of the term structure: a review . In: Eesti Majandusteaduse Seltsi, First annual conference Pärnu, 20.- 22. January 2006.

3) Other articles

Filipozzi, F. (2000). Equilibrium exchange rate of the Estonian Kroon, its dynamics and impacts of deviations, Tallinn: Working papers of Eesti Pank, n. 3, 2000.

8. Defended theses

| | |
|---|---|
| Master thesis | Public choice, voting mechanisms and monetary policy: theory and the ECB case.<br>Supervisor: Professor Donato Masciandaro, Bocconi University<br>1995 |

9. Main area or scientific work

Financial economcs, international finance, interest rate markets, foreign exchange markets, market efficiency, monetary policy.

# KOKKUVÕTE

## Intressi ja valuutaturgude efektiivsus euroalal ning Kesk- ja Ida-Euroopas

Käesolev doktoritöö keskendub turu efektiivsuse testimisele intressi- ja valuutaturgudel. Kasutades erinevaid testimismeetodeid on ühelt poolt antud hinnang erinevatele meetoditele, ühtlasi on aga hinnatud ka euroala ja Kesk- ja Ida-Euroopa riikide intressi- ja valuutaturgude efektiivsust. Doktoritöö esimene ja teine artikkel keskenduvad intressiturule ja täpsemalt sellele, millist informatsiooni tuleviku rahaturu intressi muutuste kohta võib saada rahaturu intressimääradest käesoleval hetkel, ehk teiste sõnadega, millised on finantsturgudel osalejate ootused keskpankade kehtestavate tulevaste baasintresside kohta.

Läbiviidud analüüsi peamiseks järelduseks on see, et hinnang turu efektiivsusele sõltub oluliselt kasutatud metoodikast. See ilmneb selgelt turu efektiivsuse hüpoteesi (EMH) testide lihtsamate versioonide puhul, milles ei sisaldu ajas muutuvad riskipreemiad, ja mis tavaliselt turu efektiivsuse hüpoteesi ümber lükkavad. Kui aga kasutatud metoodika võtab arvesse riskipreemiate ajas muutumise võimalikkust, siis on hüpoteesi ümberlükkamine vähem tõenäoline. Teises artiklis ongi toodud välja riskipreemiate ja majandustsükli indikaatorite korrelatsioon ning kasutades Kalmani filtri metoodikat saadud lootusandvaid tulemusi. Sellest hoolimata ei saa öelda, et turu efektiivsuse hüpoteesi saaks nende kahe artikli sisuks olevatele analüüside tulemustele tuginedes kinnitada.

Doktoritöö kolmanda, neljanda ja viienda artikli aineks ei ole mitte ainult intressi-, vaid ka valuutaturud, rõhuasetusega Kesk- ja Ida-Euroopa riikide turgudele. Analüüsides turu efektiivsuse hüpoteesi kehtivust on ühtlasi vaadeldud ja analüüsitud nende riikide finantsturgude konvergentsi Lääne-Euroopa suunas. Analüüsi on kaasatud ka äsjase ülimaailmse finantskriisi mõju Kesk- ja Ida-Euroopa turgude efektiivsusele. Kolmas ja neljas artikkel vaatlevad nii katmata (UIP) kui kaetud (CIP) intressipariteete. Teooria kohaselt peavad mõlemad pariteedid paika vaid intressi- ja valuutaturgude efektiivsuse korral. Eelnevates uurimustes on kaetud intressipariteet saanud reeglina empiirilise kinnituse, katmata intressipariteet on seevastu tavaliselt ümber lükatud. Kolmanda artikli CIP analüüs näitab huvitavaid tulemusi. Esiteks, enne kriisi pidas kaetud intressipariteet paika nendes riikides, kus finantsturud olid oma arengus kaugemale jõudnud ja konvergents Lääne-Euroopa suunas edenenud (Tšehhi, Ungari ja Poola), Rumeenias aga CIP paika ei pidanud. Teiseks selgus, et ülemaailmne finantskriis on mõjutanud erinevaid riike erinevalt. Kui Tšehhi Vabariigile polnud kriisi mõju kuigi tuntav (jättes mulje pigem "safe haven" riigist), siis Poolas ja Ungaris on kriisi tagajärjed kaetud intressipariteedile olnud märkimisväärsed ja püsivad, millest saab järeldada, et arbitraaži tingimuste toimimiseks ka stressi olukorras on lisaks finantsturgude arenguastmele oluline usaldusväärne majanduspoliitika.

Neljas artikkel käsitleb katmata intressipariteeti ja siin on saadud tulemused rohkem kooskõlas varasemate empiiriliste uuringutega - nimelt kinnitab analüüs UIP ümberlükkamist. Kui testitud võrrandile on lisatud ajas muutuva riskikartlikkuse näitajad (nii nagu seda tehti ka esimeses ja teises artiklis), siis hoolimata sellest, et need indikaatorid on osutunud statistiliselt olulisteks, pole katmata intressipariteedi hüpotees siiski kinnitust leidnud. Seega ei pruugi UIP ümberlükkamine olla tingitud mitte üksnes testimismeetoditest lähtuvatest probleemidest, vaid tõenäoliselt ka turu efektiivsuse puudumise tõttu.

Viimases artiklis vaadeldakse turu surve näitajaid ja nende võimet signaliseerida potentsiaalset kriisi. Uurinud neid näitajaid mõnedes Kesk- ja Ida-Euroopa riikides viimase kümnendi lõikes nii intressiturul (IMP) kui valuutaturul (EMP), võib peamise järeldusena tuua välja asjaolu, et globaalne finantskriis jõudis nendesse riikidesse nii intressi- kui valuutaturgude kaudu (nii IMP kui EMP jõudsid oma haripunkti 2007. aasta suve ja 2008. aasta sügise vahel), kuid kriisi mõju ei olnud kõigis riikides samasugune. Lisaks võis leida statistiliselt olulisi selgitavaid muutujaid ainult EMP jaoks (peamiselt seotud pangandussektoriga).

Kokkuvõtteks võib öelda, et turu efektiivsuse hüpoteesi empiiriline kehtivus varieerub suuresti, sõltudes vaadeldud turgudest ja riikidest, valitud perioodist ja samuti valitud testimismeetoditest. Viies artiklis läbi viidud analüüsid näitasid, et turu efektiivsuse hüpoteesi testimisel tuleb võtta arvesse ajas muutuvat riskipreemiat. See kehtib eriti siis, kui vaadeldava perioodi sisse jääb rahutu ja ebastabiilne periood nagu näiteks hiljutine ülemaailmne finantskriis. Kaetud ja katmata intressipariteetide empiirilised testid näitasid ka seda, et turu efektiivsuse hüpotees peab paremini paika riikide puhul, kus finantssektor on rohkem arenenud ja turgudevaheline integreeritus tugevam. Siiski tuleb nentida, et eriti katmata intressipariteedi puhul ei saa turu efektiivsuse hüpoteesi ümberlükkamist põhjendada üksnes ebakorrektse empiirilise metoodika või kõrgete tehingukuludega.

# ABSTRACT

## The efficiency of interest rate and foreign exchange markets in the euro area and Central and Eastern Europe

This doctoral thesis is focused on testing market efficiency in interest rate and foreign exchange markets. On one hand, different testing methodologies are applied and their effectiveness is assessed. On the other hand, the efficiency of money and currency markets is assessed, both for the euro area and for Central and Eastern European (CEE) countries.

The first and second articles of the thesis focus on the interest rate market. Namely, what kind of information about the future path of interest rates can be extracted from money market rates, or, in other words, what financial markets expect from monetary policy authorities in terms of the base rate.

The main conclusion for the analysis conducted is that the detection of market efficiency is very much dependent on the methodology employed. In particular, more simple versions of Efficient Market Hypothesis (EMH) tests, which do not account for the presence of time varying risk premiums, usually reject the hypothesis. The rejection of EMH is less straightforward when the methodology that is employed to test it allows for risk premiums to change through time. In the second article, the correlation between risk premium and economic cycle indicators is detected, and the utilization of a Kalman Filter methodology shows promising results. Nevertheless, EMH is not confirmed by the analysis conducted in the first two articles.

In the other three articles of the thesis, the attention shifts to EMH tests in the interest rate and foreign exchange markets, focusing on Central and Eastern European countries. Together with the validity of EMH, also the degree of convergence of the financial markets of these countries towards Western Europe and the effect of the global financial crisis on EMH are analyzed.

The third and fourth articles focus on the interest parity relations, the Covered Interest Parity (CIP) and the Uncovered Interest Parity (UIP). Both relations are found to hold if EMH holds. While CIP is generally confirmed by empirical tests, UIP is, on the contrary, generally rejected. In the third article, a CIP analysis shows interesting results. First, for the countries with a higher degree of convergence and deeper financial markets (the Czech Republic, Hungary and Poland), CIP was holding before the crisis, while that was not the case with Romania. Second, the effect of the crisis has been found to be different for the countries in question. While the Czech Republic has not been affected by it (looking more like a safe haven country), in Poland and Hungary the effect of the crisis on CIP has been significant and lasting, signalling that besides deep financial markets also sound policies are important for keeping arbitrage conditions to perform also under stress scenarios.

The fourth article is devoted to UIP, and in this case results for the CEE countries are more in line with previous empirical studies, namely a complete rejection of UIP. When time varying risk aversion indicators are included in the test (in line with what has been done in the first and second articles), they proved to be significant, but not enough to make UIP accepted. The rejection of UIP therefore seems to be not due to testing methodology issues only, but probably also due to the rejection of EMH.

The last article considers measures of market pressure and their ability to signal a potential crisis. When applying these measures to CEE countries over the last decade, the main finding is that the global financial crisis reached these countries through the interest rate as well as the foreign exchange channels (both EMP and IMP peaked between summer 2007 and autumn 2008), but the impact is not equal for all countries, and it is possible to find significant explanatory variables for EMP only (mainly linked to the banking sector).

To sum up, the empirical validity of EMH is highly dependent on the markets and countries analyzed, on the sample covered and, last but not least, on the methodology used for the tests. The analysis conducted in the five articles of the thesis shows that the time varying risk premium must be accounted for when testing EMH. This is particularly true when turbulent periods, such as the recent global financial crisis, are added to the sample. CIP and UIP tests also show that EMH holds better for countries with deep financial sectors and between more integrated markets. Nevertheless, particularly as regards UIP, it is difficult to attribute the EMH rejection only to transaction costs or flaws in empirical methodology.

# DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *ECONOMICS*

1. **August Aarma**. Segmented Analysis of Bank Customers and Banking Information: Estonian Case. 2001.
2. **Enn Listra**. The Development and Structure of Banking Sector: Retail Banking in Estonia. 2001.
3. **Tatyana Põlajeva**. The Comparative Analysis of Market's Attractiveness. 2001.
4. **Tuuli Tammeraid**. Modeling Flow of Funds for Estonia. 2002.
5. **Ivo Karilaid**. The Choice in General Method for Investment and Performance Evaluation. 2002.
6. **Hele Hammer**. Strategic Investment Decisions: Evidence from Survey and Field Research in Estonia. 2003.
7. **Viljar Jaamu**. The Methods and Instruments for Solving the Banking Crisis and Development of the Banking Sector in Estonia. 2003.
8. **Katri Kerem**. From Adoption to Relationships: Internet Banking in Estonia. 2003.
9. **Ly Kirikal**. Productivity, the Malmquist Index and the Empirical Study of Banks in Estonia. 2005.
10. **Jaanus Raim**. The PPP Deviations between Estonia and Non-Transitional Countries. 2006.
11. **Jochen Sebastian Heubischl**. European Network Governance – Corporate Network Systematic in Germany, the United Kingdom and France: an Empirical Investigation. 2006.
12. **Enno Lend**. Transpordiühenduse ja logistikasüsteemi interaktsioon (Saaremaa ja Hiiumaa näitel). 2007.
13. **Ivar Soone**. Interrelations between Retail Service Satisfaction and Customer Loyalty: A Holistic Perspective. 2007.
14. **Aaro Hazak**. Capital Structure and Dividend Decisions under Distributed Profit Taxation. 2008.
15. **Laivi Laidroo**. Public Announcements' Relevance, Quality and Determinants on Tallinn, Riga, and Vilnius Stock Exchanges. 2008.

16. **Martti Randveer**. Monetary Policy Transmission Channels, Flexibility of the Economy and Future Prospects of the Estonian Monetary System. 2009.
17. **Kaire Põder**. Structural Solutions to Social Traps: Formal and Informal Institutions. 2010.
18. **Tõnn Talpsepp**. Investor Behavior and Volatility Asymmetry. 2010.
19. **Tarmo Kadak**. Creation of a Supportive Model for Designing and Improving the Performance Management System of an Organisation. 2011.
20. **Jüri Kleesmaa**. Economic Instruments as Tools for Environmental Regulation of Electricity Production in Estonia. 2011.
21. **Oliver Parts**. The Effects of Cosmopolitanism on Estonian and Slovenian Consumer Choice Behavior of Foreign *versus* Domestic Products. 2011.
22. **Mart Nutt**. Eesti parlamendi pädevuse kujunemine ja rakendamine välissuhetes. 2011.
23. **Igor Novikov**. Credit Risk Determinants in the Banking Sectors of the Baltic States. 2011.
24. **Mike Franz Wahl**. Kapitaliühingute lõppomanike alusväärtuste ja tahte uurimine ning omanikkonna tüpoloogia konstrueerimine. 2011.
25. **Tobias Wiebelt**. Impact of Lease Capitalization on the Development of Accounting Standards: A Theoretical Research. 2012.
26. **Sirje Pädam**. Economic Perspectives on Environmental Policies: The Costs and Benefits of Environmental Regulation in Estonia. 2012.
27. **Juhan Värk**. Venemaa positiivse hõlvamise poliitika ja teiste välispoliitiliste liinide mõjud Eesti-Vene suhetele aastail 1991–2011. 2012.